AMPED CART

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VISION

Our vision is to decrease the limitations of human beings by increasing their capacity and ability to go further.

MISSION

To provide an off-grid solution for gear and equipment transportation for multiple terrains and environments.

CONTENTS

EXECUTIVE SUMMARY

The Amped Cart is a remote controlled, electric powered wagon or cart and power bank that will utilize solar power to charge its power bank. Its critical features are that it will move from point a to point b, carry equipment and gear, and be remotely controlled by the user.

TARGET CUSTOMERS AND MARKET

The target customers of the Amped cart include but are not limited to: 1) Individuals who are physically unable to carry a heavy backpack on rural paths such as wheelchair users and pregnant women, 2) Organizations that operate in rural areas whose personnel must transport equipment and services on foot over dirt or gravel roads such as: Doctors Without Borders (abbreviated MSF for the name in original French, Médecins Sans Frontieres), 3) Outdoor enthusiasts or beach goers who want to bring gear, supplies, or power on their excursions.

RISKS MITIGATED AND REMAINING

Many of the risks identified at the start of the project have been mitigated or discontinued. These original identified risks were: 1) The ability to communicate with a smartphone via a Bluetooth connection; 2) The ability to track the GPS location of the user and go to that location; 3) The ability to autonomously avoid collisions with surrounding objects and persons; 4) The ability to be controlled by the user; 5) The ability to steer a four-wheeled vehicle; 6) The ability to drive with a weighted load of 50 lbs.; 7) The ability to be powered electrically; 8) The ability to be charged by solar power; 9) The ability to stop safely. Important to note, Due to Risks 1 and 2 remaining unmitigated, significant changes have been made to our project. Risks 1-3 have been eliminated since they pertained to the risk associated with the changes in our project. On the other hand, Risks 5-9 have either been mitigated or decreased to a level such that we believe they will be fully mitigated. Since our updated project will use remote control to control the device, Risk 4 remains to be mitigated and is perhaps the most significant.

RECOMMENDED PATH FORWARD

Going forward, the critical features of our project will remain the same. The main changes we have made to our project plan since our DR.1.1 discussions, are that we have done away with the follow-me feature of the Amped Cart. Instead, the Amped Cart will be controlled via a remote-control, using a RC radio transmitter and receiver system.

The main tasks that will be addressed in the first week of winter quarter are to: 1. Finalize mechanical designs. 2. Prepare to start construction of the chassis and drivetrain. 3. Prepare for the RC test car build and test. 4. Set up for the solar panel system.

QUAD CHART

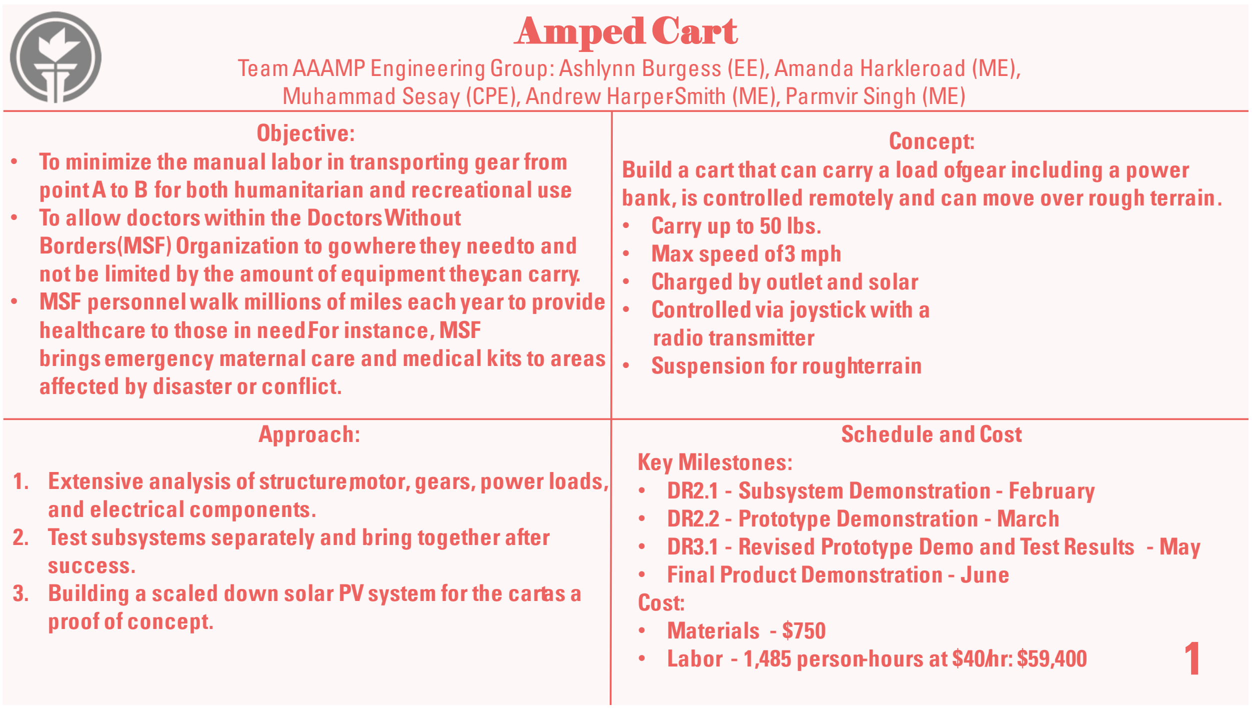


Figure 1. Amped Cart Quad Chart

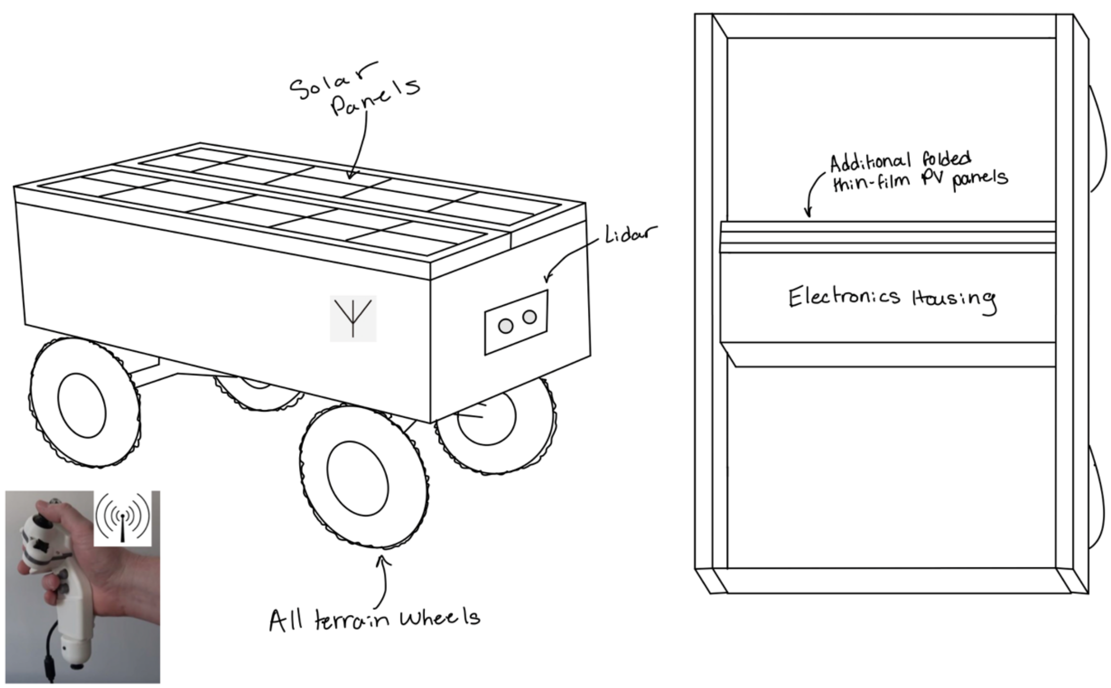


Figure 2. Amped Cart Concept Sketch

RISK REDUCTION PROTOTYPE

During the fall quarter, we proposed to build and test multiple systems that were crucial to the success of our project. Through this process of building and testing, our project changed dramatically. Our original RRP critical path included the critical path of the follow-me feature and is seen in Figure 3.

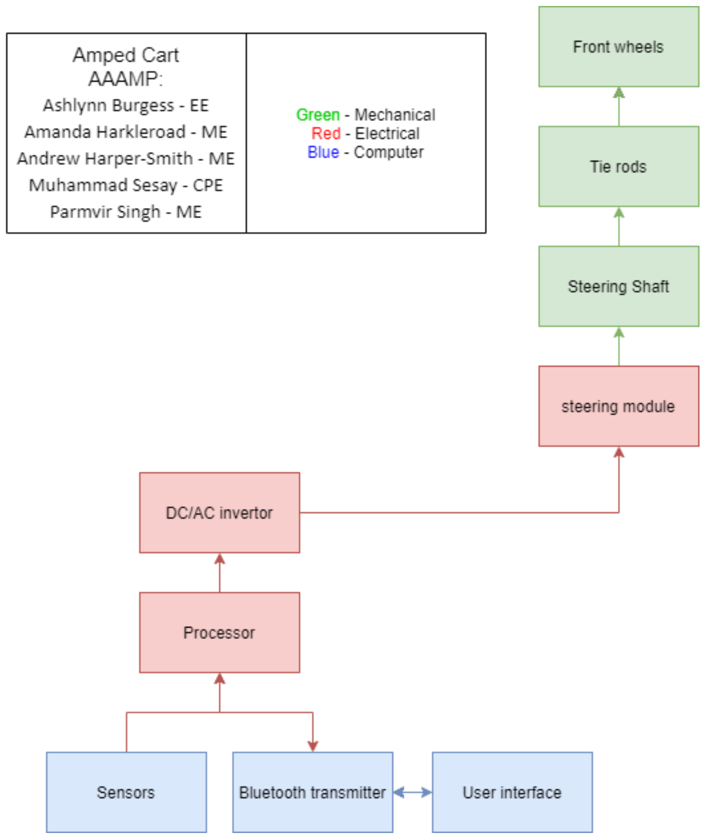


Figure 3

COMPUTER/ELECTRICAL

For the electrical and computer systems, the focuses of our fall quarter RRP were to become familiar with basic robotics and determine whether we should continue forward with a follow-me feature for our cart. To do this, we proposed to test multiple systems necessary to accomplish a follow-me feature using GPS. These are listed and discussed below.

1. Bluetooth Connection- For the RRP, we proposed to build the integrated microcontroller and Bluetooth system and show that the device establishes a Bluetooth connection within the appropriate distance.
2. Location Tracking using GPS **-** For the RRP, we proposed to build the needed program and microcontroller-Bluetooth interface for the microcontroller to receive location data from a smartphone and to calculate the path from the microcontroller to that location.

3. Object Sensor and Control - For the RRP, we proposed to model this subsystem of our design by using a small RC vehicle and modifying it with ultrasonic sensors and a microcontroller.

During this quarter, we learned much about robotics, motor control, Raspberry Pi, and Arduino while building and testing these systems. At the beginning of the RRP, we set up a schedule and some deadlines that needed to be met. With that, we decided that if we did not have significant progress towards a working follow-me feature by November 12th then we would need to make another plan. In the end, we decided against pursuing a follow-me feature for the Amped Cart. This was decided in part because of our project timeline. Our self-proposed deadline of November 12th came, and we had not made the progress we had hoped for. In addition, we decided against pursuing this feature in our design because of a lack of knowledge and experience with the technical aspects required to design an autonomous following device. For both members of the CPE/EE team, this was our first experience with the electrical and computer aspects of robotics, and we would want more time to learn the basics before diving into the deep end of robotics. If we had longer than this school year to explore building robots and using GPS with an Arduino or a Raspberry Pi, we believe that we could accomplish making an autonomous vehicle with follow-me feature. However, we felt that it was best to stick with our deadline and go forward with our new plan for the Amped Cart. The modified RC car with Arduino and L298N motor driver is seen in Figures 4 and 5. The car was programmed to go backwards, forwards and to turn to the left and right.

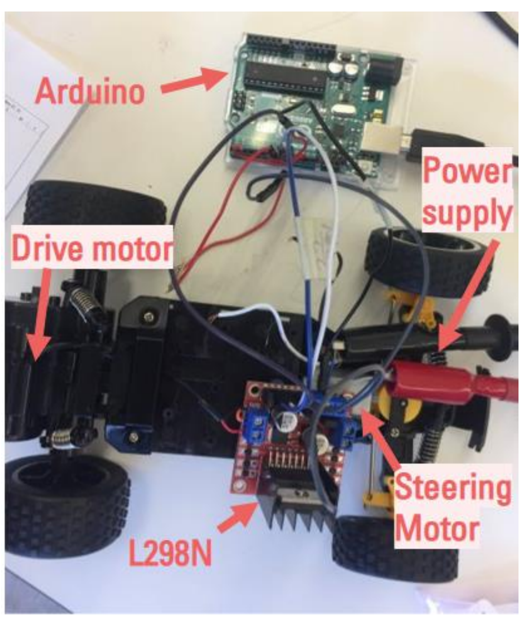


Figure 4

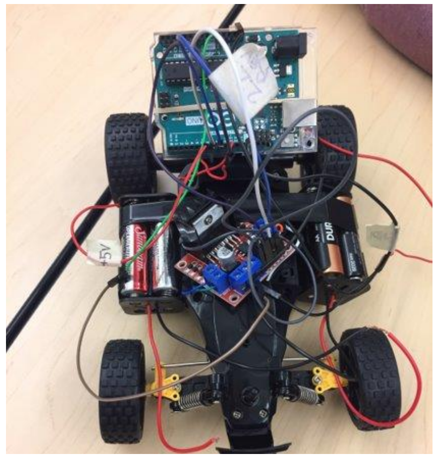


Figure 5

MECHANICAL

On the mechanical side of our project our main concern was in designing a steering system for our cart. This worried us most because none of the MEs on our team had experience in working with or designing steering system for motor vehicles. As a result, this subsystem would need a lot of background research between the three of us to determine which type of system would work best for our project and determine how we would build and test it to prove that the risk was mitigated.

1. Steering – For the RRP we propose to build a small-scale version of our final prototypes steering system. Then we plan to connect the Raspberry Pi, that has been tested on the RC car, to the steering system and test the controls on it to view its response.

The steering systems we were initially considering were a simple rack and pinion system and some variation of pivot steering. At first the rack and pinion steering seemed to be our best option because it seemed to require the least number of components and moving parts. However, we decided to move away from it since our mechanical team was only just now learning how to design gears and we did not yet feel confident in our knowledge to bring this RRP to fruition. We then discovered the Ackerman steering system which is a type of pivot steering. We decided to move forward with this system for our RRP design because of its simplicity. The maximum turning angle of the design we went with can be adjusted if needed. It also operates using a very similar motor to the RC test car, so the programming and controls done to the RC car can be transferred over. Using inspiration from the Ackerman systems we found in our research we design our own model in SOLIDWORKS, and the final print and assembly can be seen below in Figure 6.

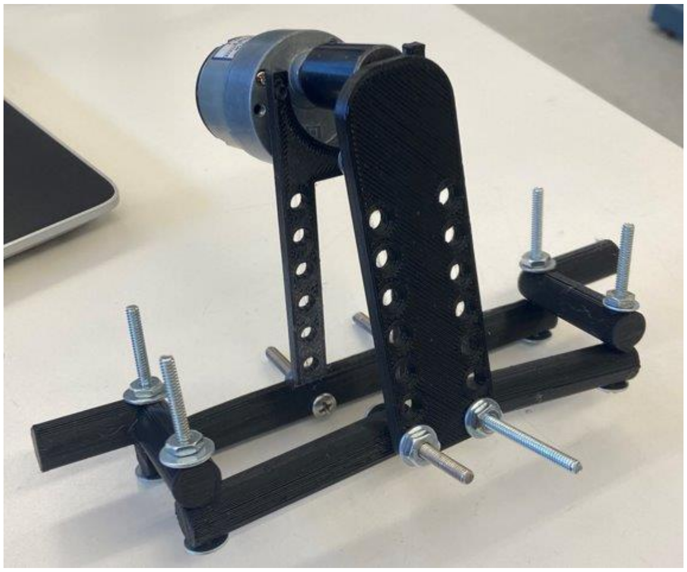


Figure 6

RRP SPECIFICATION RESULTS

SPECIFICATION 1

Spec ID	Requirement	Threshold	Objective	Validation Method	Why this threshold value	Observed
RRP001	Bluetooth connection	N/A	Indicator light on microcontroller **will** turn on when Bluetooth connection has been established between the microcontroller and smartphone	Visual observation.	Demonstrates ability for a data connection between user and device.	Light on Bluetooth Module turned on and Bluetooth module showed connection in smartphone interface.

