Design Proposal

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1.0 - Executive Summary

This document discusses and analyzes the vehicle built to satisfy the requirement stated in the provided RFP. A vehicle capable of autonomously and manually navigating a set course that included obstacles and the descension and ascension of stairs. This document outlines the product produced by the engineers from Team 2 over the course of 5 months.

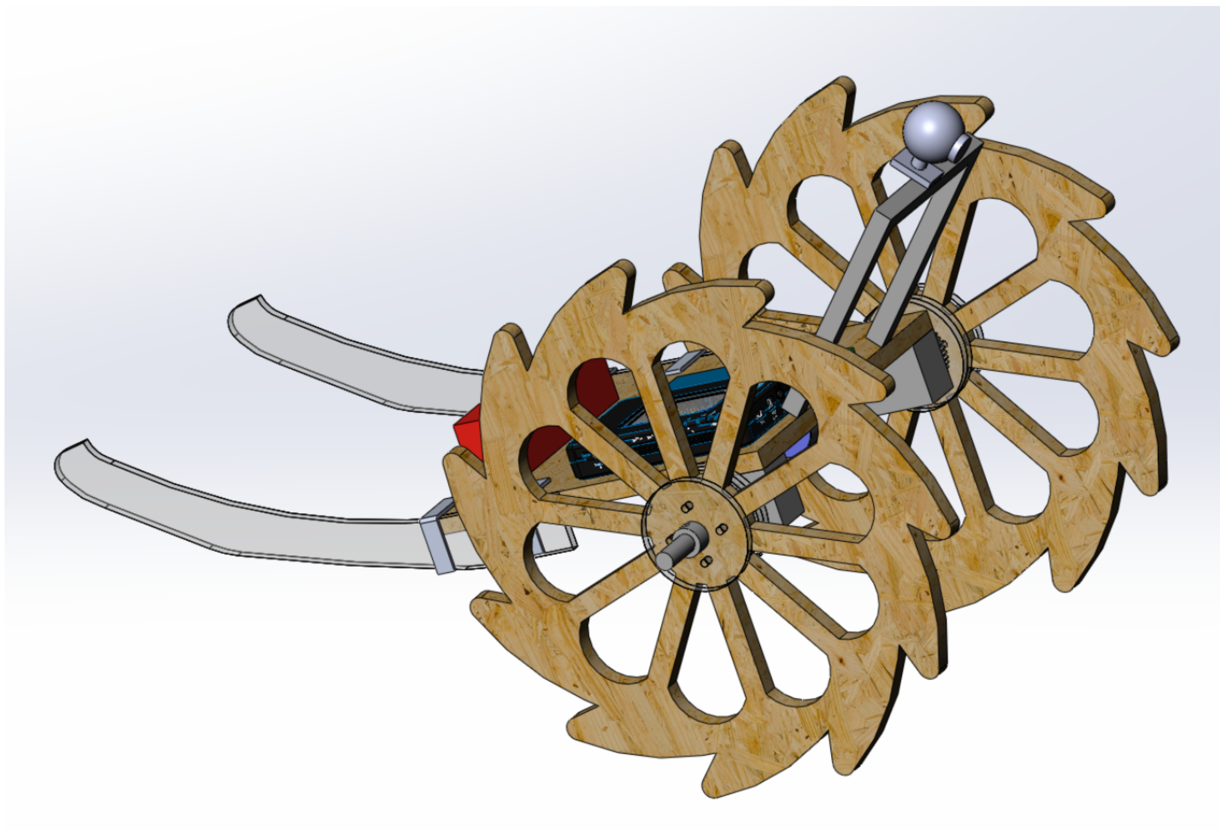

Figure 1: System Overview

As seen in above, the vehicle created to accomplish this task utilized laser-cut wooden sawtooth wheels and two laser-cut acrylic tails attached to a square base. The wheels are powered by two 118 RPM motors connected via a gear train with a 3.2 gear ratio. The wheels were fixed and turning was accomplished by manipulating the speed of both motors individually.

