Conceptual Design Review

Intelligent Ground Vehicle Competition: GoBot

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ME 463
February 1st, 2017

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Introduction

Throughout this report, alternatives for subsystems for the vehicle were considered and evaluated. For the drivetrain, different wheel layouts were considered. For powering the vehicle, a DC motor and a gasoline engine were considered. For the types of wheel, all-terrain, standard, tracked, and omni wheels were considered. For the drive type, direct and geared drives were considered. For sensing the distance to obstacles, an ultrasonic sensor, a USB camera and an IR sensor were considered. For each subsystem, between one and three best options are selected. Of these best options, the concepts are blended and evaluated in a weighted matrix based on importance of vehicle design factors. Finally, the top two choices are selected for further evaluation.

Problem Definition

More and more companies are getting interested in making autonomous cars. Following lane lines and traffic rules are a very important first step in the process, but this is not the only step. In order for the autonomous car to be safe, the car needs to be able to sense anomalies and react intelligently to them. This includes potholes, pedestrians, traffic cones, traffic, and much more. They could be in the middle of the road, but the car shouldn't run them over. The next step in the autonomous car design process is implementing a way to avoid these obstacles intelligently and continue along the path. This project is in pursuit of this goal.

Rapid concept development

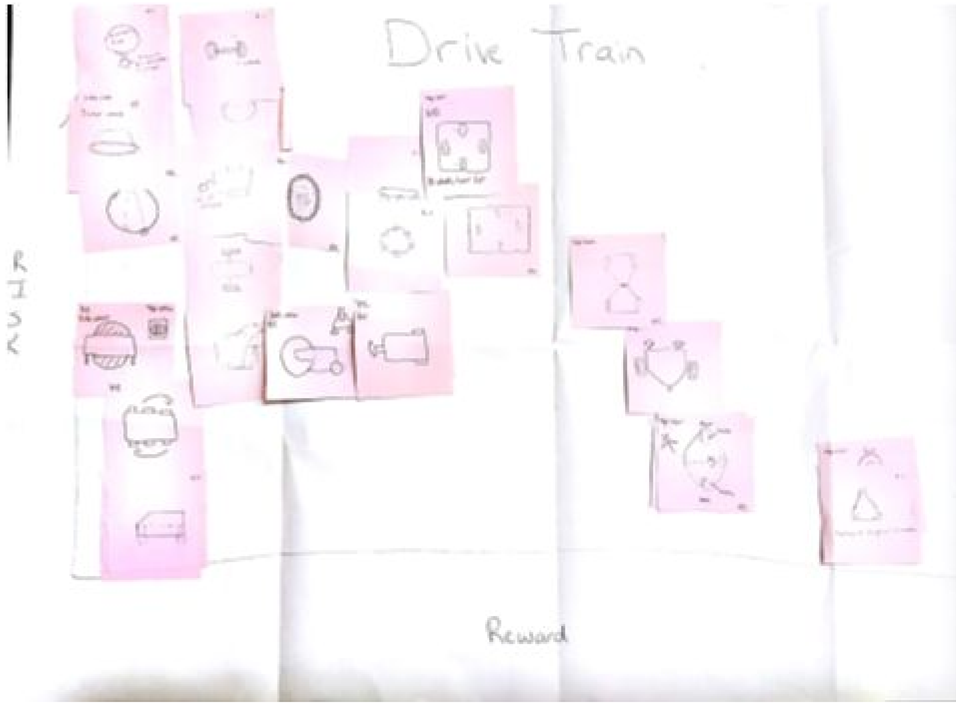


Figure 1. Reward vs. Risk concept diagram for drivetrain

Following the Reward vs. Risk plotting activity for drivetrain concepts, several concepts were generated and plotted (Figure 1). Each team member generated nine concepts and explained about the concepts briefly. Together, we considered the reward and risk of each concept, and voted on our top three favorites (Figure 2).