Table 1

Table 1 summarizes that RRP001 was met. A light on the Bluetooth module which was connected to the Arduino turned on when a Bluetooth connection had been established with a smartphone. Even though a Bluetooth connection was established, no data transfer was able to be conducted between the Arduino and the smartphone.

Due to this, the Bluetooth/Smartphone app connection assumed for RRP002 and RRP003 was not applicable for those specifications.

SPECIFICATION 2

Spec ID	Requirement	Threshold	Objective	Validation Method	Why this threshold value	Observed
RRP002	Remote Control	N/A	Will control a small-scale RC vehicle via Bluetooth and phone application (such as Blue Term or Blynk) to move the vehicle at least one foot forward, backward, and to the right and the left. A microcontroller with Bluetooth capabilities will be implemented into the RC car to accomplish this.	Visual observation, measurements	Demonstrates the abilities of the device to be remotely controlled by the user using a smartphone.	Did not use Bluetooth for control.

Table 2

Table 2 summarizes Specification 2. The modified RC car was able to be controlled from a set program to move forwards, backwards, and to turn left and right, moving at least one foot in each direction. Our RC car had wheel turning angles of 25 degrees off a straight line. Also, the RC car's Arduino was successfully programmed to receive User input from the Serial Monitor Window on the computer to control the device's movement. The modified RC car with Arduino is shown in Figure 7. Video of serial motor control is linked under Additional computer and electrical RRP documentation in Appendix 1.

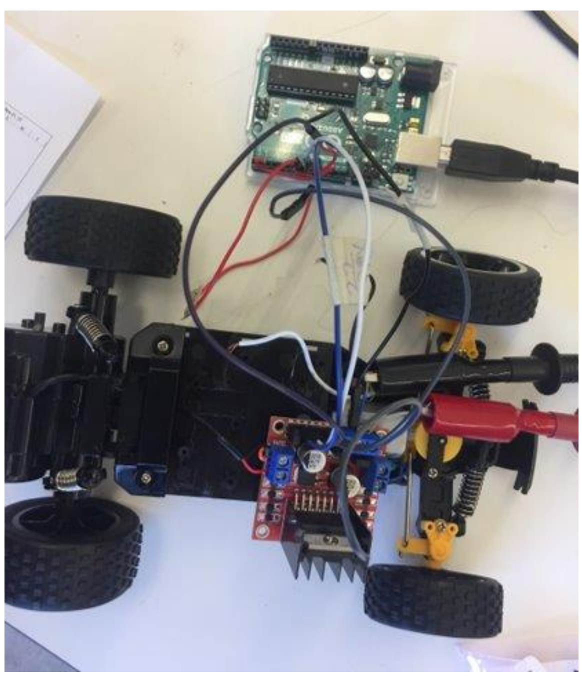


Figure 7

SPECIFICATION 3

Spec ID	Requirement	Threshold	Objective	Validation Method	Why this threshold value	Observed
RRP003	Location tracking	The microcontroller shall receive location data from a smart phone that is 10 feet away and output this data in print statements on the computer.	The raspberry pi should receive the location data of a user's smartphone that is 15 feet away and use this data to calculate the distance and the angle between itself and the phone.	Observation of print output statements in computer program	Demonstrates that the device will be able to use a smartphone's location data to calculate the vector (magnitude and direction) of the path needed for it to get from its starting point to the location of the smartphone.	Raspberry Pi received GPS data from a smartphone. The data was output on a screen.

Table 3

Table 3 summarizes our location tracking specification. Even though we were able to get GPS data from a smartphone to our microcontroller, the process of getting the data into a useable form proved problematic as there are not many resources on the interface that we were using to accomplish this. Figure 8 shows us telling the Raspberry-Pi application to receive GPS data from our smartphone at the IP address listed there. Figure 9 shows the phone GPS data being displayed in the command terminal application CGPS. We also connected a GPS module to our microcontroller, but after much trouble shooting, the GPS module would not acquire satellite signal in our testing area. Our location not being a prime location for GPS signal was a limitation that we did not expect. For the GPS module to output its location data, it needed 3-4 strong satellite connections which it was not able to get in this area. This would have made our project move only in locations and conditions where satellite connections were strong, taking away from the reliability that is needed for our target audience, Doctors Without Borders.

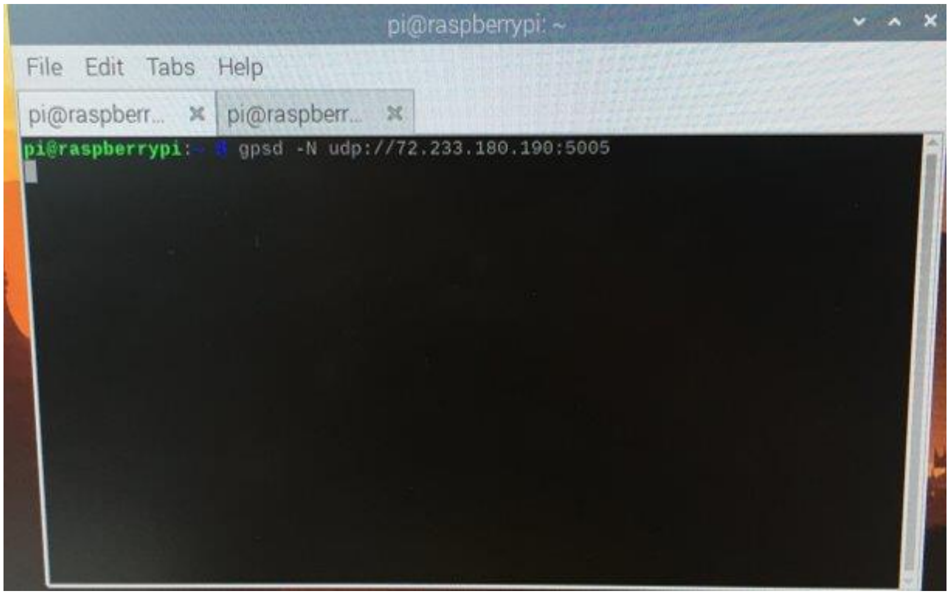


Figure 8

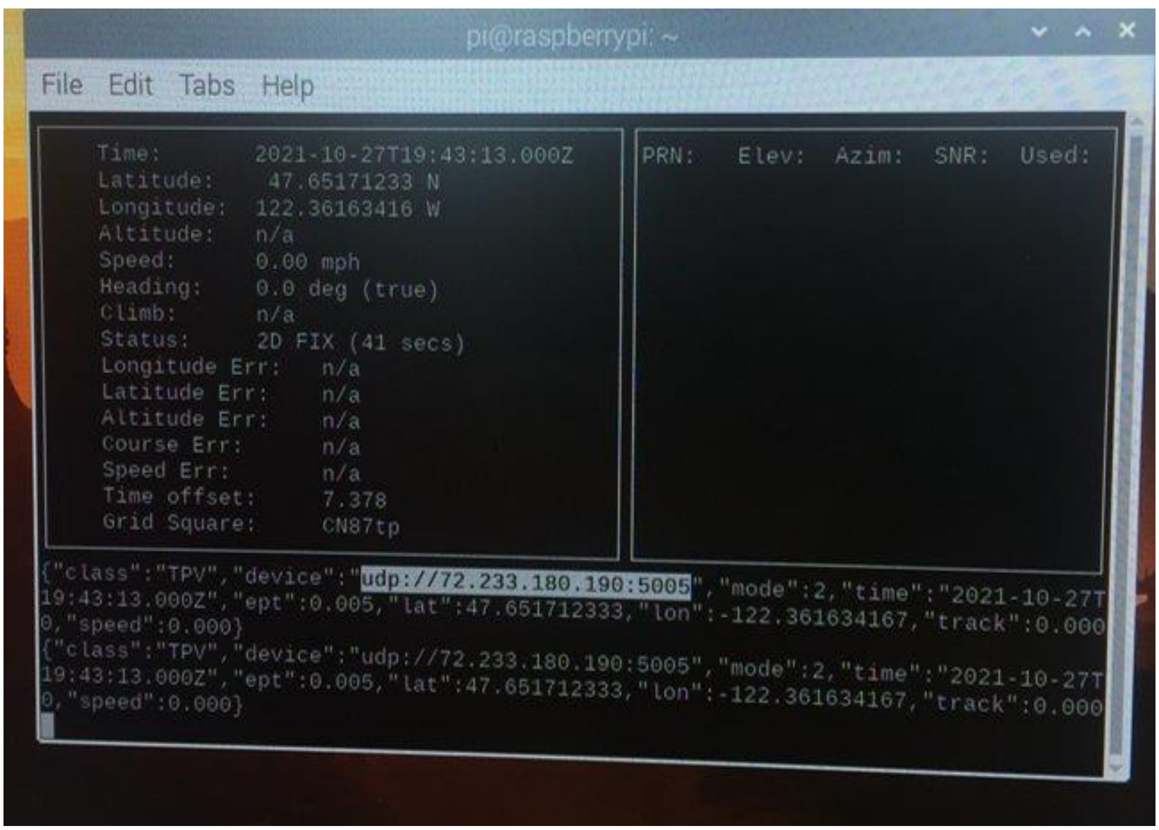


Figure 9

SPECIFICATION 4

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Observed
RRP004	Object Sensing	The Lidar sensor **shall** sense objects within 3 feet in front of it.	The Lidar sensor should sense objects within 5 feet in in front of it,	Visual observation, distance measurements using tape measure	3 feet is a safe distance for the cart to maintain between itself and objects or humans in front of it.	Lidar Sensor senses objects within 27 feet in front of it

Table 4

The updated version of RRP004 was met and summarized in Table 4. What we did to test was we used a program that would output the distance the lidar was sensing to our computer in centimeters. In order to find the farthest distance that the lidar sensor could detect was we used measuring a 25 foot measuring tape and extended it all the way and set an object at the end of the tape measure, we then moved the object back up until the readings read 900 centimeters and then we kept moving the object closer and closer until we got accurate readings which changed rather than remaining constant at 900 centimeters. From that we were able to determine that the farthest distance that the lidar sensor could detect was 27 feet. The Lidar-Arduino connection is shown in Figure 10 and the testing setup is shown in Figure 11.

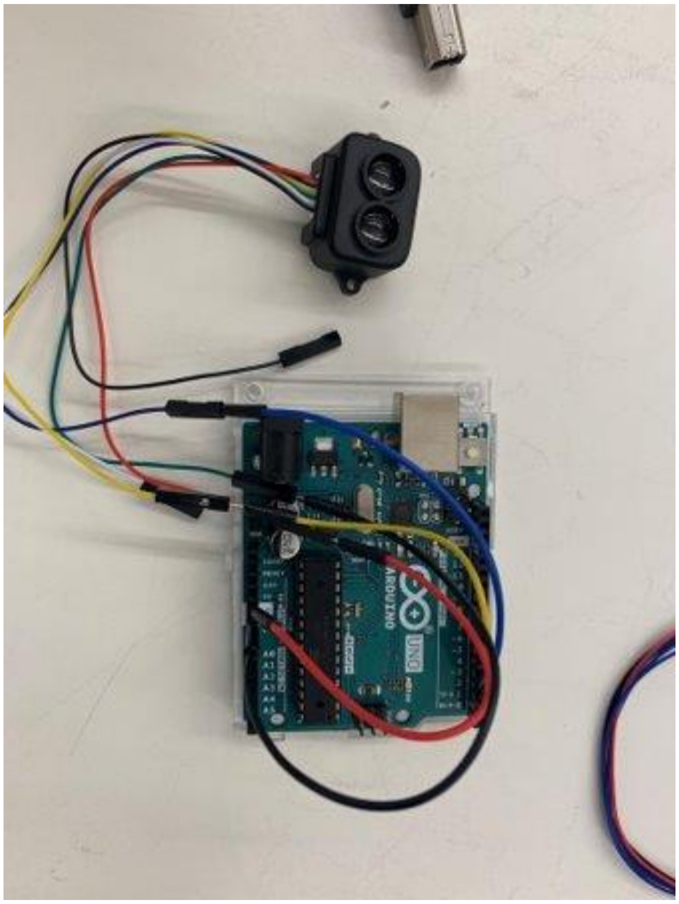


Figure 10

Figure 11

SPECIFICATION 5

Spec ID	Requirement	Threshold	Objective	Validation Method	Why this threshold value	Observed
RRP005	Steering	Shall be able to turn the wheels left or right with an angle between 30◦ to 60◦ using the side rails of the Frame as the datum.	Should be able to turn the wheels left or right with an angle between 60◦ to 90◦ using the side rails of the Frame as the datum.	Angle Finder	Demonstrates that the cart will be able to follow the non-linear path of the user.	Inner steering angle of Θ_1 = 40-degrees, and an outer angle of Θ_2 = 50-degrees was observed.

Table 5

The steering angle was measured using a protractor. We were only able to meet the shall threshold of our specifications, but if we wish to increase the steering angle, later to meet our should threshold. We can increase the length (L) (see Figure 13) between the steering rods and the motor, this will result in the steering angle increasing. The two angles mentioned in Table 5 are depicted in Figure 12 below.

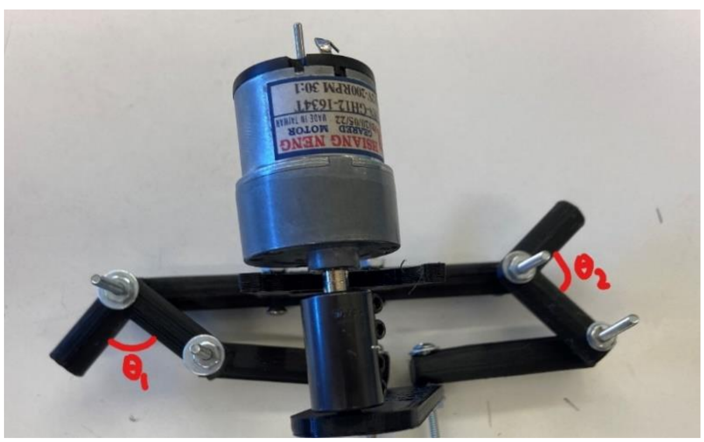


Figure 12

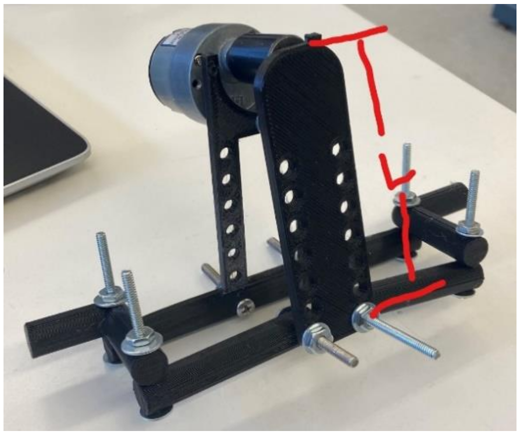


Figure 13

ENGINEERING ANALYSES

MECHANICAL

Motor Power

Purpose:

This analyses, is necessary to determine how much torque is required in the rear axle to accelerate the cart up to the desired speed in a particularly torque-heavy scenario. Using this value for torque we can then determine the power required by the motor.

Analysis Performed:

To size our motor correctly we calculated the required torque for the cart to accelerate from 0 to 3 mph in 3 sec on an incline. We used a rough estimate of 10° for this incline because we predict that the cart will be used on steeper inclines very rarely and in those cases if would be okay if the acceleration took longer. To calculate the torque required in this scenario with rear wheel drive we solved for the reaction forces parallel to the surface at both wheels and translated them to the sum of the parallel forces on the cart body. The completed equation was then rearranged to solve for torque as shown below in Eq. 1.1:

$$T = r_B\left[M \cdot a + \left(a\frac{I_A}{r_A^2} + m_A\right) + m_A g \sin\theta + a\left(m_B + \frac{I_B}{r_B^2}\right) + m_B g \sin\theta + Mg \sin\theta\right] \quad (Eq. 1.1)$$

where r_A, m_A, and I_A refer to the radius, mass and moment of inertia of the front wheels, r_B, m_B, and I_B refer to the rear wheels. M, g, θ, and a refer to the mass of the cart, gravitational acceleration, angle of incline and linear acceleration of the cart respectively.

This value for torque represents the average torque required on the rear axle to move rotate the rear axle and move the cart up the incline at a suitable acceleration. Using this average torque, we can calculate the power required by a motor by multiplying the torque by the average radial velocity of the wheel.

$$P = T\omega \quad (Eq. 1.2)$$

This radial velocity used in Eq. 1.2 is what is needed at the axles or wheels on the cart which is not to be mistaken with the radial velocity of the motor itself. This velocity is much to slow for the motor to be operating at especially for long periods of time because it can result in burn out from too much current draw. We will be determining a gear ratio between the axle and the motor that will allow the motor to operate at its rated rpm and still get the torque and slower speeds we need at the axle.