The tails were designed to drag along the ground with little frictional resistance. The sawtooth shape of the wheels was designed to optimize stair climbing ability while maintaining mobility on flat ground. When the vehicle approaches a stair, the teeth on the wheels catch on its edge and lift the front of the vehicle over the edge. The lightweight nature of the tails and having the weight distributed forward allow for the vehicle to easily lift the rear end of the vehicle over the edge of the stair. In order to prevent any slippage while climbing the stair, both wheels were covered in foam weather stripping to maximize traction.

Control of the vehicle is accomplished with an onboard controller and no wires or tethers are required. Users can remote control the vehicle from a host computer, or run the vehicle in autonomous mode where no user input is required. All electrical systems are powered from one rechargeable battery and every component is protected with overcurrent and overvoltage protection.

The vehicle accomplished all necessary requirements. It is capable of being manually controlled as well as autonomously following the yellow arrows on the path. Stair descension and ascension were accomplished repeatedly without issue. Additionally, the vehicle fit well within all weight, size, cost and assembly requirements.

2.0 - Introduction

The goal of this project is to create a working prototype, able to demonstrate both remote controlled and autonomous navigation around the ECS building. The robot is to simulate a Mars Rover, so it should be able to navigate around obstacles and be able to go over different terrain. To simulate multiple terrain operation, 6 inch stairs will be incorporated into the course, and the vehicle must be able to ascend and descend them.

3.0 - Design Requirements

3.1 - Change History

3.1.1 1.11.2017 Initially Published

3.1.2 1.16.2017 Requirements 16-21 added

3.1.3 1.17.2017 Requirements altered to have only 1 requirement per bullet point

3.1.4 1.22.2017 Format Changed to group requirements by type, requirement 2 removed due to redundancy

3.1.5 1.28.2017 Requirement 3.5.2 added.

3.1.6 5.2.2017 Requirement 3.5.5 amended to 0.5 m/s

Requirement 3.5.3 amended to "maximum turning radius"

3.1.7 5.16.2017 Requirement 3.4.3 amended to three laps

3.2 - Environmental

3.2.1 The system should be able to perform in temperatures between 0 and 32 °C. (Team)

3.2.2 The prototype should be able to perform on wet bricks, but with no standing water present. (Team)

3.2.3 The prototype should be water resistant to protect all motors and wiring in case of rain. (Team)

3.3 - Physical

3.3.1 The complete system must not exceed a weight of 15 lbs. (RFP)

3.3.2 The system when packed in its ground-handling container must be less than 2'x2'x2'(RFP)

3.3.3 The system must be able to withstand a drop of 8 ft. onto a concrete surface while packed in its ground-handling container. (RFP)

3.3.4 All packing material must be biodegradable. (RFP)

3.3.5 System must be powered by electric OR stored mechanical energy sources. Chemical (liquid, solid, or gas) sources are NOT allowed. (RFP)

3.4 - Electrical Operation

3.4.1 All electrical components, except those purchased with an individual battery housing, should be powered from a single battery through a circuit that distributes the necessary voltage and power levels. (RFP)

3.4.2 All electric components (controller, wiring, boards, etc.) must be able to be removed from and reinstalled into the system in 2 minutes by one person with manual hand tools only. This requirement does NOT include DC motors,servos. (RFP)

3.4.3 The battery life of the prototype should be sufficient to complete three complete loops of the ECS building. (Team)

3.4.4 The remote-controlled system should function over Wi-Fi at a distance of up to 100 m from the controller . (Team)

3.4.5 The prototype should implement ultrasound sensors capable of scanning 10 times per second with a range of 1 meter in the forward direction of the vehicle to detect obstacles. (Team)