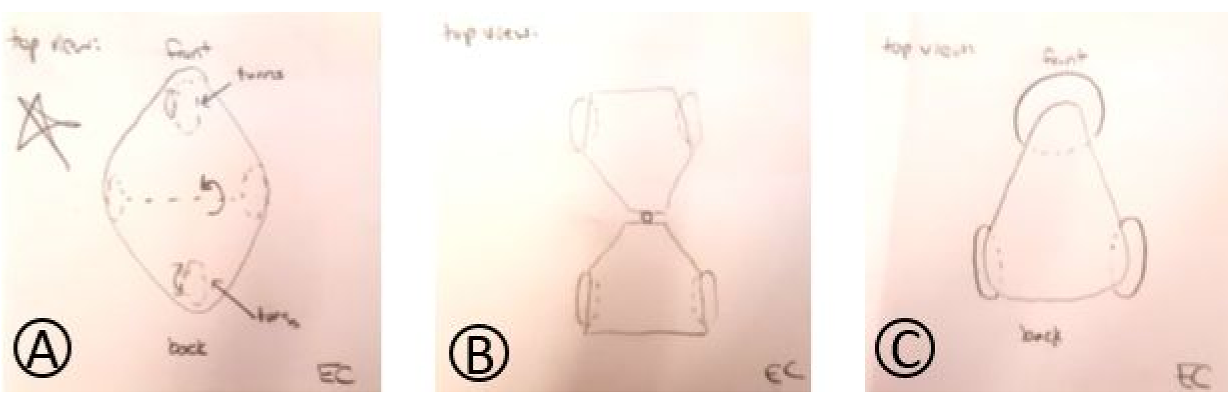


Figure 2. The voted concepts

The concept “A” was considered as a best concept among three concepts. Concept “A” has four wheels. The top and bottom wheels rotate and guide the vehicle. The two side wheels are connected to the motor and propel the vehicle forward or backward. The concept “B” is has to similar parts connected with a hinge or link. Both sides has a set of wheels that can all turn and propel the car. The advantage of this design is the ability for either side to be the “front”. The concept “C” has three wheels, one directional wheel in front and two driving wheels in back. The type of directional wheel is the omni wheel.

Performance matrix

A performance matrix was used to evaluate the generated concepts. Factors like economic, reliability, mobility, performance and safety are evaluated from one star (bad) to 3 stars (good). The top 1 or 2 evaluated concepts are highlighted. A better feature design can be generated based on the top alternatives of each subfunction. Six concepts were evaluated including the three voted concepts. The remaining three concepts evaluated are shown in Figure 3.