Results:

Case 1		
Parameter	**Value**	**Units**
Mass of Cart (M)	150	lbs.
Mass of front wheels (m_A)	10	lbs.
Mass of rear wheels (m_B)	10	lbs.
Radius of front wheels (r_A)	6	in
Radius of rear wheels (r_B)	6	in
Inertia of front wheels (I_A)	360	$lbin^2$
Inertia of rear wheels (I_B)	360	$lbin^2$
Angle of incline (θ)	10	Degrees
Initial speed	0	mph
Final speed	3	mph
Duration	3	s
Acceleration (a)	1.466667	ft/s^2
Radial velocity	4.4	rad/s
Average Torque	**229.0466**	**lbfin**
	25.87883	**Nm**
Power	**113.8669**	**W**
	0.152698	**HP**

Table 6

This first case includes an incline of 10 degrees and a linear acceleration of 1.467 ft/s^2. We felt that 10 degrees was a very common incline for our cart to face, so to find the motor power required for starting at rest and accelerating to operational speed in this scenario would give a good estimate of the maximum power required by a motor for our project. As shown in table 6 the average torque required in this time frame is 229.0466 lbf*in at the axle and the power was 0.153 HP. This was a good amount under our predicted value of ½ HP.

Case 2:		
Parameter	**Value**	**Units**
Mass of Cart (M)	150	lbs
Mass of front wheels (m_A)	10	lbs
Mass of rear wheels (m_B)	10	lbs

Radius of front wheels (r_A)	6	in
Radius of rear wheels (r_B)	6	in
Inertia of front wheels (I_A)	360	$lbin^2$
Inertia of rear wheels (I_B)	360	$lbin^2$
Angle of incline (θ)	45	Degrees
Initial speed	0	mph
Final speed	3	mph
Duration	20	s
Acceleration (a)	0.22	ft/s^2
Radial velocity	4.4	rad/s
Average Torque	**729.0377**	**lbfin**
	82.37033	**Nm**
Power	**362.4294**	**W**
	0.486025	**HP**

Table 7

To see what the limits were of ½ HP for our cart we tried the torque and power calculation at a much higher incline. The value for the incline was set to 45 degrees and we allowed the cart a 20 second window to accelerate from 0 to 3 mph (Table 7). The torque required in this case was 729.038 lbf*in and the power was just under ½ HP at 0.486 HP.

Although the equations above are very useful in giving us a rough estimate of the torque and power required by our system, they do neglect to include losses and inefficiencies from heat dissipation in the motor as well as frictional resistance in the transmission and bearings. We are hoping that ½ HP motor will be enough since it is 3 times the power calculated in case 1 but there is still research, calculations and testing to be done here.

Gear Box

Purpose:

Determine the size and kind of gears needed to achieve the correct gear ratio and transmit power from the motor to the wheels. This is important to achieve the desired speed of our cart, and to transport heavier loads.

Analysis Performed:

To perform analysis, motor power and motor selection needs to occur first and only after can gear box analysis be done. We have talked about roughly what kind of gear ratio that may be needed with the estimations of torque from motor power. Through further analysis and research on gears in general and gear ratio, we can determine what exactly will be needed in the gear box. Further research and analysis will be needed and done during winter break.

Suspension

Purpose:

Find maximum force needed from a shock absorber based on the max weight and determine suspension needed.

Analysis Performed:

To determine the spring rate or stiffness required to support our load and provide protection from shaking and vibration we used two methods. The first method was to determine the spring rate of a shock spring using a free body diagram. By doing so we could determine the spring rate required to counteract the weight on each of the shocks were we to use 4 of them. This method was done with a coil-over shock at a 20-degree angle (from completely vertical) and at 0 degrees (QA1). The second method we discovered from consulting with BAJA. It was suggested to us to look up coil-over shocks by weight capacity.

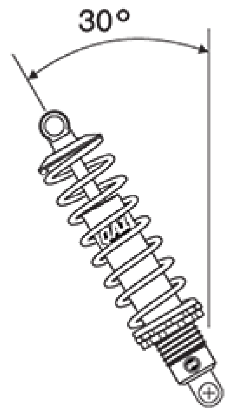


Figure 14

Results:

Case 1	
Parameter	**Value**
Total cart weight (M)	150 lbf
Weight on each wheel (W)	32.5 lbf
Angle of coil-over (A)	20 degrees
Length of spring (L)	10 in
Percent compression	35%
Spring Rate (SR)	**9.878 lbf/in**

Table 8

For this first case in table 8, we assumed a 20-degree angle. We felt this was a good rough estimate of the angle we would design for because it would focus most of its absorption vertically but still provide some horizontal absorption as well.

Case 2	
Parameter	**Value**
Total cart weight (M)	150 lbf
Weight on each wheel (W)	32.5 lbf
Angle of coil-over (A)	0 degrees
Length of spring (L)	10 in
Percent compression	35%
Spring Rate (SR)	**9.286 lbf/in**

Table 9

If we were to go with a simpler design and have the shocks completely vertical, we wanted to find a spring rate value for this case as well and the result can be seen in Table 9.

When using the second method of looking up coil-over shocks by weight capacity we quickly realized that this apparatus was an over design for our project. We could not find coil-overs whose capacity was anywhere close to the weight that would be applied to them in our cart. This is because the coil-over are used in much more rugged and faster applications and would have too stiff of springs for our application. We then decided to investigate vibration isolators instead and found ones that had a matching capacity with ours and would provide and soft spring rate much better suited for our cart.

Mass Distribution

<u>Purpose:</u>

Determine the static forces and loads of the cart in order to ensure the system is stable.

<u>Analysis Performed:</u>

To start with we researched/analysis different the different components of our Cart to come up with initial weight calculations. Based on research, discussion with professors and past physical experience, we decided to have the center of mass of the load in exactly the center of the cart for even distribution. We may need to relocate the center of mass towards the rear more to increase the traction on the rear wheels and decrease the risks of the cart flipping over.

<u>Results:</u>

Weight Estimations:	**lbs**
Chassis/drivetrain	30
Motors	10
Other Components	5
Batteries	10
Thin Film Solar Panels	10
Suspension	15
Wheels	20
Load Capacity	50
Total Weight:	**150**

Table 10

Brakes

<u>Purpose:</u>

Find how much power is needed to bring the device to a stop. Important to prevent the device from running into people or objects and from rolling downhill.

<u>Analysis Performed:</u>

To simplify our design, we have opted to use our motor turning in the opposite direction of the travel of the cart, to slow the cart down and bring the cart to a stop. Through research and experience with electrically motorized vehicles, we believe that the motor we picked out, along with the friction in the drivetrain will prove to be enough power to achieve this. Further analysis and testing is planned in this area.

COMPUTER/ELECTRICAL

Power consumption

Purpose:

For this analysis, we needed to compute the maximum electrical power consumption of the system by summing the maximum power needs of all components. This analysis was contingent on knowing the motor power.

Analysis Performed:

To determine the power consumption of the system, it was first necessary to calculate the power needs of each electrical component. These were determined using Equation 1.3 where *P* is power, I is current, and V is voltage. Additionally, the percent power consumption was determined by taking each components power, dividing it by the total power and multiplying it by 100% (Equation 1.4). The results of these calculations are seen in the table below.

$$P = IV \quad (Eq. 1.3)$$

$$\%P = \frac{P_{component}}{P_{total}} * 100\% \quad (Eq. 1.4)$$

Results:

Device	Current (A)	Voltage (V)	Horsepower	Power (kW)	% Power Consumption
Drive Motor			0.50	0.373	94.7%
Steering Motor	1.5	12		0.018	4.6%
Arduino	0.02	12		0.00029	0.1%
Charge controller	0.2	12		0.0024	0.6%

Lidar Sensor	0.07	5		0.00035	0.1%
			Total kW:	0.394	

Table 11

The total power consumption of our system added to 0.394 kW, and the largest load of the system, as expected, was the drive motor, which accounted for 94.7% of the total needed power. These results were important for sequential analysis, design, and component selection.

Battery

Purpose:

For this analysis, we needed to determine how much power is needed to run the motor for a specified amount of time. We also needed to calculate how much power the battery would need to supply.

Analysis Performed:

The power consumption analysis showed that the drive motor is the system's most significant load, and this load was used to determine the approximate battery sizes the cart would require. First, the power needed per charge was determined using Equation 1.5 where *P* is the power in horsepower and the result is Watt-hours needed per charge.

$$1\ motor * P_{horsepower} * \frac{745W}{1hp} * hours\ of\ run\ time = \frac{Wh}{charge} \quad (Eq. 1.5)$$

Next, the Watt-hours per charge calculations were used to determine the corresponding size of lead acid and lithium battery respectively. This was done by multiplying the Watt-hours by the depth of discharge (DOD) and the inefficiency factors for each respective battery type. Equations 1.6 was used for lead acid battery sizing for which the DOD factor is $\frac{1}{0.5}$ and the inefficiency factor is 1.2. Equation 1.7 was used for lithium battery sizing for which the DOD factor is $\frac{1}{0.8}$ and the inefficiency factor is 1.05.

$$\frac{Wh}{charge} * \frac{1}{0.5} * 1.2 = \frac{Wh}{charge} \quad (Eq. 1.6, Lead\ Acid\ Sizing)$$

$$\frac{Wh}{charge} * \frac{1}{0.8} * 1.05 = \frac{Wh}{charge} \quad (Eq. 1.7, Lithium\ Sizing)$$

The last step was to divide the resulting Watt-hours by the battery voltage to get the resulting battery Amp-hours rating. The results of this analysis were summarized in the table as well as in line graphs shown in figures 15 and 16. The columns highlighted in blue in Table 12 contain the data that is used for the vertical axis of the line graphs and the *hours of use* column is used for the horizontal axis of the graphs.

Results:

			Battery Size (kWh)		12 V Battery Ah		24 V Battery Ah		48 V Battery Ah	
Load Description	*Hours of use*	*kWh /Charge*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*
	0.5	0.1865	0.4476	0.2	37.3	19.6	18.65	9.8	9.3	4.9
	1	0.373	0.9	0.5	74.6	39.2	37.3	19.6	18.65	9.8
	2	0.746	1.8	0.9	149.2	78.3	74.6	39.2	37.3	19.6
	3	1.119	2.7	1.4	223.8	117.5	111.9	58.7	55.95	29.4
	4	1.492	3.6	1.9	298.4	156.7	149.2	78.3	74.6	39.2
1/2 HP motor	5	1.865	4.476	2.3	372.5	195.8	186.5	97.9	93.3	49.0
	6	2.238	5.4	2.8	447.6	235.0	223.8	117.5	111.9	58.7
	7	2.611	6.3	3.3	522.2	274.2	261.1	137.1	130.55	68.5
	8	2.984	7.2	3.8	596.8	313.3	298.4	156.7	149.2	78.3
	9	3.357	8.1	4.2	671.4	352.5	335.7	176.2	167.85	88.1
	10	3.73	9.0	4.7	746	391.7	373	195.8	186.5	97.9
			Battery Size (kWh)		12 V Battery Ah		24 V Battery Ah		48 V Battery Ah	
Load Description	*Hours of use be*	*kWh /Charge*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*
	0.5	0.093	0.2235	0.1	18.625	9.8	9.3125	4.9	4.7	2.4
	1	0.186	0.4	0.2	37.25	19.6	18.625	9.8	9.3125	4.9
	2	0.373	0.9	0.5	74.5	39.1	37.25	19.6	18.625	9.8
	3	0.559	1.3	0.7	111.75	58.7	55.875	29.3	27.9375	14.7
	4	0.745	1.8	0.9	149	78.2	74.5	39.1	37.25	19.6
1/4 HP motor	5	0.931	2.235	1.2	372.5	97.8	93.125	48.9	46.6	24.4
	6	1.118	2.7	1.4	223.5	117.3	111.75	58.7	55.875	29.3
	7	1.304	3.1	1.6	260.75	136.9	130.375	68.4	65.1875	34.2
	8	1.490	3.6	1.9	298	156.5	149	78.2	74.5	39.1
	9	1.676	4.0	2.1	335.25	176.0	167.625	88.0	83.8125	44.0
	10	1.863	4.5	2.3	372.5	195.6	186.25	97.8	93.125	48.9

Table 12

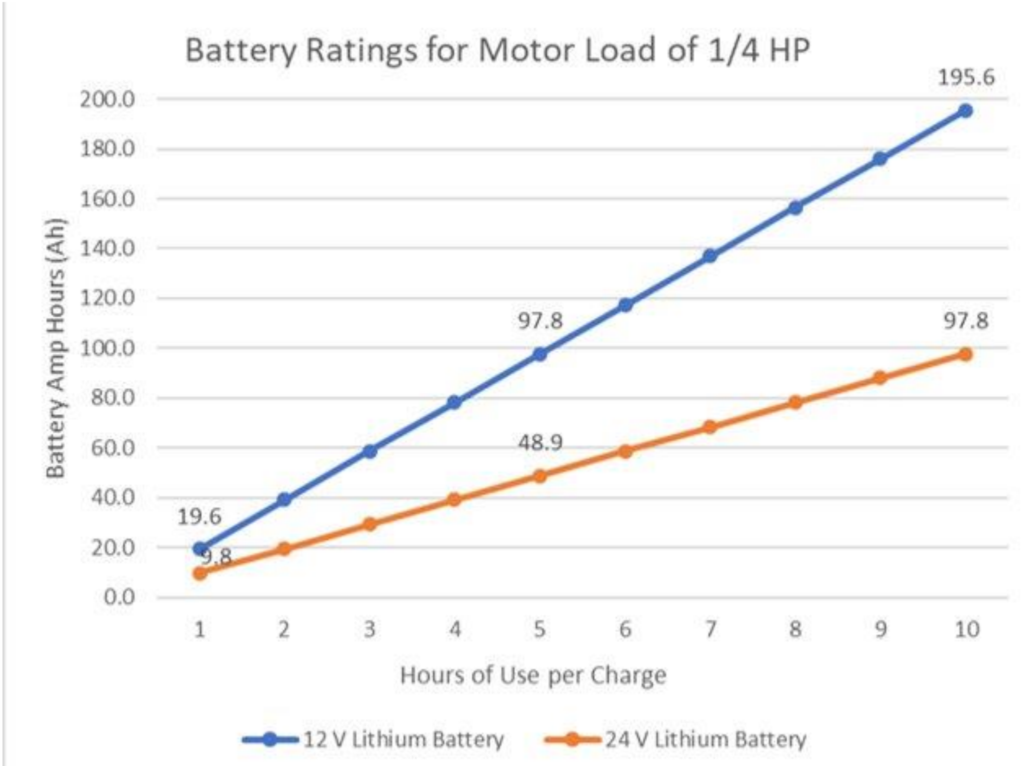


Figure 15

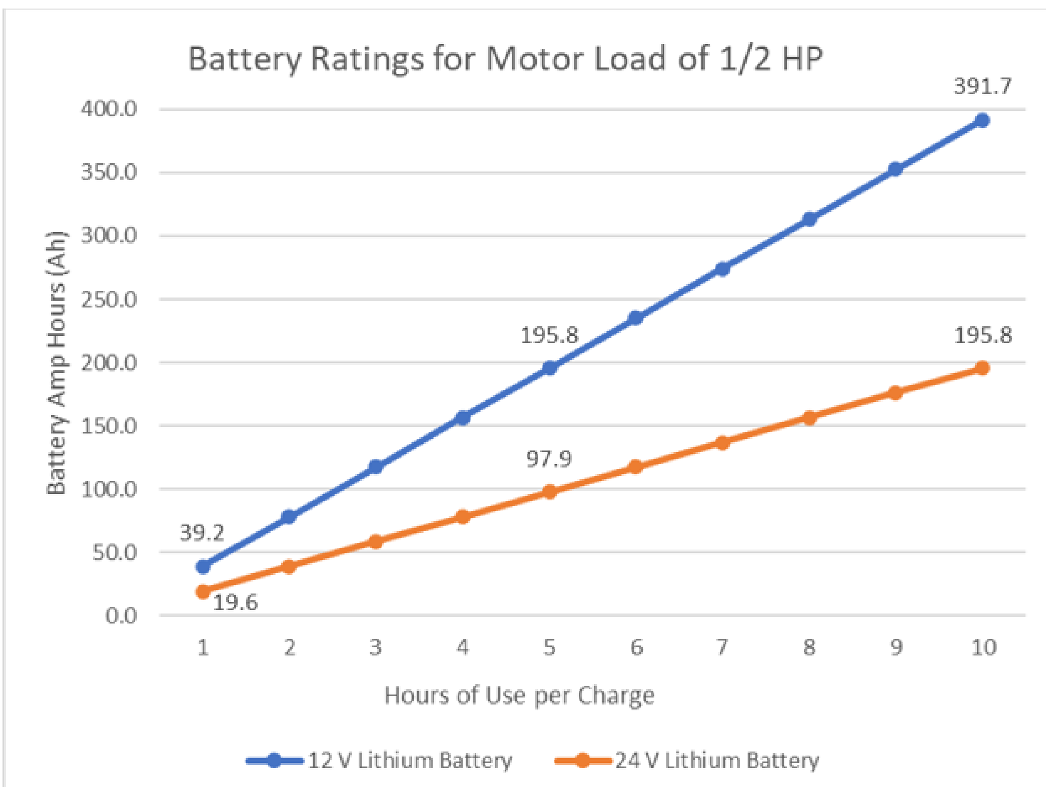


Figure 16

Unsurprisingly, the results demonstrated that the cart would need a sizeable battery or battery bank. To operate a ½ hp motor for 5 hours, we need a 200 Ah 12 V battery or a 100 Ah 24 V battery. Since our drive motor has yet to be selected, this analysis could change. However, this gives us a starting point to weigh the costs and benefits of the length of the operation time between charges of the Amped Cart. Important to note, once we decide upon the optimal length of operation time, we will analyze the charge and discharge rates of our battery.