3.4.6 The prototype should have live video feed capabilities to assist in its remote control navigation. (Team)

3.5 - Mechanical Operation

3.5.1 The prototype must be able to climb and descend stairs 15 cm high. (Team)

3.5.2 The prototype must be able to drive on a path with a maximum incline of 15 degrees (Team)

3.5.3 The complete system should have a maximum turning radius of 1 m. (Team)

3.5.4 The prototype should be able to respond to and evade obstacles along its path autonomously. (Team)

3.5.5 The prototype should be able to reach a maximum speed 1 mph. (Team)

3.5.6 At the maximum speed the prototype should be able to detect and avoid obstacles effectively. (Team)

3.6 - Manufacturing

3.6.1 All in-house parts for this project must be fabricated by the design team using the facilities provided. (RFP)

3.7 - Safety

3.7.1 Important components must have a current surge protection using a fuse circuit or equivalent. (RFP)

3.8 - Budget

3.8.1 The total cost of all out- sourced parts and materials must not exceed the $70 per team member, totalling a maximum of $280. (RFP)

3.8.2 All parts or materials used for this project, excluding those given to each team by management, must be purchased or pre owned by team members. (RFP)

3.8.3 All preowned components must be included in the total budget of the project. (RFP)

3.9 - Time

3.9.1 The fully-functioning prototype must be demonstrated no later than May 26, 2017. (RFP)

4.0 - Concept Selection

4.1 - Design Analysis

2 designs were compared to determine the best design for this project. Each design was evaluated on the requirements in Section 3. Some of the requirements would not be affected by the design chosen. For example, requirement 3.7.1, regarding surge protection, would not affect the design chosen. Some of the most important requirements regarding the design of the vehicle were chosen. Each design was graded for each requirement, with 1 being the lowest possible score and 5 being the highest. The chosen requirements were 3.3.1 regarding the total weight of the vehicle, 3.3.3, regarding the durability of the vehicle when undergoing an 8 ft drop, 3.5.1, regarding the stair climbing ability of the vehicle, 3.5.3, regarding the turning radius of the vehicle, and 3.5.5, regarding the maximum speed of the vehicle. See Section 3.3 and 3.5 for the exact requirements. The stair climbing and descending ability were each scaled by a factor of 3, as it is the most important function of the vehicle. If the vehicle is unable to ascend and descend

stairs, it will not be able to complete the course. The remaining requirements were scaled at a factor of 2, as they are important but not quite as important as stair climbing. Additionally, the overall complexity of the vehicle was estimated and graded, as some designs would take much more time and effort to complete. This would make them unfeasible, and not worth making if an easier design could accomplish the same tasks. This grade was scaled by a factor of 1, as it is worth considering, but is the least important of all of the criteria. This criteria matrix can be seen below in Table A.1.

Two prototypes were compared. The first was a three wheel vehicle with a 16” back wheel, and 2 12” front wheels. All three wheels were powered and a servo motor was used to turn, using an Ackerman steering system. The second prototype was a 2 wheel design, with a tail arching off the back of the base to assist in stair climbing. Two wheels were used and steering was performed through motor control. As shown in the comparison matrix of Table A.1, Prototype 2, the two wheeled design with a tail was far superior to the 3 wheeled design. Although the 3 wheel design had superior stair descent, the major drawbacks of this design were its inferior stair climbing ability, its complexity and its weight.

Table A.1: Prototype Requirement Comparison Matrix.

	Prototype 1	Prototype 2
Stair Climbing Ability (x3)	3	5
Stair Descending Ability (x3)	5	3
Level of complexity (x1)	1	5
Speed (x2)	3	4
Turning Capabilities (x2)	4	5
Durability (x2)	5	5
Weight (x2)	1	5
Total Score	50	67

**Scale: 1-5. 5 being best, 1 being worst.

4.2 - Steering Analysis

The options considered for the steering system of the vehicle are the Ackerman steering system and motor controlled steering. The criteria for a good steering system included the complexity of the design, the effectiveness in turning the vehicle and the space that it takes up on the vehicle. The complexity is important to consider, as a complex system is more expensive, generally costing more money, interfering with requirement 3.8.1 regarding the budget of the vehicle. Additionally, a more complex system is more likely to break and need repair, which can cost more time than it is worth, if a comparable, less complex option is available. For these reasons, the complexity was inflated at a rate of 2. The turning capabilities are obviously a vital criteria of a steering system. In order to fulfil requirement 3.5.3, the vehicle must have a maximum turning radius of 1 m, so this quantifies how good the steering system must be. As this is the most important function of the steering system, it was ranked at a x3 rate. Finally, the amount of space that the steering system takes up must be considered, to assist in fulfilling requirement 3.3.2 regarding fitting in a 2' by 2' by 2' box. Because the steering system is the only thing that will help meet this requirement, it is not inflated in the grading scale for the comparison matrix.