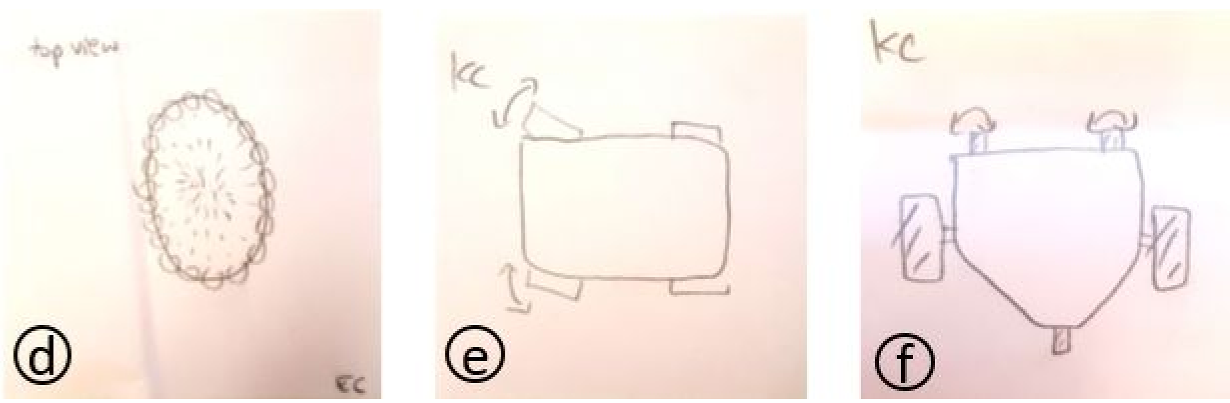


Figure 3. The concepts that were evaluated in performance matrix

Drive Train

Factors/ Alternatives	Ⓐ "2+2"	Ⓑ Link vehicle	Ⓒ "2+1"	Ⓓ Multiple rollerball vehicle	Ⓔ Common 4 wheels vehicle	Ⓕ Wheelchair vehicle
Economic	☆☆☆	☆	☆☆	☆☆	☆☆	☆☆
Reliability	☆☆☆	☆	☆	☆☆	☆☆	☆
Mobility	☆☆	☆☆☆	☆	☆☆☆	☆☆☆	☆☆☆
Performance	☆☆	☆	☆	☆☆☆	☆☆☆	☆☆
Safety	☆☆☆	☆	☆	☆☆☆	☆☆	☆

Table 1. Drive train performance matrix

Power

	1	2
		
Concepts	DC Motor [6]	Gasoline Engine [2]
Reliability	☆☆	☆☆
Economic	☆☆☆	☆
Weight	☆☆	☆☆
Performance	☆☆	☆☆☆

Table 2. Vehicle power performance matrix

For powering the vehicle, a DC motor and a gasoline engine were considered. The two power sources are common for robots and RC cars and easy to purchase and to construct.

Wheel type

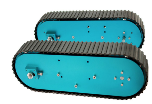
	1	2	3	4
				
Concepts	All-terrain Wheel [8]	Standard Wheel [9]	Tracked Wheel [3]	Omni-wheel [5]
Safety	☆☆☆	☆☆	☆	☆☆☆
Economic	☆☆	☆☆☆	☆	☆
Reliability	☆☆☆	☆☆	☆☆	☆☆

Table 3. Vehicle wheel type performance matrix

For the types of wheel, all-terrain, standard, tracked, and omni wheels were considered. The type of wheel depends on the types of drivetrain, but for our evaluation, all-terrain and standard wheel were selected. Different types of standard wheels are applied for different purposes, like driving and turning. A less friction standard wheel will be used for the direction changing wheels.

Drive type

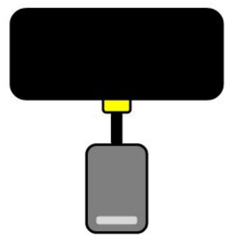
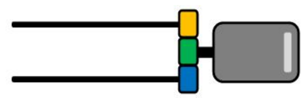
	1	2
		
Concepts	Direct drive	Geared drive
Reliability	☆☆☆	☆
Economic	☆☆☆	☆☆
Safety	☆☆☆	☆☆

Table 4. Drive type performance matrix

For the drive type, direct and geared drives were considered. The drive type also depends on the types of drivetrain. If the drivetrain performs changing direction and driving forward simultaneously, then the direct drive will be used. Other than that, the geared drive will be used.

Sensor

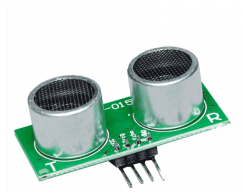
	1	2	3
			
Concepts	Ultrasonic Sensor [1]	USB Camera [4]	IR Sensor [7]
Reliability	☆☆☆	☆☆	☆☆☆
Economic	☆☆☆	☆☆	☆☆☆
Adaptability	☆☆☆	☆☆	☆

Table 5. Distance sensor performance matrix

For sensing the distance to obstacles, an ultrasonic sensor, a USB camera and an IR sensor were considered. The ultrasonic sensor calculates distance based on the time between sending and receiving the signal. It can be used for objects with uneven surfaces, under difficult ambient conditions, with highly transparent media, with moving objects, and with highly reflective liquid surfaces. The USB camera can give the distance as well as the vision feedback, but it needs to be calibrated with standard sized objects. Then, it calculates the actual distance based on the pixel change. The IR camera is widely use indoors but it can be negatively impacted by the sunshine. As a result, we have selected the ultrasonic sensor.

Concept Evaluation

Concept Blending

Based on the top one or two options for each subsystem, blended concepts were generated. The top view, side view, and front view of each concept are shown below.