Solar Power with Charge Controller

Purpose:

The purpose of this analysis was to determine how many solar panels will be needed to charge the battery and to determine how much time will be needed for this number of panels to charge the battery.

Analysis Performed:

To determine how many solar panels would be sufficient, it was first necessary to pick a couple of locations for the application of the solar power system. For our purposes, Seattle, Washington, U.S.A, and Cape Town, South Africa were chosen. Seattle was chosen as an application location, because this is where future testing of the system will take place, and Cape Town was chosen, because the target organization, Doctors Without Borders, has ongoing projects and locations there. The following equation, Equation 1.8, was used to determine how much charge capacity a solar panel could provide to a power bank in each location on an average day.

$$sun\ hours * \frac{P_{panel}}{V_{battery}} = I_{capacity} \quad (Eq. 1.8)$$

In this equation *sun hours* is the average amount of sun hours per day the location receives, *P* is the solar panel's power rating in Watts, *V* is the voltage rating of the battery in Volts, and *I* is the charge capacity in Amp hours that the given solar panel will be able to provide to the battery. The results for the two chosen locations using 100 W and 200 W solar panels are summarized in the tables below.

Results:

Location	Sun hours/year	Avg Sun hours/day	Solar Panel Wattage	Battery Voltage	Calculated Charge Capacity (Ah)
Seattle, Washington	2100	5.8	100 W	12V	47.9
				24V	24.0
Cape Town, South Africa	3100	8.5		12V	70.8
				24V	35.4

Table 13

Seattle, Washington	2100	5.8	200 W	12V	95.9
				24V	47.9
Cape Town, South Africa	3100	8.5		12V	141.6
				24V	70.8

Table 14

From the tables above, a 200 W solar panel used with a 24 V battery would charge said battery to about 48 Ah on the average day in Seattle and would charge said battery to about 71 Ah on the average day in Cape Town. The same rating of solar panel used with a 12 V battery would charge said battery to about 96 Ah on the average day in Seattle and would charge said battery to about 142 Ah on the average day in Cape Town. Next, we will need to cross reference these numbers with those determined in the Battery Analysis and determine the power rating needed for our device's solar array. Based on the outcome of these analyses, the cart will need a solar array that is rated greater than 200 W to fully charge a battery capable of giving our motor a run time of 5 hours. The desired run-time of our cart is not finalized, but these calculations will aid us in picking a run time that is both practical for our application and cost-effective (i.e., fits within the budget).

Bluetooth transmitter

Purpose:

For this analysis, it was necessary to determine the power needed to operate the microcontroller for transmitting a Bluetooth signal.

Analysis Performed:

Commonly called the "Power Equation", Equation 1.3, which was shown earlier in the Power Consumption Analysis portion of this document, was used for this analysis,

Results:

Device	Current (A)	Voltage (V)	Total Power (kW)
Bluetooth module	0.08	3.6	0.000288

Table 15

This analysis could be included with the power consumption analysis, but due to shifting away from using Bluetooth, we no longer need to know the power consumption of the Bluetooth module.

RISKS REDUCED OR REMAINING

MECHANICAL

Motor Power

Our main concern with motor power was that we would size it incorrectly and our motor would fail to meet the power requirement and burn out. Estimating the required torque and power in a particularly torque-heavy scenario we felt would mitigate this risk. Another concern we had would be that the power requirement would be very large and need so many batteries that there wouldn't be enough space for gear. Based on our calculation of 0.15 HP this should not be an issue.

There is still some risk remaining when it comes to choosing our motor. The analysis done this quarter did not include inefficiencies in the motor or friction loss in the transmission. As of now we are planning for a ½ HP motor for our cart to be conservative however, we plan to do further calculations before ordering any motors. These additional calculations require that we have planned out our transmission which we were not able to get to in detail this quarter.

Gear Box

The RRP for gear box has been reduced slightly, however there is still a considerable amount of work needed in this area. We have found motor power needed and the next step would be to select motor so that we can move forward with gear box analysis mainly finding the gear ratio and how the system will look like in general. There is still a lot to consider here with the analysis as we have decided on direct chain drive from the gear box to the rear axle as our cart will be using rear wheel drive. Due to this there is research and analysis needed in this area so that we can select the most optimal gear box for our motor and cart in general.

Suspension

Through our suspension analysis this quarter, we were able to estimate the requirements of shock absorption in our cart. We discovered that coil-over shocks would be an over design for our project because the weight of our cart is much lighter, and the cart moves a lot slower than other vehicles that use these shock absorbers. A better suited apparatus for our requirements would be a floor mounted vibration isolator which have lower weight capacity and therefore a spring rate closer to what we would need.

Although we have a better idea of what the suspension will look like for our cart, we still need to design the framing around vibration isolators now rather than coil-overs. Since vibration isolators are new to our team members, we to do some additional research to learn what our constraints are when using these as well. An option for further mitigating the risks involved with suspension we are considering ordering the vibration isolators and conducting experiments on them individually.

Mass Distribution

Having the center of mass of our load, in the center of the cart reduces the risks of the cart tipping over and simplify our design significantly. The center of mass may have to be located more towards the rear of the cart to increase traction at the rear wheels, however that would increase the risks of the cart tipping over backwards, so there our remaining risk in this area. Further analysis, research and testing is planned to determine the most efficient position for the center of mass, to provide us with as much traction as possible at the rear wheels, while minimizing the risks of the cart tipping over backwards.

Brakes

To simplify our braking system, we have opted to use the drive motor, running in the opposite direction of the travel of the cart to slow down and stop the cart. We believe this will be a successful braking system as the cart isn't designed to move any faster than a brisk walk of 3 mph. We still do have some risks in this area, as we will have to confirm that the motor, we pick out will have enough power to slow the cart down to a dead stop on a downward inclined slope. We will also have to take into consideration that the cart is now only rear wheel drive, so all the stopping power will be coming from the rear wheel. Henceforth further analysis/testing will be done in this area to confirm that the motor we pick will be able to stop the cart.

Steering

The steering RRP reduced our risk in that area, as we achieved an outer steering angle of 50-degrees, and an inner steering angle of 40-degrees, which is within our specs. Our steering design has multiple parameters that can be increased if we decide we want a greater steering angle, it also operates by a simple 12v electric motor. We have no identified risks remaining in this area.

COMPUTER/ELECTRICAL

Power Consumption

The Power Consumption Engineering Analysis gave us the power in kW that the cart will use each hour that it is in use. This gives us clarity in our design of the solar power and battery system. Seeing that the largest load to account for is the Drive Motor, we will need to take special care in our selection of that motor. The risk related to this analysis has been mitigated, and we are confident that we can design a system to supply the power needed for the cart.

Battery

The Battery Engineering Analysis provided us with a starting point for selecting the Amp hour (Ah) rating of our cart's battery. The risk of being able to supply enough power the cart has been mitigated through this analysis, since we now know the battery Ah and Voltage ratings needed to operate the cart for any given number of hours. . The risk of the battery being able to power the cart for a long period of time remains to be mitigated. Thus, analysis on the charge and discharge rate of the battery and on the comparison of battery costs and hours of cart use from battery will be conducted before the final selection of a battery or battery bank.

Solar Power with Charge Controller

The Solar Power with Charge Controller Engineering Analysis showed that solar arrays of 100 W or even 200 W may not be sufficient for the cart's power needs depending on how many hours the cart is designed to operate for. Currently, with our analyses, the max number of hours of use per charge is a variable. To move forward with the design and in the selection process of our components, this cannot remain a variable. In one sense, the risk that we will be able to sufficiently charge a battery using solar panels has been mitigated through this analysis. Even so, until we reach a conclusion on the optimal hours of use per charge, we cannot select a solar array for our solar powered system. Additionally, a compatible charge controller cannot be selected until the solar array has been selected. All in all, we are confident that we can design for a solar array to supply the charge needed for our system.

Bluetooth Transmitter/Connection

The Bluetooth analysis and RRP are no longer relevant to the future of the Amped Cart project because the cart will not be designed to have a Bluetooth autonomous tracking feature. Due to this, the risk of being able to establish a Bluetooth connection has been eliminated.

Location Tracking

The Location analysis and RRP are no longer relevant to the future of the Amped Cart project because the updated vision for the cart does not involve GPS location tracking. Due to this, the risk of being able to track the location of a user has been eliminated, and thus, mitigated.

Object Sensor and Control

The object sensor specification was originally supposed to be met using ultrasonic sensors which we would use to detect any objects within 3 feet. Through more research, we decided to go with a 2D lidar sensor. For testing we used a program that would output the data that the lidar sensor was receiving and output that to a computer which gave us the distance in centimeters. For control what we initially proposed was Bluetooth control however, the applications that we wanted to use were not as intuitive and through more research we found that remote control was more reliable than Bluetooth, so we decided to mitigate that from our design. For RRP since we decided to not use Bluetooth, we were controlling our remote-control car with serial input motor control. That is, when a user inputs the direction that they would like the car to move in into a serial window on their computer, it would move in that direction. Overall, we were able to use motor drivers and a microcontroller to control a steering motor and a driving motor on a remote-control car, and going forward, we are confident that we can complete a remote-control system for the project. The risk of being able to use lidar object detection will be something that we will mitigate if needed.

UPDATED PROJECT

The Amped Cart is a remote controlled, electric powered wagon or cart that will utilize solar power to charge its power bank. Its critical features are that it will move from point a to point b, carry equipment and gear, and be remotely controlled by the user. The cart will be equipped with four wheels, back-wheel drive, front wheel steering, and all-terrain tires. Its body will consist of a box to contain gear or equipment and the housing for the motor, battery, and electronics. The user will be able to control the movement of the cart using a small handheld controller. The Amped Cart will be designed to carry up to 50 pounds of gear and travel up to 4 miles per hour (I.e., walking speed). Outfitted with solar panels, the cart will be capable of charging through both a wall outlet and through a solar charging system. This dual charging capability is needed so that the user can charge the battery when off the grid. Additionally, the cart will have a handle that can be used to manually push or pull the cart if the cart runs out of battery.

Block diagram

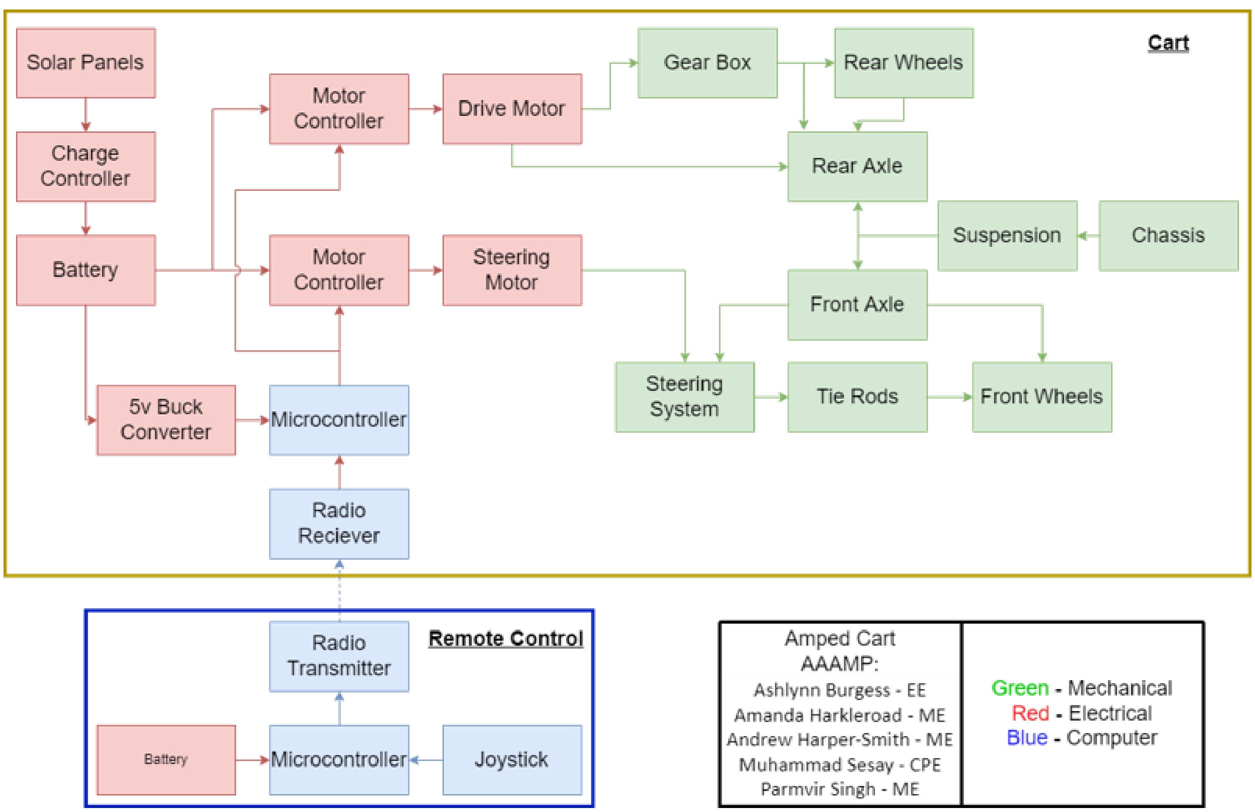


Figure 17

Critical Features

<u>Move:</u>

This feature allows the device to go from point A to point B, including forward, backward, and lateral motion.

<u>Carry:</u>

This feature allows the device to hold the user's equipment while in motion or stopped.

<u>Control:</u>

This feature allows the user to have control of the device's movement.

As you can see, this updated version of our project satisfies our original critical features. Our cart is designed to move at the same speed and with the same abilities as before. As stated in our first concept, our cart will carry an estimated load of 50 lbs. Finally, even though our method by which the user will control the cart has changed, our original criteria to allow for user control has remained the same.

WINTER BREAK SCHEDULE

We propose a rigorous winter break schedule and plan to meet over Microsoft teams on December 6th. The agenda for this meeting is seen in Appendix 6 as well as the current status of our project schedule.

Task	Owner	Comments
Select and order drive motor	Amanda	Communicate with Ashlynn on desired voltage for motor based on batteries
Select and order suspension component	Amanda	Find vibration isolator that would work best with our design
Select and order additional battery and solar panels	Ashlynn	Ashlynn will communicate with MEs to order a battery
Select and order motor controllers	Ashlynn	Ashlynn will communicate with MEs to order controllers
Research, analyze, and design/select gear box	Parmvir	Parmvir will research, analyze, and design/select gearbox for the drive chain.
Design, Select and order chassis materials	Andrew	Andrew will design the chassis, choose and order the material, considering weight and price.
Research methods of integrating motor and cart	Amanda	Andrew is more familiar with working on MV so Amanda will need to catch up to help
Work on team website	Team	Whenever we can get on campus we will work this.
Research and intro-experimentation for Remote control	Ashlynn, Muhammad	Will research how we want to implement the remote control and ways to do so

FIRST WEEK OF WINTER QUARTER SCHEDULE

Task	Owner	Comments
Finalize Chassis Design	Andrew	
Finalize Suspension Design	Amanda	Work with Andrew to make sure chassis works with suspension
Finalize Drivetrain Design	Andrew/Amanda	
Order Remaining Components	Amanda	
Finalize Gear Box Analysis/Design	Parmvir	
Prepare for RC build/test	Muhammad/Ashlynn	Plan out what materials will be needed to create RC
Prepare for solar to battery system build/test	Ashlynn	Parts should be in and should be ready for connections and testing

REFERENCES

ONLINE AND TEXT

"Spring Rate Tech." QA1, https://www.qa1.net/tech-center/spring-rate-tech.