Table A.3 shows the comparison matrix between the two options given the criteria discussed above. As shown, the motor controlled steering proved superior in all categories, so it was chosen for the steering system of the vehicle.

Table A.3: Steering Comparison Matrix:

	Ackermann	Motor Controlled
Complexity (Number of Parts Required) (x2)	3	5
Turning Capability (x3)	4	5
Space Taken Up (x1)	3	5
Total Score:	21	30

4.3 - Wheel Analysis

Two options were compared when choosing the best wheels for this design. The first was a 16" foam wheel, and the second, a 15" plywood, laser cut wheel. The criteria for a good wheel included being durable, light weight, low cost and having sufficient traction to grip and climb a 6" stair. The durability of the wheel was important to fulfil requirements 3.3.3 and 3.4.3, regarding sustaining an 8' drop and completing three laps of the course at one time. Additionally, durable wheels are important so they do not have to be replaced often given the magnitude of testing that occurred. The weight of the is important to ensure fulfilment of requirement 3.3.1 regarding the overall weight of the vehicle. The cost of the wheel is important to ensure that the vehicle meets requirement 3.8.1 of not exceeding a total cost of $280. The smoothness of the driving will affect both the the turning radius and maximum speed of the vehicle discussed in requirements 3.5.3 and 3.5.5 respectively. This effect is not extraordinary, but still must be considered. Finally, the traction of the vehicle is important to assist it in completing requirement 3.5.1, ascending a 6” stair.

Table A.5 shows the comparison matrix used to compare the two wheels given the above criteria. The traction of the wheel was weighted as the most important, at a x3 value. This is because it plays a key component in allowing the vehicle to ascend stairs, and therefore is very important. The cost, and weight of the vehicle were both ranked at a x2 value, as they are important to consider, but are not the most important. Finally the durability and smoothness of the driving are not inflated as they must be considered, but are the lowest priority.

As shown in Table A.5, the wooden wheel proved to be far superior than the foam wheel. Although the driving is noticeably more bumpy that with a conventional foam wheel, the benefits of the wooden wheel in all other aspects counteract this, and make it a much better choice.

Table A.5: Matrix comparing scores of wheels to choose the best option.

Wheel Type	Wooden	Foam
Weight (x2)	5	3
Cost (x2)	5	2
Traction (x3)	5	3
Durability (x1)	3	4
Smooth Driving (x1)	2	5
Total Score	40	28

5.0 - Design Technical Description

5.1 - Mechanical Systems

3 main mechanical subsystems will be analyzed. These subsystems are the drive train subsystem, the base of the vehicle, the wheels used, and the tail subsystem. The total system weighed 10.5 lbs, almost 5 lbs less than the requirement of a maximum weight of 15 lbs as defined by requirement 3.3.1. To disassemble the vehicle and package it, the wheels, and camera mount are removed. Disassembled, the vehicle fits in a 22”x22”x10” box, meeting requirement 3.3.2.

5.1.1 - Drive Train Subsystem

The drive train subsystem consists of a 118 RPM Planetary Gear DC Motor, 64 and 20 tooth aluminum gears providing a gear ratio of 3.2 and a ½ inch aluminum axle. All of the parts are assembled into a machined aluminum mount shown below in Figure 5.1.1. Aluminum was chosen due to being lightweight and strong enough to insure a constant gear mesh even under the stress of climbing stairs. The placement of the axle hole and motor hole had to be very precise so that the mesh was tight and the wheel could spin properly. The 64 tooth gear has a pitch diameter of 2” and the 20 tooth gear a pitch diameter of .625”. Given these measurement, the spacing between the center of each gear is 1.375”. In order to take this into account the center of the motor hole was positioned at .75” from the trailing edge and .71” from the top of the of the block, with a radius of .63”. To maintain a tight mesh between the gears, the axle hole was positioned at 2.2” from the trailing edge and also .71” from the top of the block, with a radius of .25”.