1. Common 4 wheels vehicle + DC motor + direct drive + ultrasonic sensor + terrain wheel/ standard wheel

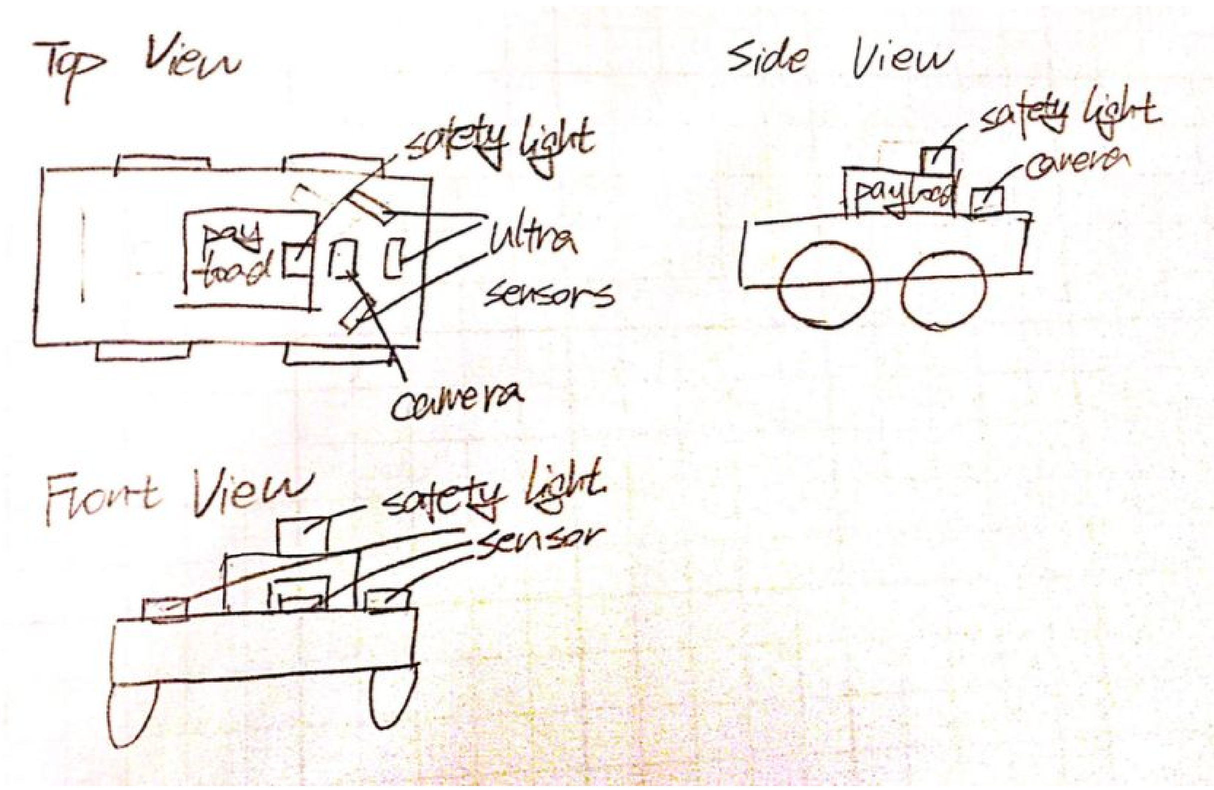


Figure 4. Blending concept for common 4 wheels vehicle

2. Two motor-driven wheels + two direction change wheels + DC motor + direct drive + ultrasonic sensor + terrain wheel/ standard wheel