"Maternal Health." *Doctors Without Borders - USA*, https://www.doctorswithoutborders.org/maternal-health.

"International Activity Report 2020: MSF." *Médecins Sans Frontières (MSF) International*, 29 July 2021, https://www.msf.org/international-activity-report-2020.

"Transport: MSF on the Move." *MSF UK*, https://msf.org.uk/article/transport-msf-move.

"Average Monthly Hours of Sunshine in Cape Town (Western Cape), South Africa." World Weather & Climate Information, https://weather-and-climate.com/average-monthly-hours-sunshine,cape_town,south-africa.

"Average Annual Sunshine by State." Average Annual Sunshine by USA State - Current Results, https://www.currentresults.com/Weather/US/average-annual-state-sunshine.php.

PEOPLE

Kinnon McPeak – BAJA

Quinton Cline – Cypress Semiconductor

Daniel Keene – Seattle Pacific University

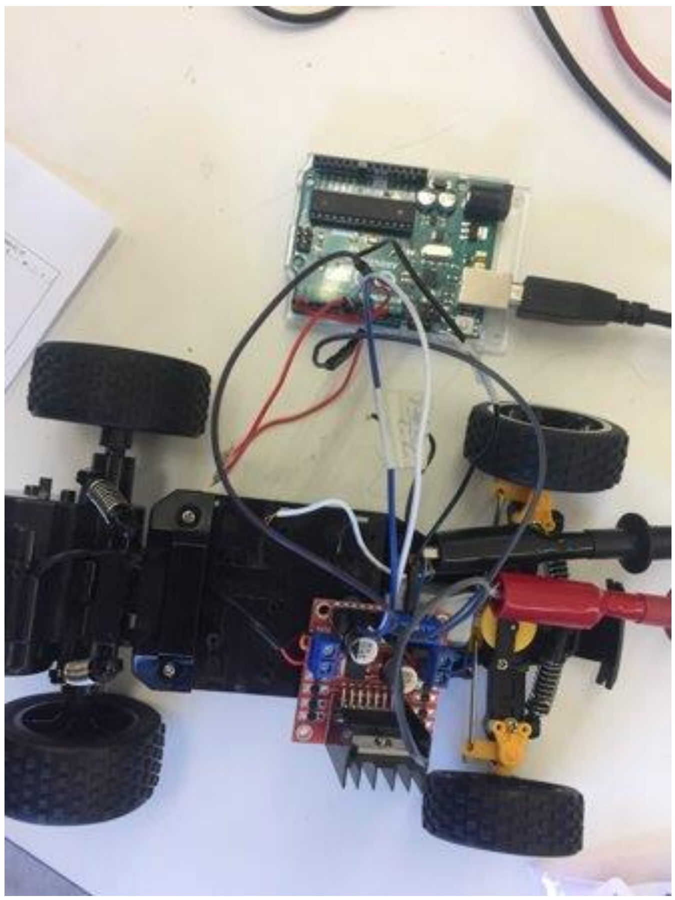
APPENDIX

The following pages contain additional documentation for RRP builds and experimentation and engineering analyses as well.

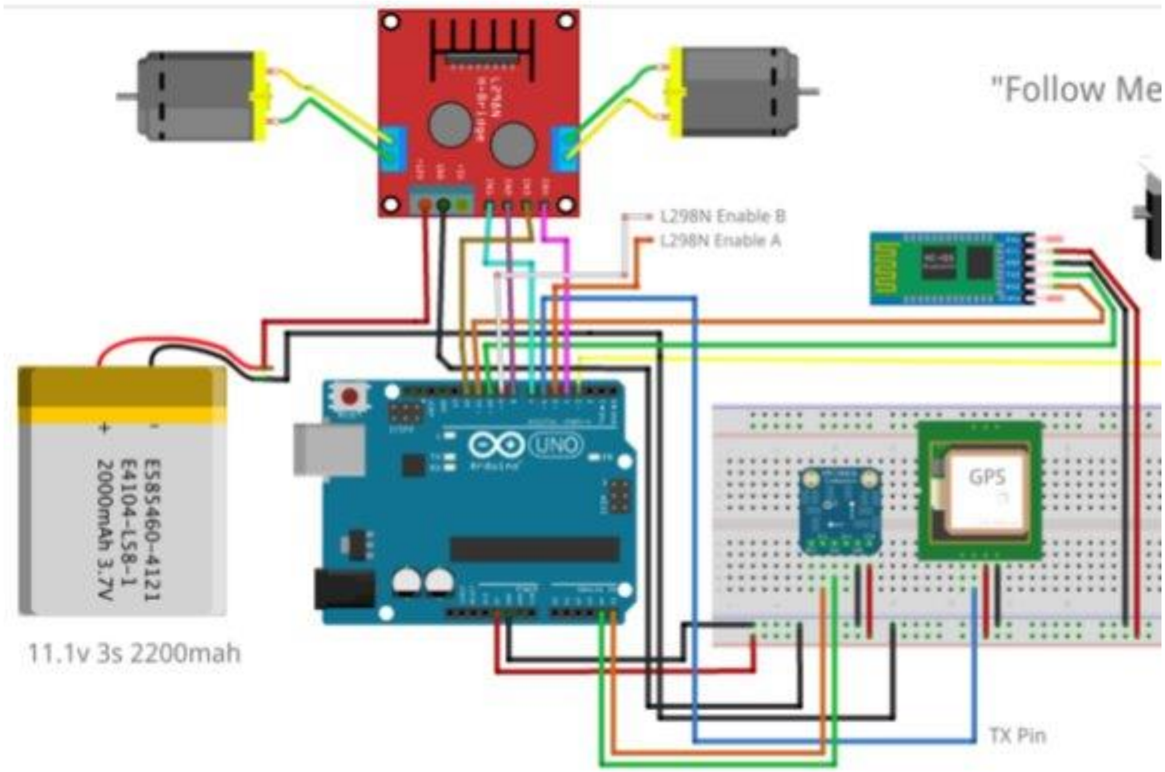
APPENDIX 1
Additional computer and electrical RRP documentation

Link for video of RC car moving forward back and turning wheels to the left and right:

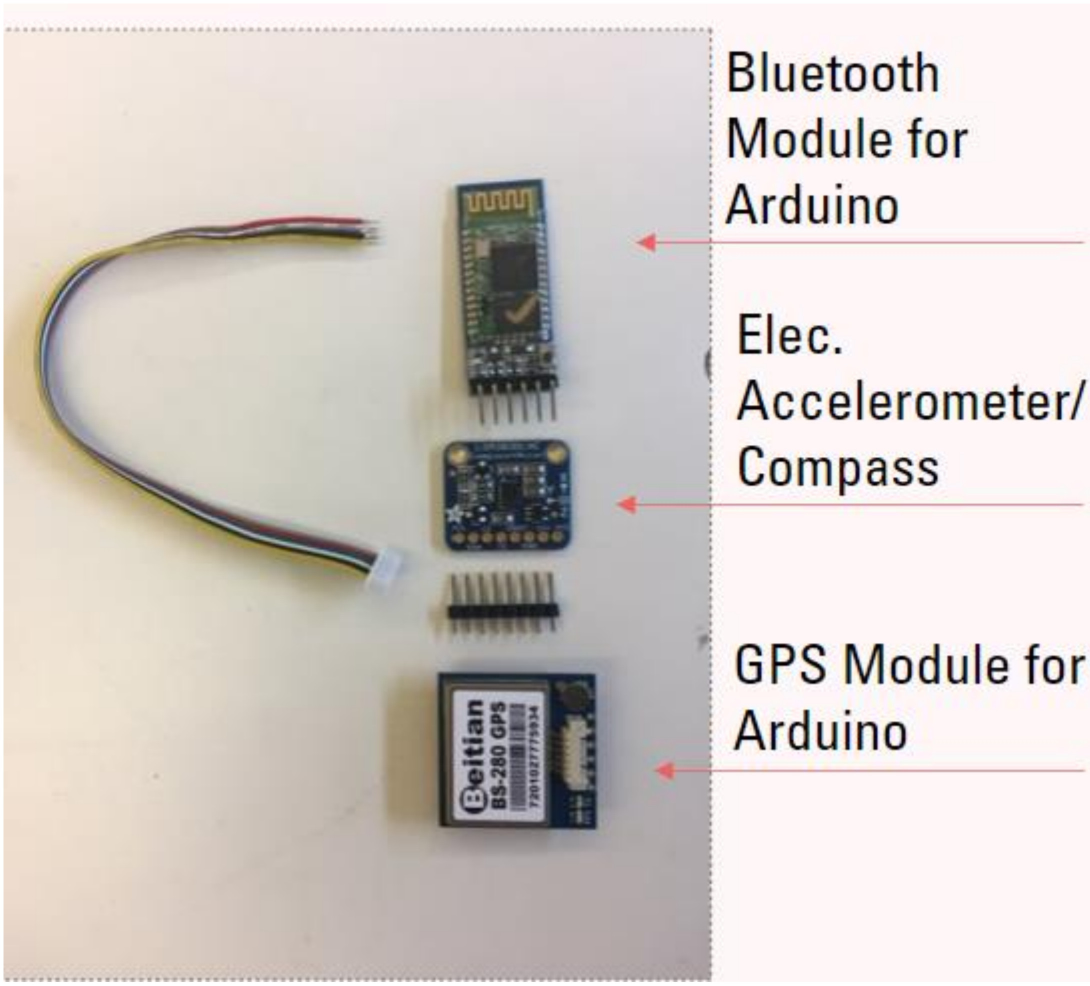
https://www.youtube.com/watch?v=gAMr-3wgYU8



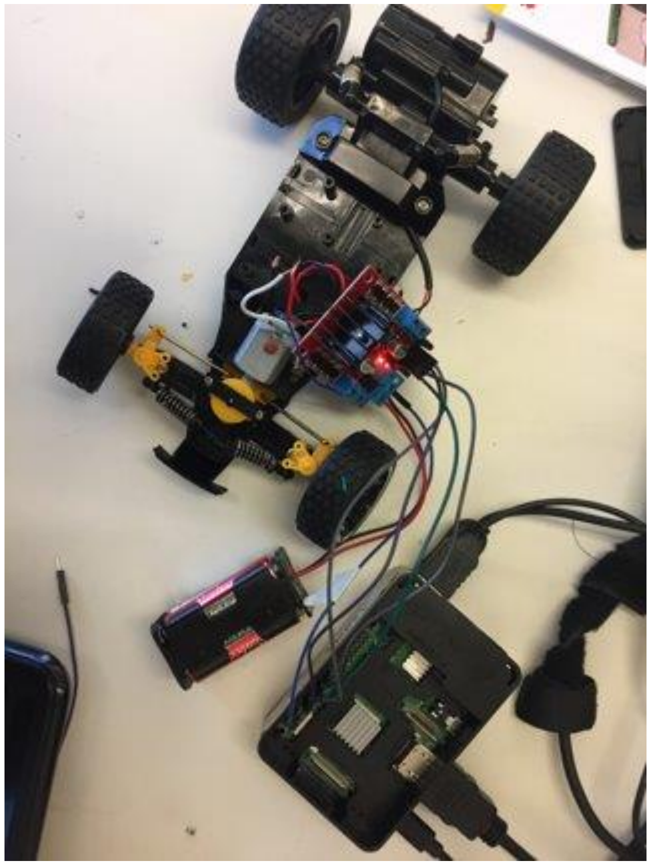
Appendix 1-1 RC modified car



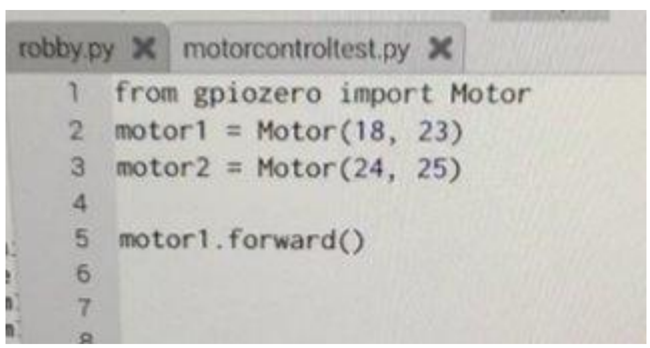
Appendix 1-2 Initial circuit for Follow-Me feature using Bluetooth and GPS



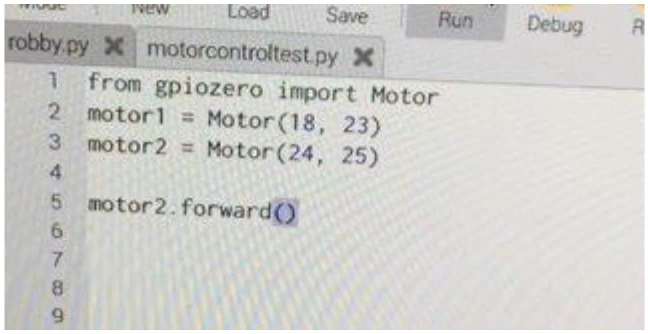
Appendix 1-3 Components that were tested but ultimately not implemented in our design



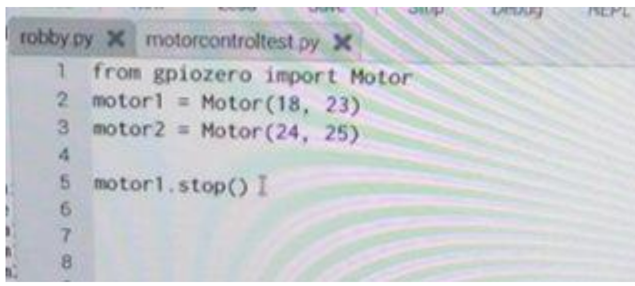
Appendix 1-4 RC car modified with Raspberry Pi for motor control



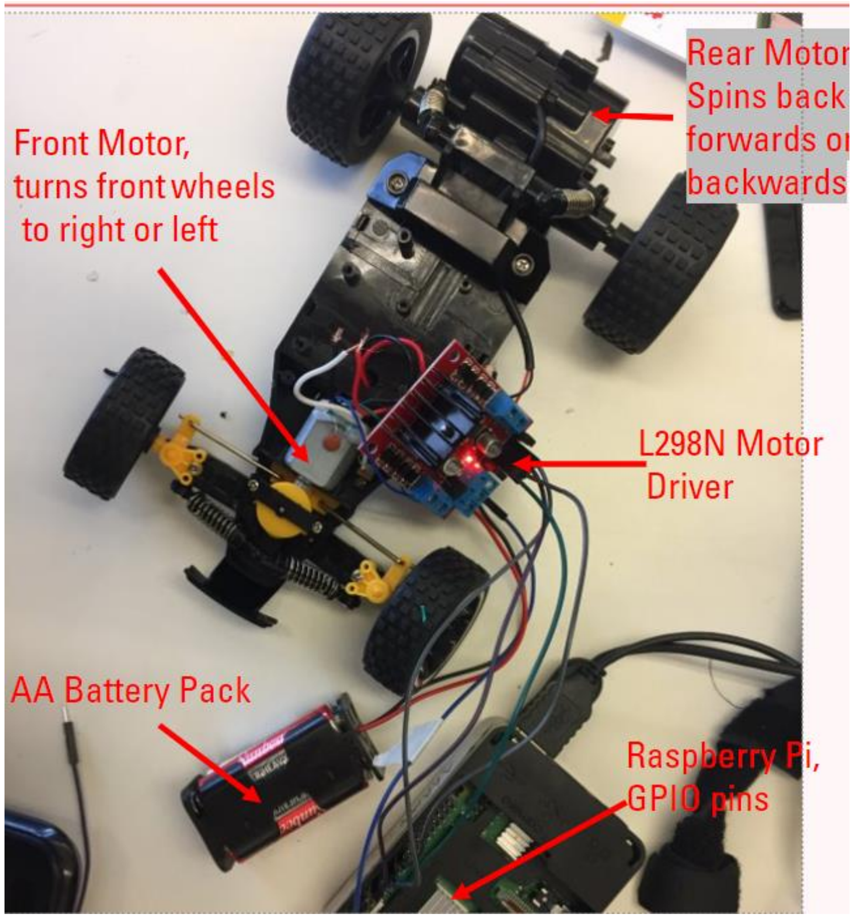
Appendix 1-5 Executing this code successfully caused the back motor to turn the wheels forward. To go in reverse, I simply executed the statement, ‘motor1.reverse()’



Appendix 1-6 Executing this code successfully caused the front motor to steer the wheels to the left. To go to the right, I executed the code, ‘motor2.reverse()’



Appendix 1-7 Executing this code successfully caused the back motor to stop turning. Executing the statement: ‘motor2.stop()’ causes motor 2 to align the front wheels straight ahead.