The gear ratio of 3.2 proved to be far more than was necessary for this design. It was originally necessary for a heavier smaller wheeled design, and when the design was changed, the ratio was kept. Keeping the previously fabricated mounts saved the time of constructing a new set up and money by not replacing parts. Additionally, the high gear ratio allowed for a high factor of safety by reducing the loads and stresses on the subsystem. Without a gear train, the motors produce 6.77 Nm of torque; the required torque values for the 10.5 pound vehicle on flat ground and climbing stairs are 5.08 Nm and 7.12 Nm respectively, as shown in Calculation E.1. This means that a minimum gear ratio of 1.05 was required, and the used gear ratio of 3.2 provides ample room for error. The drivetrain and wheels effortlessly climb stairs and meet requirement 3.5.1. Calculation E.2 shows that the theoretical maximum linear velocity of the product is 1.75 mph, which is reduced to 1.05 mph with a 60% duty cycle. This accomplishes requirement 3.5.5 stating the the vehicle should have a minimum velocity of 1 mph.

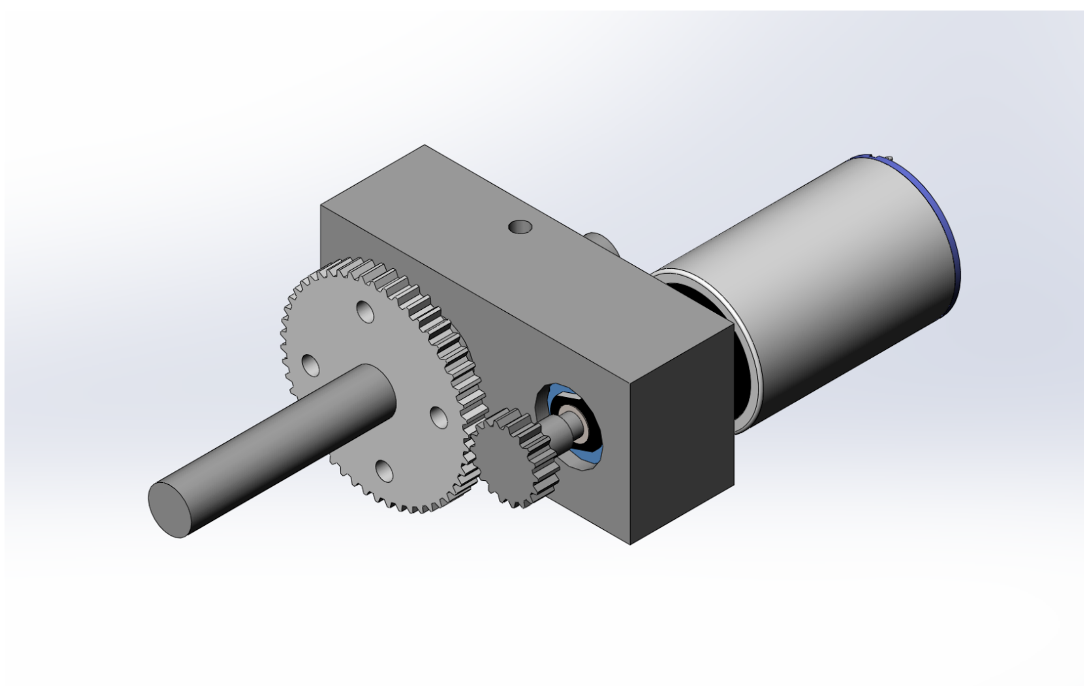

Figure 5.1.1: Drive Train Assembly

5.1.2 - Base Subsystem

The vehicle's base, built out of ½ inch plywood, was kept at a compact square 10 inches to a side. The motor mounts holding the drivetrain were attached on the underside of the front left and right corners of the base with two #10 bolts and nuts. The two acrylic tails were attached to the rear sides of the base using wood screws and 1.5 inch L-brackets. A camera and sensor mount was also attached to the front of the vehicle, approximately 8" off of the base, so to perform path detection and obstacle avoidance without wheel interference. The camera mount is seen in Figure A.9. Four 1.5 inch L-brackets and electrical tape were used to hold the battery at the rear end of the base. The MyRio and speed controller were both held on using wood screws. The MyRio conveniently has three keyhole slots that allowed to quick removal.