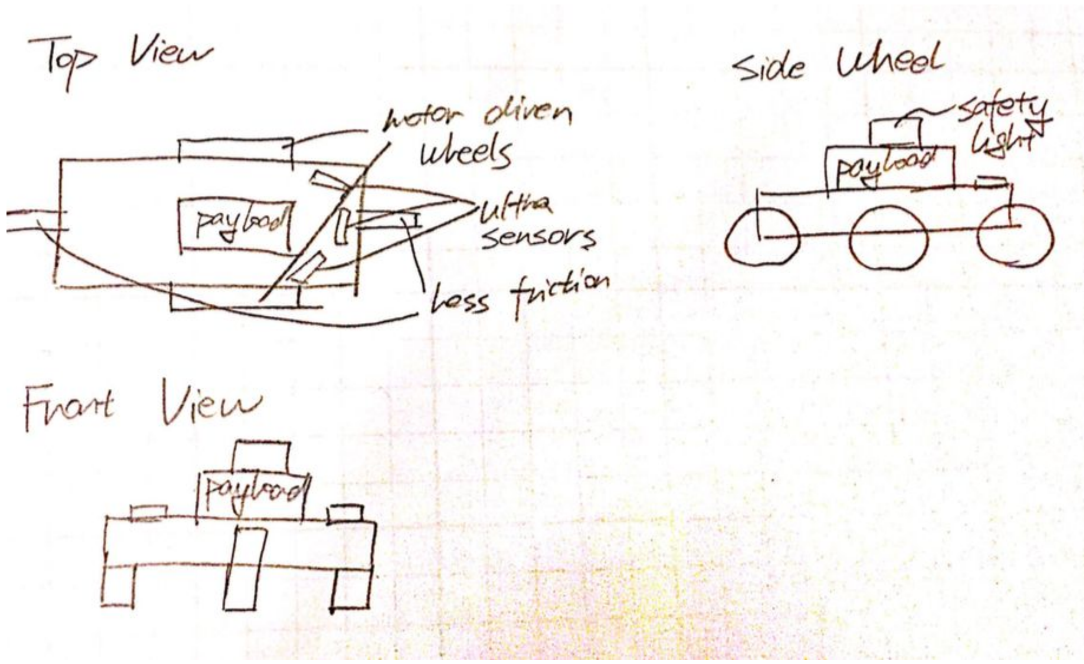


Figure 5. Blending concept for “2+2” vehicle

3. 2 motor-driven wheels + 1 direction change wheels + DC motor + direct drive + ultrasonic sensor + terrain wheel/ standard wheel