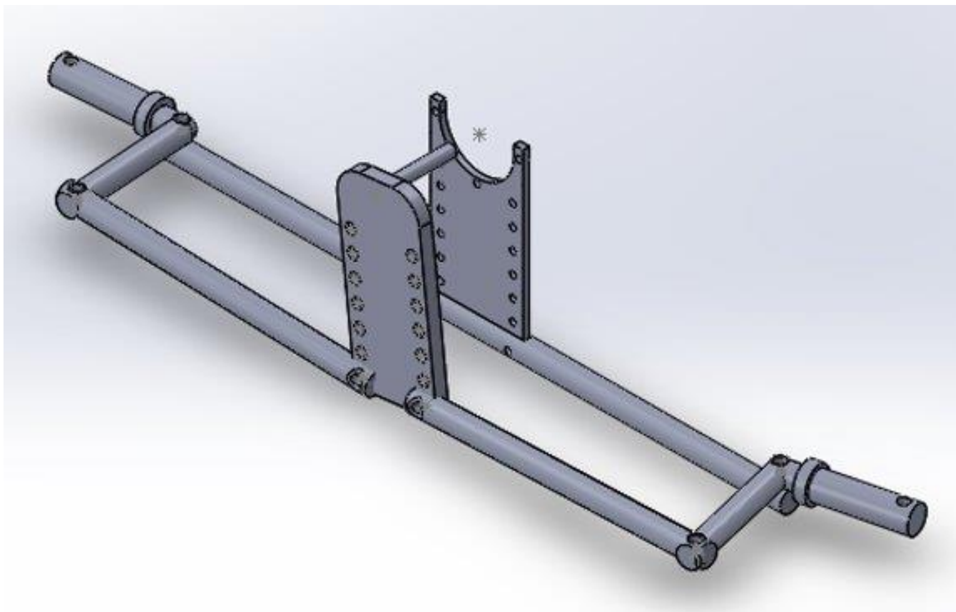


Appendix 1-8 RC car modified with Ras[berry Pi and component descriptions

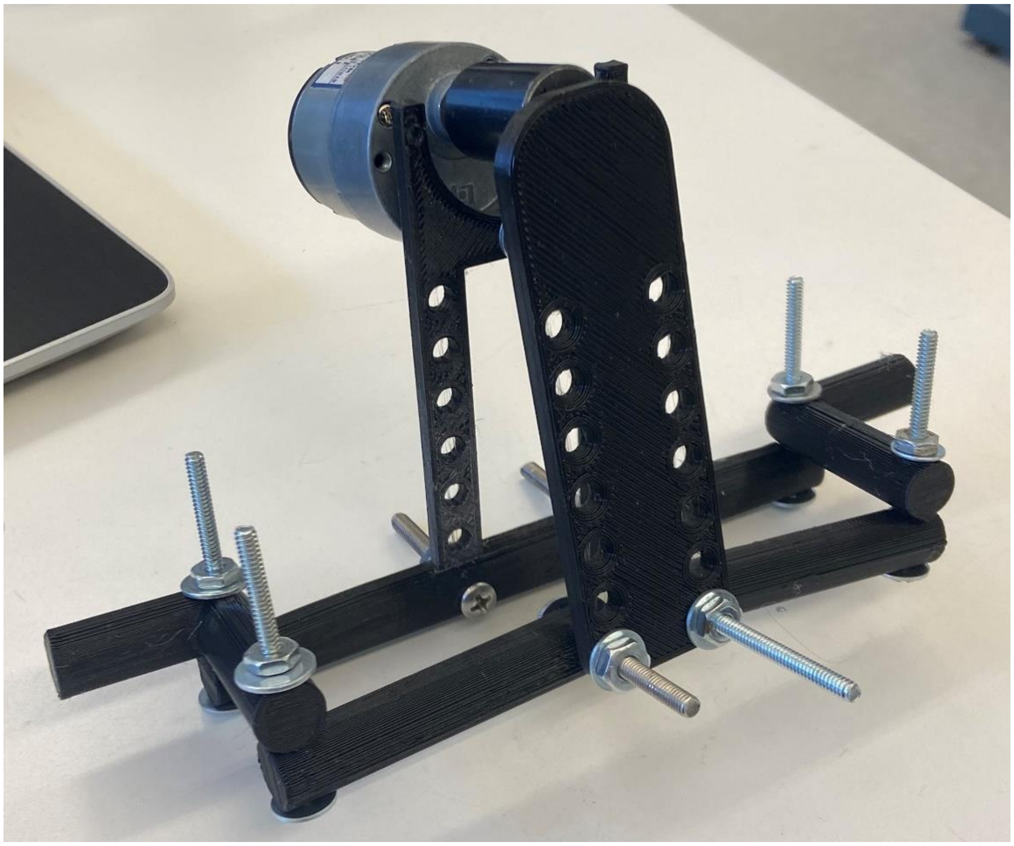
APPENDIX 2
Additional mechanical RRP documentation

Steering

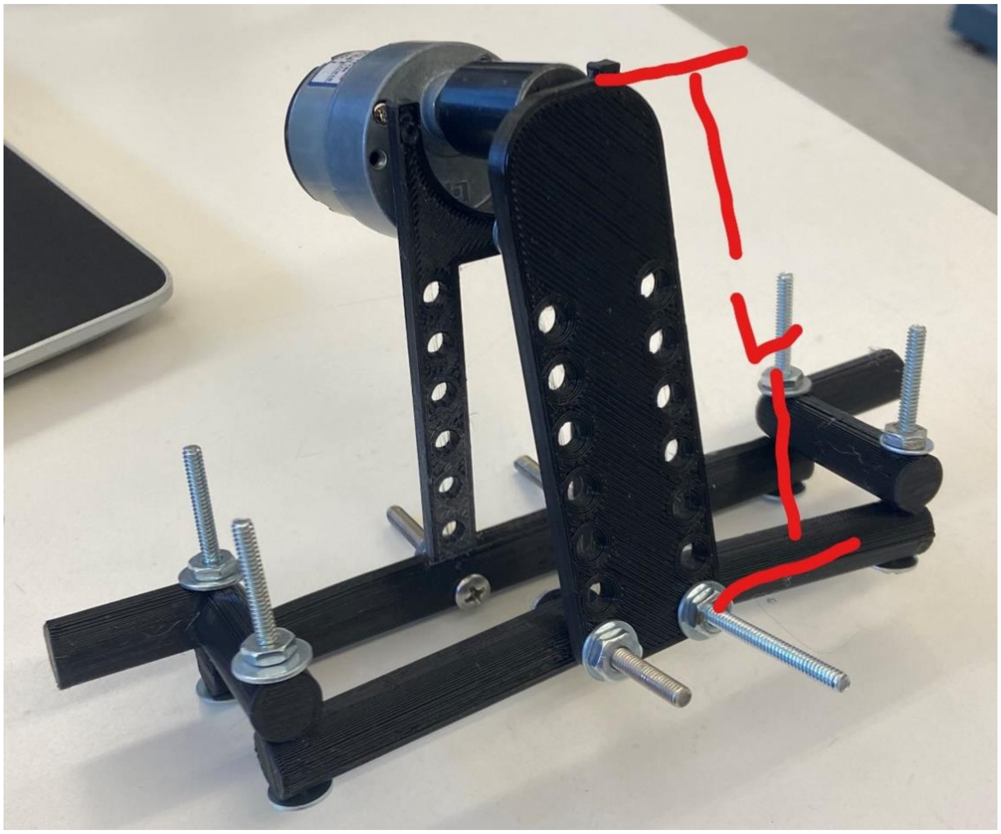
We designed an Ackerman steering system using solid works, and then 3d-printed it for testing. If we wish to increase the steering angle, we can increase the length L.



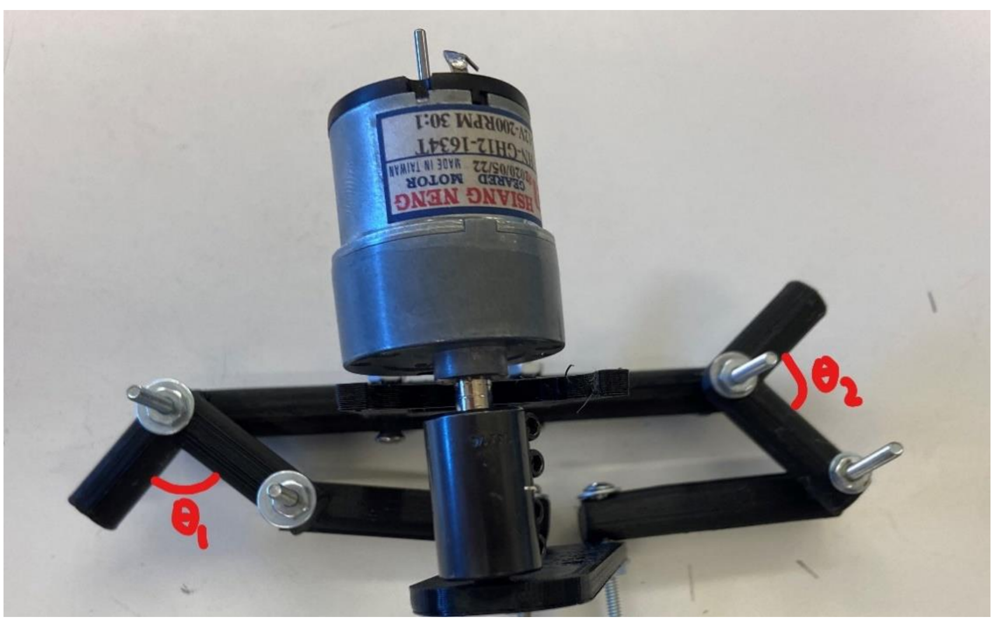
Appendix 2-1



Appendix 2-2



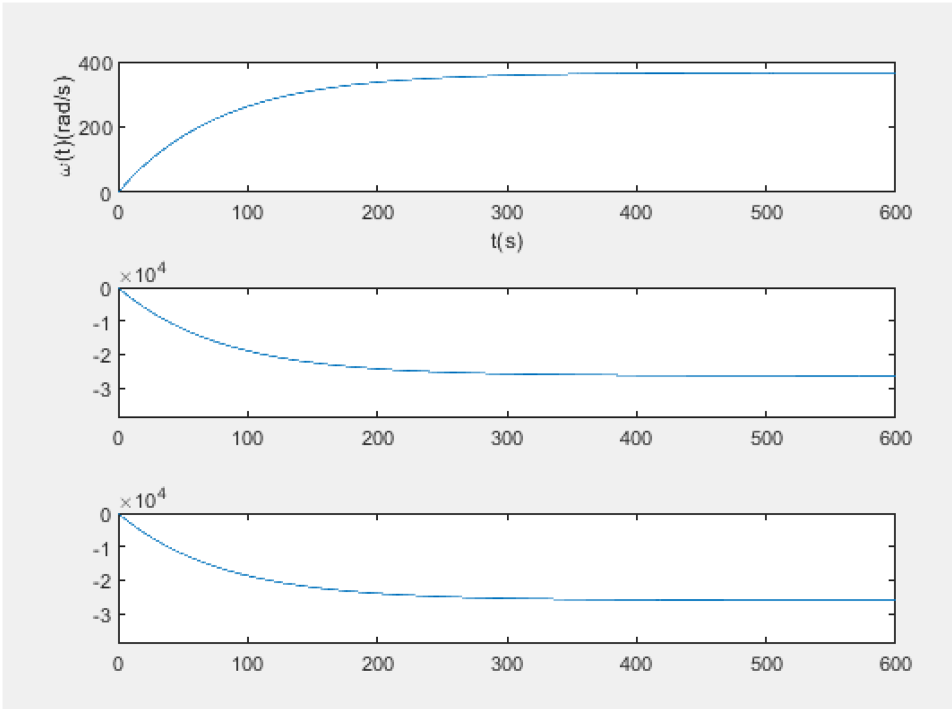
Appendix 2-3



Appendix 2-4

Motor Power related

Transfer function for finding the correct torque with power graphs. Can be used if needed.



ω(t)(rad/s)
400
200
0
0
100
200
300
400
500
600
t(s)
×10^4
0
-1
-2
-3
0
100
200
300
400
500
600
×10^4
0
-1
-2
-3
0
100
200
300
400
500
600

Appendix 2-5

APPENDIX 3
Additional computer and electrical analyses documentation

Power consumption

Purpose:

For this analysis, we needed to compute the maximum electrical power consumption of the system by summing the maximum power needs of all components. This analysis was contingent on knowing the motor power.

$$P = IV \quad (Eq. 1.3)$$

$$\%P = \frac{P_{component}}{P_{total}} * 100\% \quad (Eq. 1.4)$$

Results:

Device	Current (A)	Voltage (V)	Horsepower	Power (kW)	% Power Consumption
Drive Motor			0.50	0.373	94.7%
Steering Motor	1.5	12		0.018	4.6%
Arduino	0.02	12		0.00029	0.1%
Charge controller	0.2	12		0.0024	0.6%
Lidar Sensor	0.07	5		0.00035	0.1%
			Total kW:	0.394	

Appendix 3-1

The total power consumption of our system added to 0.394 kW, and the largest load of the system, as expected, was the drive motor, which accounted for 94.7% of the total needed power. These results were important for sequential analysis, design, and component selection.

Battery

Purpose:

For this analysis, we needed to determine how much power is needed to run the motor for a specified amount of time. We also needed to calculate how much power the battery would need to supply.

$$1\ motor * P_{horsepower} * \frac{745W}{1hp} * hours\ of\ run\ time = \frac{Wh}{charge} \quad (Eq. 1.5)$$

$$\frac{Wh}{charge} * \frac{1}{0.5} * 1.2 = \frac{Wh}{charge} \quad (Eq. 1.6, Lead\ Acid\ Sizing)$$

$$\frac{Wh}{charge} * \frac{1}{0.8} * 1.05 = \frac{Wh}{charge} \quad (Eq. 1.7, Lithium\ Sizing)$$

Results:

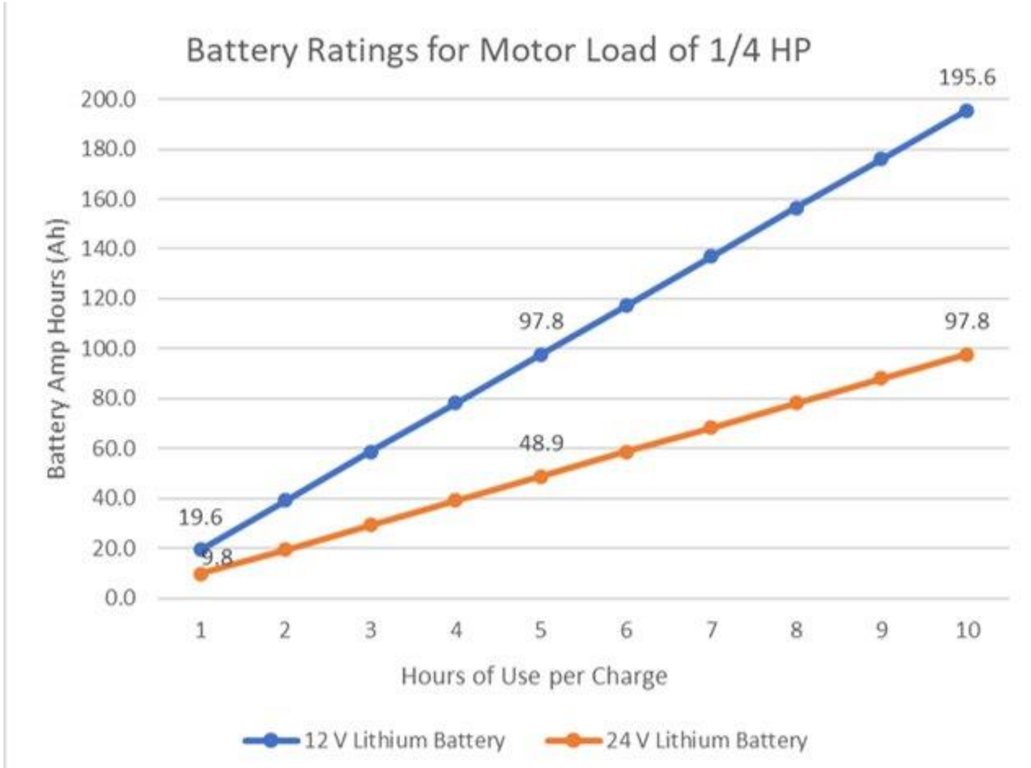
			Battery Size (kWh)		12 V Battery Ah		24 V Battery Ah		48 V Battery Ah	
Load Description	*Hours of use*	*kWh /Charge*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*
1/2 HP motor	0.5	0.1865	0.4476	0.2	37.3	19.6	18.65	9.8	9.3	4.9
	1	0.373	0.9	0.5	74.6	39.2	37.3	19.6	18.65	9.8
	2	0.746	1.8	0.9	149.2	78.3	74.6	39.2	37.3	19.6
	3	1.119	2.7	1.4	223.8	117.5	111.9	58.7	55.95	29.4
	4	1.492	3.6	1.9	298.4	156.7	149.2	78.3	74.6	39.2
	5	1.865	4.476	2.3	372.5	195.8	186.5	97.9	93.3	49.0
	6	2.238	5.4	2.8	447.6	235.0	223.8	117.5	111.9	58.7
	7	2.611	6.3	3.3	522.2	274.2	261.1	137.1	130.55	68.5
	8	2.984	7.2	3.8	596.8	313.3	298.4	156.7	149.2	78.3
	9	3.357	8.1	4.2	671.4	352.5	335.7	176.2	167.85	88.1
	10	3.73	9.0	4.7	746	391.7	373	195.8	186.5	97.9
			Battery Size (kWh)		12 V Battery Ah		24 V Battery Ah		48 V Battery Ah	
Load Description	*Hours of use be*	*kWh /Charge*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*	*Lead Acid*	*Lithium*
1/4 HP motor	0.5	0.093	0.2235	0.1	18.625	9.8	9.3125	4.9	4.7	2.4
	1	0.186	0.4	0.2	37.25	19.6	18.625	9.8	9.3125	4.9
	2	0.373	0.9	0.5	74.5	39.1	37.25	19.6	18.625	9.8
	3	0.559	1.3	0.7	111.75	58.7	55.875	29.3	27.9375	14.7
	4	0.745	1.8	0.9	149	78.2	74.5	39.1	37.25	19.6
	5	0.931	2.235	1.2	372.5	97.8	93.125	48.9	46.6	24.4
	6	1.118	2.7	1.4	223.5	117.3	111.75	58.7	55.875	29.3
	7	1.304	3.1	1.6	260.75	136.9	130.375	68.4	65.1875	34.2
	8	1.490	3.6	1.9	298	156.5	149	78.2	74.5	39.1
	9	1.676	4.0	2.1	335.25	176.0	167.625	88.0	83.8125	44.0
	10	1.863	4.5	2.3	372.5	195.6	186.25	97.8	93.125	48.9