5.1.3 - Sawtooth Wheel Subsystem

One of the key components in achieving effective and efficient stair climbing capabilities was the unique design of the two powered wheels. The wheels used incorporated a notched design similar to a saw blade. The total diameter was 14.31 inches. The sawtooth design was developed to achieve the necessary amount of traction required to raise the vehicle over the 6 inch stairs. The large diameter was decided on after early trials indicated that climbing was more effective when the radius of the wheels was greater than the object being climbed.

Figure 5.1.2: Sawtooth Wheel

In order to achieve even greater traction and avoid unnecessary slipping when pulling the acrylic tails up the stairs, foam weather stripping was stapled to each tooth for added grip. The foam wore down quickly, but remained effective for longer than the required two laps. An engineering drawing of the wheel design is seen in Figure A.4.

5.1.4 - Tails Subsystem

These acrylic pieces, referred to as tails, are an integral part to the vehicles stair climbing capabilities. Each tail is approximately 14” long. The arch is concave to give the vehicle a more natural backwards tilt, which helps it climb a stair with a shorter tail. This is because with a convex tail, once the wheels are above the stair the tail has to be long enough to so that the curved part of the tail hits the stair, and the vehicle has to overcome the arch that wants to resist the movement of the vehicle. Contrarily, if the curve is concave, it will more naturally slide over the curved section as the tail maintains less contact over the stair. Additionally, a concave tail assists in stair descent, another important part of the requirements. The concave tail allows the vehicle to slide down a step and maintain contact over the duration of the descent, instead of dropping 6 inches each time the end of the tail loses contact with the previous step. Additionally, by allowing the tail to be shorter, the vehicle spans less steps while descending. By allowing the entire vehicle to sit on one step, instead of spanning 2 stairs, the angle of tilt is cut in half, which helps keep the vehicle from tipping forward, and having the tail flip over the front.

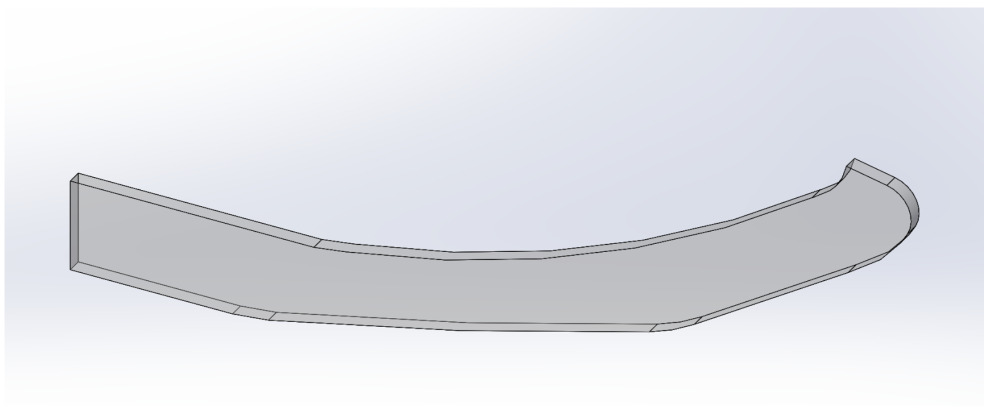

Figure 5.1.3: CAD Model of Acrylic tail

5.2 - Electrical Systems

The electrical systems on this product are comprised of three main subsystems. These are the drive motors, on-board controller, and battery power. Each was selected to well exceed the stated requirements while minimizing cost and weight.