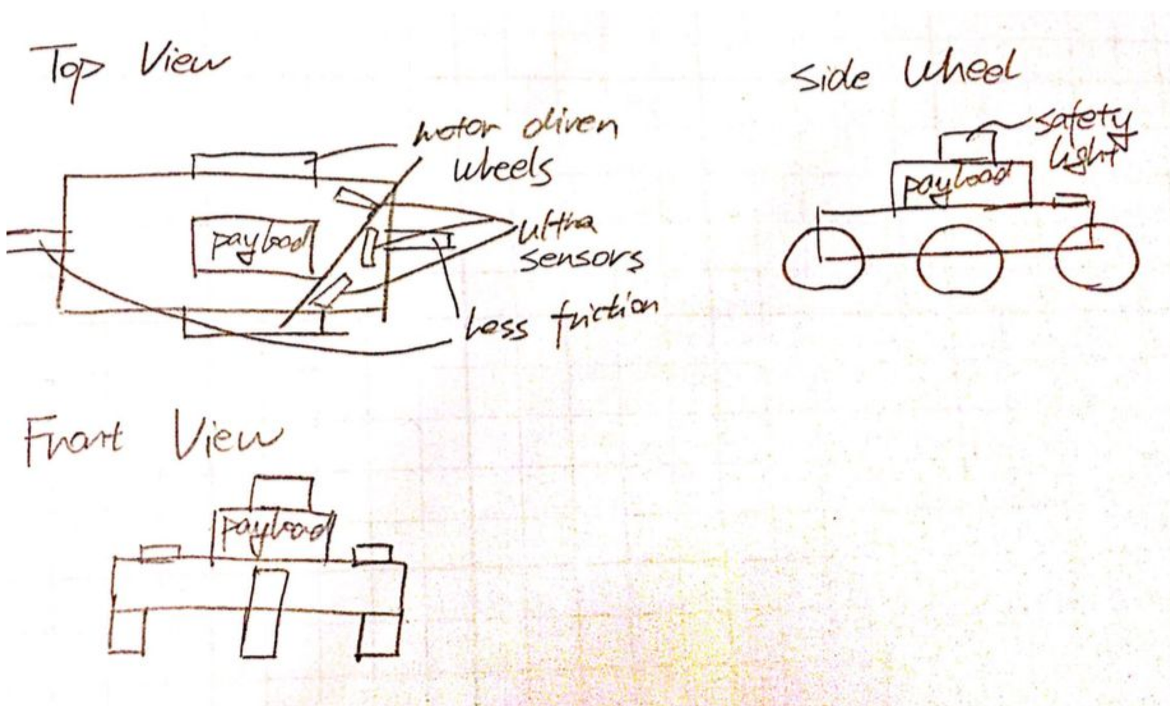


Figure 6. Blending concept for “2+1” vehicle

Weighted Matrix

According to the blended concepts, a weighted matrix is used as the decision-making tool. Several factors like safety, reliability, cost, performance, and mobility were evaluated from 1 (poor) to 5 (perfect), and each factor was weighted from 1 (not important) to 5 (very important). The weighted total points are calculated to decide the top two alternatives. The details of the weighted matrix is shown below.

Factors	Economic	Reliability	Mobility	Safety	Weight	Total
Weights	3	5	4	5	3	
common 4 wheels + DC motor + terrain wheel + ultrasonic	4	4	3	5	4	81
common 4 wheels + DC motor + standard wheel + ultrasonic	5	3	4	3	4	73
"2+2" + DC motor + terrain wheel + ultrasonic	3	4	5	4	3	78
"2+2" + DC motor + standard wheel + ultrasonic	4	4	4	4	3	77
"2+1" + DC motor + terrain wheel + ultrasonic	3	3	4	3	3	64
"2+1" + DC motor + standard wheel + ultrasonic	4	2	4	3	3	62

Table 6. Weighted matrix of blending concepts

The “common 4 wheels” design is the best economically because each of the four wheels are the same. The “2+2” design uses less friction wheels for the two turning ones, and those are a little more expensive. The “2+1” design uses two standard wheels and one omni-wheel, which is also more expensive. Terrain wheels are also more expensive than standard wheels, but they are also safer. The competition will be on a grassy and possibly wet surface, so we need to make sure that the vehicle can operate safely on that surface. With the “common 4 wheels” design, the payload weight can be distributed uniformly and is safer than the other methods. As a result, the two driving wheels for the “2+2” and the “2+1” cost more than that of the “common 4 wheels” vehicle because the weight requirement is higher. In addition, the supporting capacity of the "common 4 wheels" design is higher than other drive train concepts.

Simple Calculation

A simple calculation is made to evaluate and narrow down possible solutions. The free body diagram for the three wheel drivetrain is shown in Figure 7.

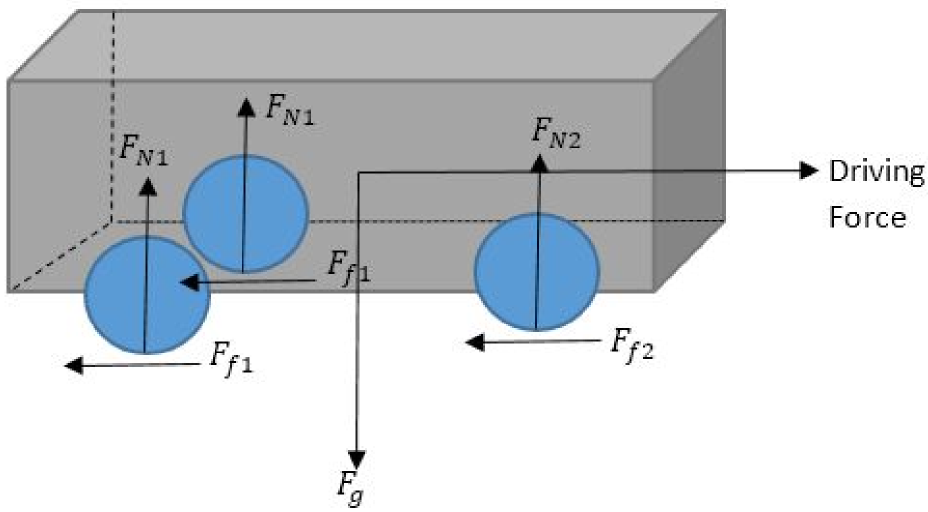


Figure 7. Free body diagram for three wheels vehicle

Consider the moment just before the vehicle moves. There is driving force exerting on the vehicle, which causes static friction. Assume that the center of mass is at the center of the block. The normal forces and frictional forces on the back two wheels are the same because they have the same distance to the center of mass. Assume that the dimension of the entire vehicle is 3ft * 1ft * 1ft, and the distance between front and back wheels is 2 ft. Summing moments at the center of mass:

$$\Sigma M = F_{N1} * 1 - F_{f1} * (0.5 + r) = 0$$
$$F_{N1} = (0.5 + r) * F_{f1} = (0.5 + r) * \mu * F_{N1}$$
$$r = \frac{1}{\mu} - 0.5$$

Where r is the radius of the wheel. The friction coefficient depends on the material properties of both wheels and contact surface. Assume that the wheels are made of rubber, and the contact surface is grass, the static friction coefficient can vary from 0.3-0.7. Taking the mean value $\mu = 0.5$, the radius of the wheel is calculated as 1.5 ft, which is oversized. Therefore, through calculation, it is noticed that the three wheel drivetrain is not an ideal solution. More detailed calculation for first and second choice with four-wheel drivetrain is shown in the next section.

First and second Choices

The first choice has the design of a normal car. The free body diagram is shown in Figure 8.

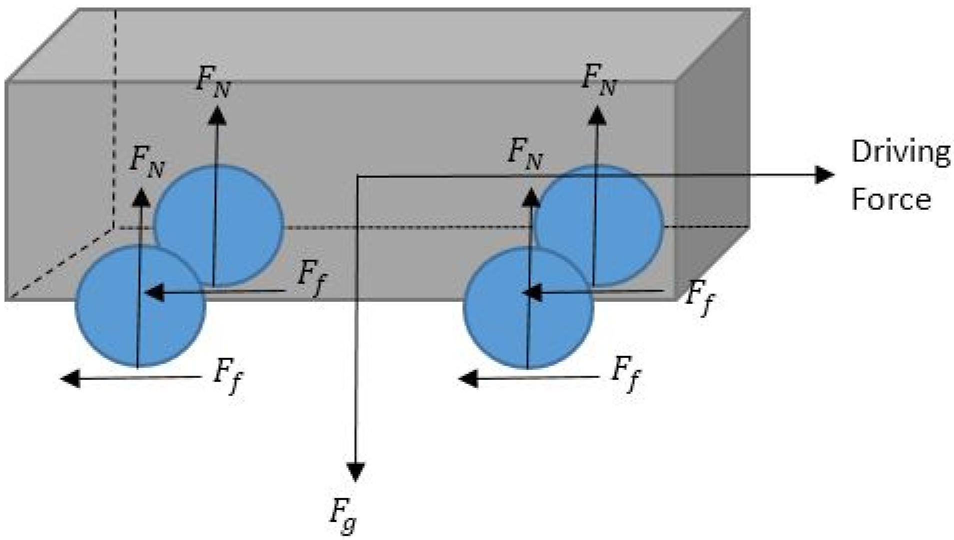


Figure 8. Free body diagram of common 4 wheels vehicle

With the same assumptions as the previous section, the normal force on each wheel is the same due to geometry, which is one-fourth of the entire vehicle weight. With desired velocity of 1 mph, and 2 seconds to reach desired velocity, the desired acceleration for the vehicle driving on a flat surface can be calculated as $0.22m/s^2$. Summing the forces in the horizontal direction:

$$F_{net} = ma = F - 4 * F_f = F - 4 * \mu mg * \frac{1}{4}$$

$$F = ma + \mu mg$$

Where F is the required driving force. With the entire vehicle mass of 20 lb including the 10 lb payload, and friction coefficient of 0.5, the force output required from motor is calculated. Units are converted to SI Units:

$$F = ma + \mu mg = 9.07185{*}0.22{+}0.5{*}9.07185{*}9.8{=}46.48 \text{ N}$$

On an inclined surface, the acceleration is calculated by adding an additional term to the original acceleration:

$$a_{inclined} = a + m * sin(\vartheta * \pi/180)$$

Assume that the inclined angle ϑ is 10 degrees:

$$a_{inclined} = a + (32.2ft/s) * sin(\vartheta * \pi/180) = 0.22 + (9.81456m/s) * sin(\pi/18) = 1.924m/s^2$$

$$F = ma + \mu mg = 9.07185{*}1.924{+}0.5{*}9.07185{*}9.8{=}61.9 \text{ N}$$

$$T = F_f * r = 0.25\mu mg * r$$

For the second choice, one wheel is placed in the middle on each side of the vehicle, the free body diagram is shown in Figure 9