Appendix 3-2

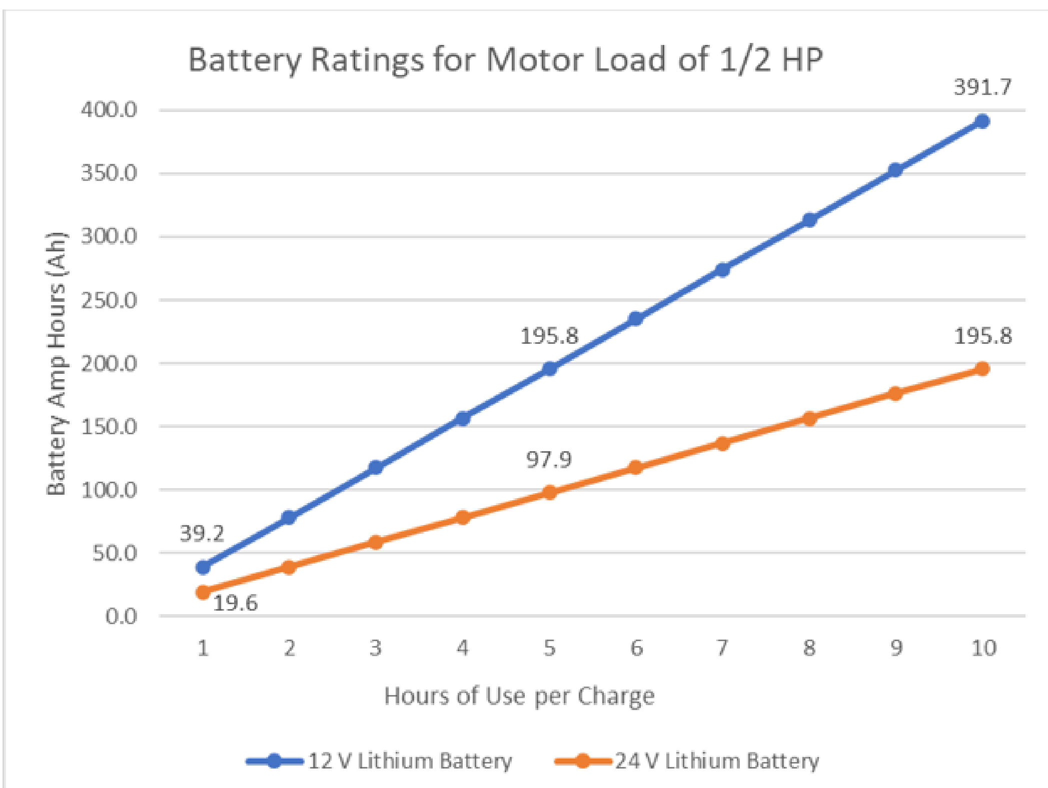
for ½ HP Motor Load			for ¼ HP Motor Load		
Hours of charge	12 V Lithium Battery Ah	24 V Lithium Battery Ah	Hours of charge	12 V Lithium Battery Ah	24 V Lithium Battery Ah
0.5	19.6	9.8	0.5	9.8	4.9
1	39.2	19.6	1	19.6	9.8

2	78.3	39.2	2	39.1	19.6
3	117.5	58.7	3	58.7	29.3
4	156.7	78.3	4	78.2	39.1
5	195.8	97.9	5	97.8	48.9
6	235.0	117.5	6	117.3	58.7
7	274.2	137.1	7	136.9	68.4
8	313.3	156.7	8	156.5	78.2
9	352.5	176.2	9	176.0	88.0
10	391.7	195.8	10	195.6	97.8

Appendix 3-3



Appendix 3-4



Appendix 3-5

Solar Power with Charge Controller

Purpose:

The purpose of this analysis was to determine how many solar panels will be needed to charge the battery and to determine how much time will be needed for this number of panels to charge the battery.

$$sun\ hours * \frac{P_{panel}}{V_{battery}} = I_{capacity} \quad (Eq. 1.8)$$

Results:

Location	Sun hours/year	Avg Sun hours/day	Solar Panel Wattage	Battery Voltage	Calculated Charge Capacity (Ah)
Seattle, Washington	2100	5.8	100 W	12V	47.9
				24V	24.0
Cape Town, South Africa	3100	8.5		12V	70.8
				24V	35.4

Appendix 3-6

Seattle, Washington	2100	5.8	200 W	12V	95.9
				24V	47.9
Cape Town, South Africa	3100	8.5		12V	141.6
				24V	70.8

Appendix 3-7

Bluetooth transmitter

Purpose:

For this analysis, it was necessary to determine the power needed to operate the microcontroller for transmitting a Bluetooth signal.

$$P = IV \quad (Eq. 1.3)$$

Results:

Device	Current (A)	Voltage (V)	Total Power (kW)
Bluetooth module	0.08	3.6	0.000288

Appendix 3-8

APPENDIX 4

Additional mechanical analyses documentation

Motor Power

Purpose:

This analyses, is necessary to determine how much torque is required in the rear axle to accelerate the cart up to the desired speed in a particularly torque-heavy scenario. Using this value for torque we can then determine the power required by the motor.

$$T = r_B\left[M \cdot a + \left(a\frac{I_A}{r_A^2} + m_A\right) + m_A g \sin\theta + a\left(m_B + \frac{I_B}{r_B^2}\right) + m_B g \sin\theta + Mg\sin\theta\right] \quad (Eq.1.1)$$

where r_A, m_A, and I_A refer to the radius, mass and moment of inertia of the front wheels, r_B, m_B, and I_B refer to the rear wheels. M, g, θ, and a refer to the mass of the cart, gravitational acceleration, angle of incline and linear acceleration of the cart respectively.

$$P = T\omega \quad (Eq.1.2)$$

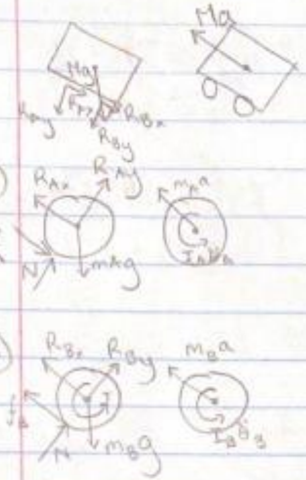
Parameter	**Value**	**Units**
Mass of Cart (M)	150	lbs
Mass of front wheels (m_A)	10	lbs
Mass of rear wheels (m_B)	10	lbs
Radius of front wheels (r_A)	6	in
Radius of rear wheels (r_B)	6	in
Inertia of front wheels (I_A)	360	lbin^2
Inertia of rear wheels (I_B)	360	lbin^2
Angle of incline (θ)	10	Degrees
Initial speed	0	mph
Final speed	3	mph
Duration	3	s
Acceleration (a)	1.466667	ft/s^2
Radial velocity	4.4	rad/s
Average Torque	**229.0466**	**lbfin**
	25.87883	**Nm**
Power	**113.8669**	**W**

Appendix 4-1

Case 2:		
Parameter	**Value**	**Units**
Mass of Cart (M)	150	lbs
Mass of front wheels (m_A)	10	lbs
Mass of rear wheels (m_B)	10	lbs
Radius of front wheels (r_A)	6	in
Radius of rear wheels (r_B)	6	in
Inertia of front wheels (I_A)	360	lbin^2
Inertia of rear wheels (I_B)	360	lbin^2
Angle of incline (θ)	45	Degrees
Initial speed	0	mph
Final speed	3	mph
Duration	20	s
Acceleration (a)	0.22	ft/s^2
Radial velocity	4.4	rad/s
Average Torque	**729.0377**	**lbfin**
	82.37033	**Nm**
Power	**362.4294**	**W**
	0.486025	**HP**

Appendix 4-2

Rear Wheel Drive



$M = 150\,lb$

$m_A = 10\,lb$

$m_B = 10\,lb$

$I_A = m_A r^2 = (10\,lb)(6\,in)^2 = 360\,lb{\cdot}in^2$

$I_B = m_B r^2 = (10\,lb)(6\,in)^2 = 360\,lb{\cdot}in^2$

$T = ?$

$\theta = 10°$

$a = 14.67\ ft/s^2$

Wheel A:

$$+\nwarrow \Sigma F_x = m_A a$$

$$R_{Ax} - m_A g \sin\theta - f_A = m_A a \quad (4)$$

$$\circlearrowleft + \Sigma M_{GA} = I_A \ddot{\theta}_A$$

$$f_A r_A = I_A \ddot{\theta}_A = I_A \frac{a}{r_A}$$

$$f_A = I_A \frac{a}{r_A^2} \quad (5)$$

$$R_{Ax} - m_A g \sin\theta - I_A \frac{a}{r_A^2} = m_A a \quad (4+5)$$

$$R_{Ax} = m_A g \sin\theta + I_A \frac{a}{r_A^2} + m_A a$$

$$R_{Ax} = a\left[\frac{I_A}{r_A^2} + m_A\right] + m_A g \sin\theta \quad (6)$$

Appendix 4-3

Wheel B:

$$\nwarrow^{+} \sum F_x = m_B a$$

$$R_{Bx} + f_B - m_B g \sin\theta = m_B a \quad (1)$$

$$(\circlearrowleft +) \sum M_{GB} = I_B \ddot{\theta}_B$$

$$T - f_B r_B = I_B \ddot{\theta}_B \quad \text{(non-slip)}$$

$$\frac{T}{r_B} - f_B = \frac{I_B \ddot{\theta}_B}{r_B}$$

$$f_B = \frac{T}{r_B} - I_B \frac{\ddot{\theta}_B}{r_B} = \frac{T}{r_B} - I_B \frac{a}{r_B^2} \quad (2)$$

$$R_{Bx} + \left[\frac{T}{r_B} - I_B \frac{a}{r_B^2}\right] - m_B g \sin\theta = m_B a \quad (1+2)$$

$$R_{Bx} = m_B a + m_B g \sin\theta - \frac{T}{r_B} + I_B \frac{a}{r_B^2}$$

$$R_{Bx} = a\left[m_B + \frac{I_B}{r_B^2}\right] + m_B g \sin\theta - \frac{T}{r_B} \quad (3)$$

Car Body:

$$\nwarrow^{+} \sum F_x = M_a$$

$$-R_{Ax} - R_{Bx} - Mg\sin\theta = Ma \quad (7)$$

$$(3+6+7) \quad -\left[a\left(\frac{I_A}{r_A^2} + m_A\right) + m_A g \sin\theta\right] - \left[a\left(m_B + \frac{I_B}{r_B^2}\right) + m_B g \sin\theta - \frac{T}{r_B}\right] \ldots$$

$$\ldots - Mg\sin\theta = Ma$$

$$\frac{T}{r_B} = Ma + a\left(\frac{I_A}{r_A^2} + m_A\right) + m_A g \sin\theta + a\left(m_B + \frac{I_B}{r_B^2}\right) + m_B g \sin\theta + Mg\sin\theta$$

$$\boxed{T = r_B\left[Ma + a\left(\frac{I_A}{r_A^2} + m_A\right) + m_A g \sin\theta + a\left(m_B + \frac{I_B}{r_B^2}\right) + m_B g \sin\theta + Mg\sin\theta\right]}$$

$$T = 0.6\,\text{in}\Big[(150\,\text{lb})(1.467\,\text{ft/s}^2) + (1.467\,\text{ft/s}^2)\left(\frac{360\,\text{lb}\cdot\text{in}^2}{36\,\text{in}^2} + 10\,\text{lb}\right) + (10\,\text{lb})(32.2\,\text{ft/s}^2)\sin(10^\circ)$$

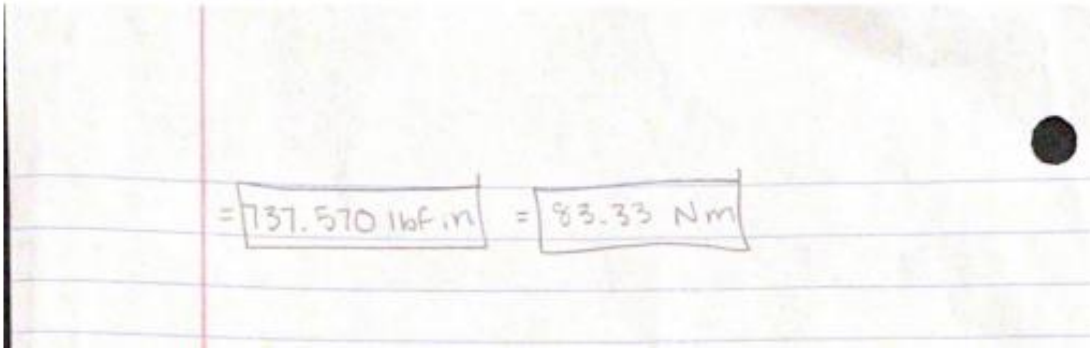
$$+ (1.467\,\text{ft/s}^2)\left(10\,\text{lb} + \frac{360\,\text{lb}\cdot\text{in}^2}{36\,\text{in}^2}\right) + (10\,\text{lb})(32.2\,\text{ft/s}^2)\sin(10^\circ)$$

$$+ (150\,\text{lb})(32.2\,\text{ft/s}^2)\sin(10^\circ)\Big]$$

$$= 0.6\,\text{in}\Big[220.05\,\text{lbft/s}^2 + 29.34\,\text{lbft/s}^2 + 55.915\,\text{lbft/s}^2 + 29.34\,\text{lbft/s}^2 + 55.915\,\text{lbft/s}^2$$

$$+ 838.721\,\text{lbft/s}^2\Big]$$

Appendix 4-4

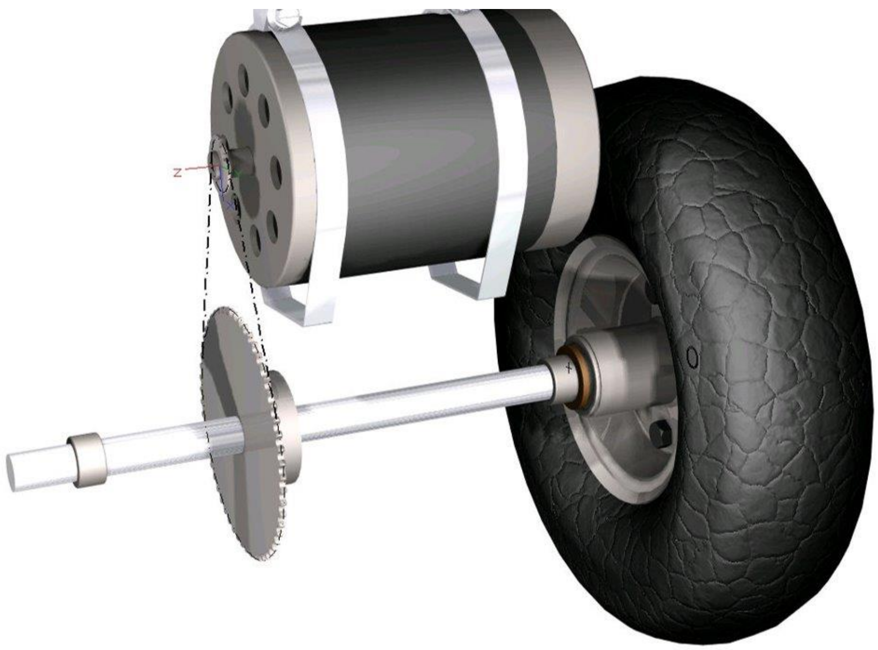


Appendix 4-5

Gear Box

Purpose:

Determine the size and kind of gears needed to achieve the correct gear ratio and transmit power from the motor to the wheels. This is important to achieve the desired speed of our cart, and to transport heavier loads.

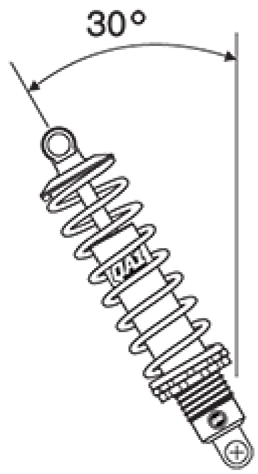


Appendix 4-6

Suspension

Purpose:

Find maximum force needed from a shock absorber based on the max weight and determine suspension needed.



Appendix 4-7

Case 1	
Parameter	**Value**
Total cart weight (M)	150 lbf
Weight on each wheel (W)	32.5 lbf
Angle of coil-over (A)	20 degrees
Length of spring (L)	10 in
Percent compression	35%
Spring Rate (SR)	**9.878 lbf/in**

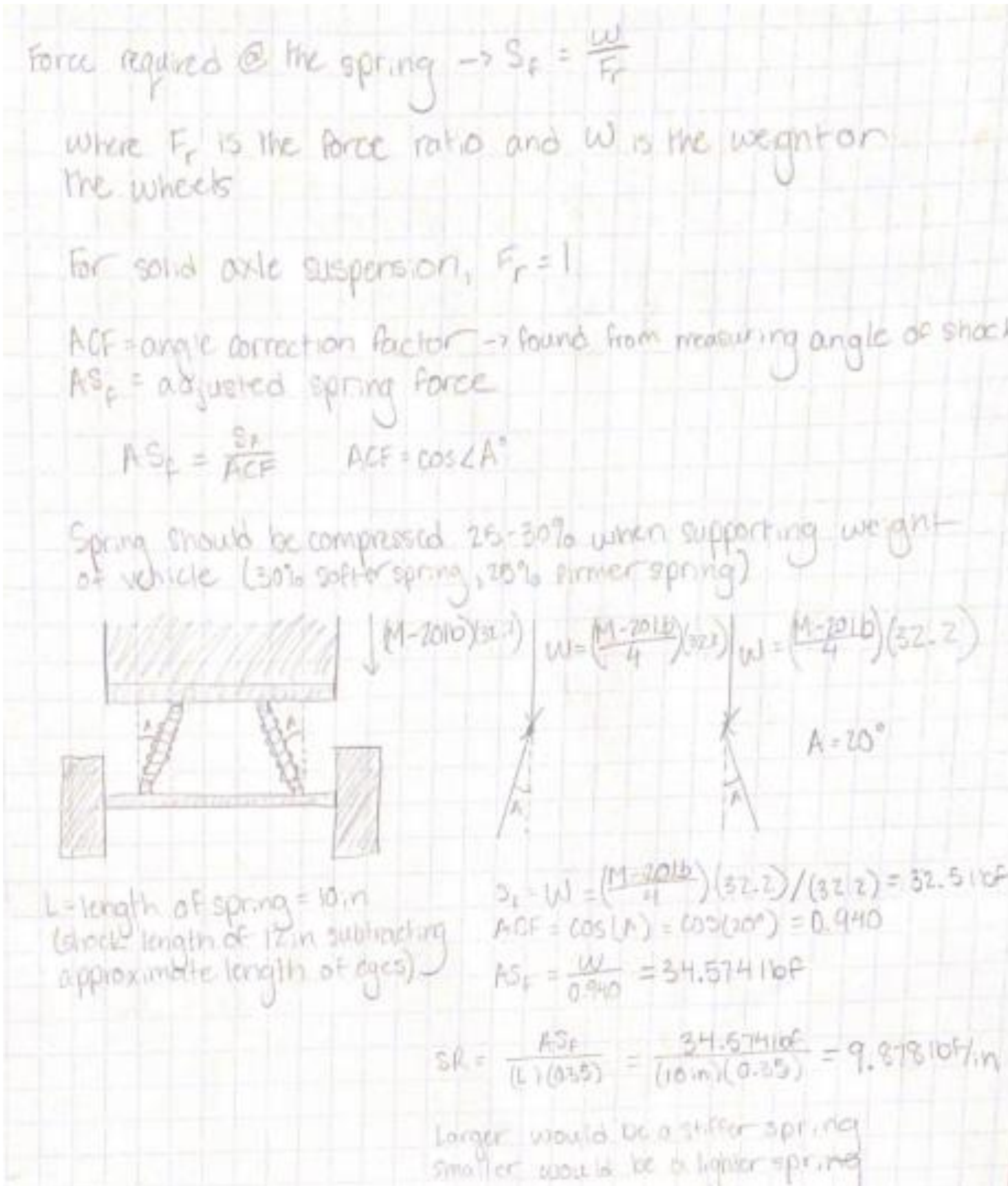
Appendix 4-8

For this first case we assumed a 20-degree angle. We felt this was a good rough estimate of the angle we would design for because it would focus most of its absorption vertically but still provide some horizontal absorption as well.

Case 2	
Parameter	**Value**
Total cart weight (M)	150 lbf
Weight on each wheel (W)	32.5 lbf
Angle of coil-over (A)	0 degrees
Length of spring (L)	10 in

Percent compression	35%
Spring Rate (SR)	**9.286 lbf/in**

Appendix 4-9


Force required @ the spring → $S_f = \frac{W}{F_r}$
where F_r is the force ratio and W is the weight on the wheels
For solid axle suspension, $F_r = 1$
ACF = angle correction factor → found from measuring angle of shock
AS_f = adjusted spring force
$AS_f = \frac{S_f}{ACF}$ ACF = cos∠A°
Spring should be compressed 25-30% when supporting weight of vehicle (30% softer spring, 25% firmer spring)

L = length of spring = 10 in (shock length of 12 in subtracting approximate length of eyes)
$S_f = W = \left(\frac{M-2016}{4}\right)(32.2)/(32.2) = 32.5$ lbf
ACF = cos(A) = cos(20°) = 0.940
$AS_f = \frac{W}{0.940} = 34.574$ lbf
$SR = \frac{AS_f}{(L)(0.35)} = \frac{34.574 \text{ lbf}}{(10 \text{ in})(0.35)} = 9.878$ lbf/in
Larger would be a stiffer spring
Smaller would be a lighter spring

Appendix 4-10

Mass Distribution

Purpose:

Determine the static forces and loads of the cart in order to ensure the system is stable.

Weight Estimations:	**lbs**

Chassis/drivetrain	30
Motors	10
Other Components	5
Batteries	10
Thin Film Solar Panels	10
Suspension	15
Wheels	20
Load Capacity	50
Total Weight:	**150**

Appendix 4-11

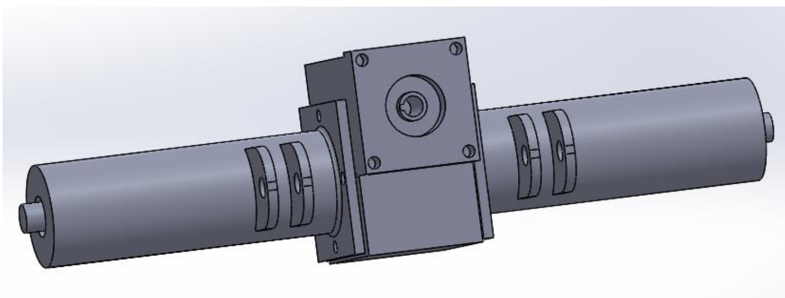
Brakes

<u>Purpose:</u>

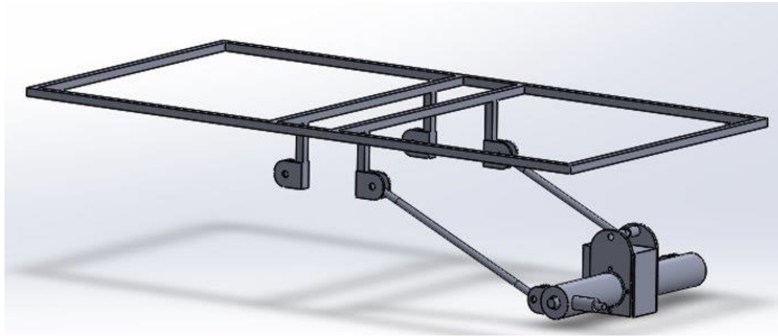
Find how much power is needed to bring the device to a stop. Important to prevent the device from running into people or objects and from rolling downhill.

Cart Design:

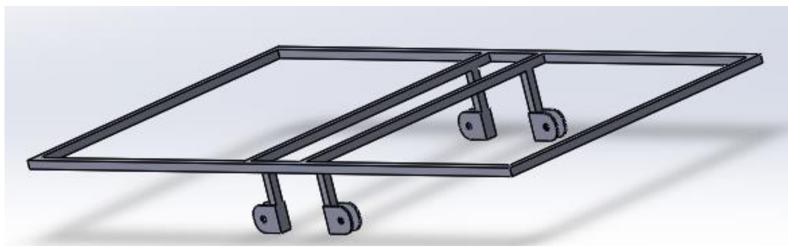
Cad designs of our initially proposed chassis and drive train components – Note: we plan to change the drivetrain design in the ways discussed earlier in the document, but the Frame design should stay about the same



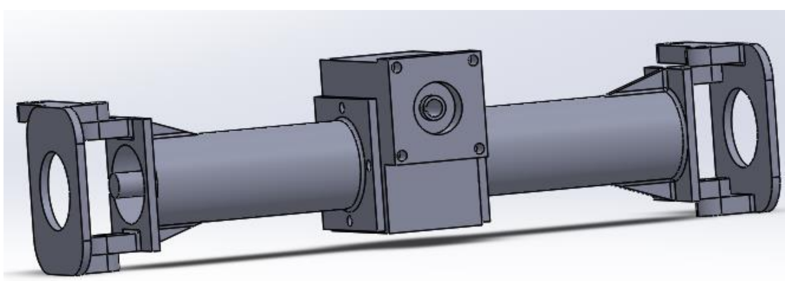
Appendix 4-12



Appendix 4-13



Appendix 4-14



Appendix 4-15

APPENDIX 5

About AAAMP Engineering Group

Team Vision and Mission

Vision:

Our vision is to decrease the limitations of human beings by increasing their capacity and ability to go further.

Mission:

To provide an off-grid solution for gear and equipment transportation for multiple terrains and environments.

Team Bios

Ashlynn Burgess

My passion for making the world a better place through engineering technology has brought me from Eagle River, Alaska, to Seattle, Washington, where I am currently pursuing a Bachelor of Science in Electrical Engineering. This summer I had the opportunity to live in Juneau, Alaska, where I worked for Alaska Electric Light and Power as their Transmission and Distribution Engineering Intern. After I graduate in June 2022, I hope to work as an electrical engineer and explore my interests in sustainable building design and renewable energy. Also, in the future I hope to use the technical skills and knowledge I have acquired to serve others through volunteer or missions-based work. Outside of the classroom I love to hike, bike, spend time with family and friends, explore, play piano and guitar, read, and try new things. Having played college basketball for four years, I now enjoy being involved in athletics by volunteering as a student manager for the Seattle Pacific women's basketball team, playing intermural volleyball and basketball, and working for SPU's Athletics Event Staff.

Amanda Harkleroad

I am in my 4th year pursuing an ABET accredited degree in Mechanical Engineering and a minor in Appropriate and Sustainable Engineering. Having received my AA during the final two years of high school and completing most of my general education requirements I have been able to take extra technical electives such as Electricity and Magnetism, Problem Solving and Programing (C++), and an extra course in Circuits. I have also been able to diversify my education and take electives such as Voice Class, Foundations of the Spiritual Life, Women's Choir, Concert Choir and Gospel Choir. I chose to pursue mechanical engineering because I felt that it was the best way to put my talents to use in giving back to the world, whether it be developing technologies that improve people's lives or helping make our way of life more sustainable to protect our planet. I am currently an intern at Lawrence Berkeley National Lab where I am assisting in developing a simulation of cancer cell migration using mechanical forces. In my free time, I love to hike, camp, rock climb, play guitar and keep up with all the latest and greatest movies!

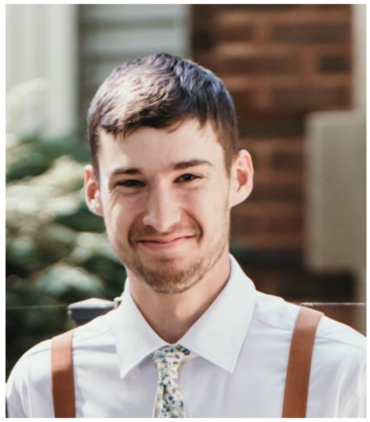
Muhammad Sesay

I am a 4th year pursuing a Computer Engineering degree at Seattle Pacific University. I was born in Monrovia Liberia and grew up in SeaTac Washington. Originally, I was pursuing an Electrical Engineering degree but as time progressed I had more of a passion and interest for computer science and programming and switched majors. Upon graduation I hope to learn more about different tech stacks and progress my skills in programming. I hope that what I work on has real impacts and can help all types of people. Making their lives easier and improving their quality of life as well. Outside of school I enjoy watching true crime tv shows and Anime. I enjoy reading books that can give me new perspectives on life and teach me new life skills that I can apply right away. I also really enjoy being active and outdoors. Whether it be basketball, hiking, snowboarding or jet skiing. I really enjoy trying new things and expanding my horizons.

Parmvir Singh

I am a 4th year senior as a Mechanical Engineering student at Seattle Pacific University. I have spent and enjoyed my whole life inside the state of Washington as a proud resident of Kent. After receiving my AA, I have been working towards my degree focusing on Mechanical Engineering, taking electives such as Appropriate and Sustainable Engineering, which really speak towards what I look forward to in the future and much more. After I graduate, I plan and hope to work to find a career inside the industry focusing in on sustainable energy. In my free time, I love to workout, spend time with family and friends, play sports with friends and videogames as well.

Andrew Harper-Smith



I am a third year senior Mechanical Engineering student at Seattle Pacific University. Although I am originally from Illinois, I have been a proud Washington resident for the last six years. I thoroughly enjoy the outdoors, whether it's fishing, hiking, or just cruising back roads, I enjoy it all. My greatest personal accomplishment was fully reviving a 1977 Ford F350 that had been rotting away in the Olympic national forest for 8+ years. I enjoy working on anything that drives, floats or flies and hope to find a career in the marine industry after graduation.

APPENDIX 6
AAAMP Team Schedule and Meeting Agenda

ID	% Complete	Task Mode	Task Name
1	84%		**Project Title**
2	100%		Start Project
3	100%		**Initiate**
5	100%		**Start**
10	79%		**Execute**
11	72%		**Analysis**
12	100%		**Mass Distribution**
15	83%		**Motor Power**
20	19%		**Gear Box**
23	81%		**Suspension**
26	100%		**Power Consumption**
28	100%		**Battery**
31	100%		**Solar Panel**
34	91%		**RRP**
35	82%		**Object Sensor and Control**
39	100%		**Steering**
44	100%		**Monitor**
45	100%		Week 7 Update
46	100%		Week 8 Update
47	100%		Week 9 Update
48	100%		**Close**

Appendix 6-1

Winter Break Microsoft Teams Meeting:
Date: 12/6/21 Time: 10 AM PST

- Agenda:
  - Update on individual tasks
  - Get on same page for ordering components
  - Order components and plan for who/where they will be shipped to
  - Website update
  - Discuss design plan for remote control
  - Discuss more plans for first week back in January
  - Discuss roles and if they need updated

Appendix 6-2