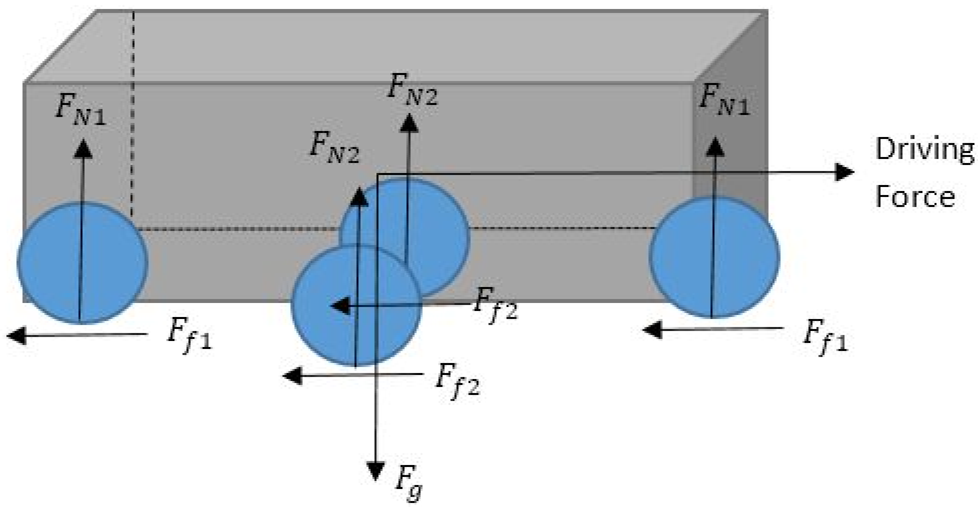


Figure 9. Free body diagram of “2+2” vehicle

Similarly, if the load exerts at the center of the vehicle, two wheels at the front and back would have same normal force, while two wheels at the left and right would have same normal force. Summing the moment at the left tire under static case:

$$\Sigma M = mg * 1.5 - F_{N1} * 3 = 0$$

$$F_{N1} = 0.5mg$$

Therefore, two wheels will not experience normal force in the static situation. By applying the greatest normal force:

$$F_{net} = ma = F - 2F_{f1} = F - 2 * \mu * F_{N1} = F - 2\mu * 0.5mg = F - \mu mg$$

$$F = ma + \mu mg$$

Although the driving force required is the same, the torque is increased greatly:

$$T = F_{f1} * r = 0.5\mu mg * r$$

After torque is calculated, the power required can be obtained, which is proportional to the magnitude of torque:

$$P = T * \omega = T * v/r$$

Where ω is the angular velocity, v is the linear velocity, and r is the radius of the wheel. Since the second design requires a higher torque and greater power supply, it will increase the cost in BOM. So the first choice is better than the second one.

Conclusion

Throughout this report, multiple alternatives for subsystems for the vehicle were considered and evaluated. For the drivetrain, the top designs include a regular four wheel car design and a four wheel design with two driving wheels, one on the left side and one on the right side, and two turning wheels, one in the front and one in the back. For powering the vehicle, the DC motor was selected. For the types of wheel, all-terrain wheels were selected for the reliability on grassy surfaces. For the drive type, direct drive was selected. For sensing the distance to obstacles, an ultrasonic sensor was selected.

Reference

[1] High Accuracy Ultrasonic Sensor. (n.d.). Retrieved January 22, 2017, from http://www.progressiveautomations.com/lc-217?gclid=CjwKEAiAqozEBRDJrPem0fPKtX0SJAD5sAyH_V5-pgZMDnbGI4odyl5Y4trEv1qqyN8ia13WKetbCRoCr67w_wcB

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