The drive motor subsystem is comprised of a speed controller board and two planetary gear DC motors. The speed controller takes in power and ground from the battery, and outputs two sets of power wires for the motors. These power wires are the same voltage as the battery

(14.8V) but can be controlled by the controller through two PWM pins and two digital output pins. The speed controller can send up to 10A per motor continuously, or 30A per motor for up to 10 seconds at a time. This was chosen as having more available current per channel increases the power that can be sent to the motors before they stall, which will assist with climbing stairs. In addition, the speed controller used needs no heat sinks, due to its NMOS H-bridge circuit design. This is an improvement over the originally provided speed controller board, which needed to be modified with several heat sinks to complete multiple laps of the course.

The motors used have a stall current of 20A, however in all testing they never stalled. A 15A fuse on the whole system was used, and measured current to each motor never went above 6A when climbing stairs. This shows that the chosen speed controller board is always able to provide the necessary current.

The on-board controller used in this project is an NI MyRio-1900. In order to run the project wirelessly, this controller needs to be powered safely without an AC adapter. This requires both a voltage regulator and a fuse to ensure that the voltage and current never damage the controller. This is accomplished with a few parts, a fast acting 1A fuse (Part E-05 in Appendix D) to stop current flow if too much current is being supplied, and a 12V voltage regulator (Part E-03 in Appendix D) to regulate the voltage supplied to the MyRio. These parts are soldered onto the MXP expansion board connected to the MyRio and a barrel connector adapter is used to physically power the MyRio. (Part E06 in Appendix D)

Finally, the battery being used is a four cell LiPo battery that outputs 14.8V with 5200 mAh of charge. This battery was chosen due to its low weight and high amount of charge. Weighing only one pound, it allows the vehicle to easily stay under the fifteen pound weight limit outlined in the requirements section. In addition, it has a similar amount of output power and charge compared to many heavier batteries. This battery is also significantly physically smaller than other options. The downside of this battery is the cost. At almost $50, it is very expensive compared to other options. Access to long lasting, lightweight power in a small form factor was determined to be a priority, which is why so much of the budget was spent on this component.

In addition to the voltage regulator and 1A fuse protecting the MyRio, there is a 15A slow fuse directly after the system switch from the battery before any other components. This serves to protect the entire system in the case of excessive discharge by the battery. These components, and the fact that one battery is used to power the entire system, satisfy requirement 3.4.1, 3.7.1, and 3.3.5. No additional power sources or batteries are required for operation.

Given the battery life of 5200 mAh, and the system power calculated in Figure 5.2.1 below as 4A (4000mA), the system has at least one hour of usable battery life before a charge is required. Given that laps take no longer than fifteen minutes even in autonomous mode, this gives the vehicle enough onboard power to complete four laps, more than the stated requirement of three laps (Req. 3.4.3).

Component	Number of Parts	Nominal Power Draw	Total Power Draw
DC Planetary Motor	2	1.6A[1]	3.2A
NI MyRio	1	700mA[2]	700mA
HC-SR04 Ultrasonic Sensor	2	15mA	30mA
Photoresistor Circuit	1	0.07 - 4.54 mA[3]	4.54 mA
System Power Need:			**~4A**

Figure 5.2.1: Vehicle Power Consumption

This chart shows the power requirements for all systems on the vehicle.

1 Motors on flat ground pull less than this current. This figure is an attempt to come up with an averaged value for the entire course. On flat ground motors do not draw more than 1A each, however when climbing stairs motors can pull as much as 7A each.

Assuming that 10% of the course is stair climbing, and 90% is flat ground, average draw can be calculated as $I_{avg} = (0.9 * 1) + (0.1 * 7) = \mathbf{1.6A}$.

2 Max power draw to the NI MyRio is 14W, which at 12V would be 1.16A. However, even in autonomous mode the MyRio never uses all systems at 100%. This has been verified with multimeter readings and the fact that the 1A fuse protecting the MyRio has never blown. Based on readings taken, the average current drawn by the MyRio is 700mA.

3 Photoresistor Circuit: $V = IR \rightarrow I = V/R$

No light: $R = 1k\Omega$, $PR = 70k\Omega$, $RT = 71k\Omega \rightarrow I =$ $\mathbf{5V/71k\Omega = 0.07\ mA}$

Light: $R = 1k\Omega$, $PR = 100\Omega$, $RT = 1.1k\Omega \rightarrow I =$ $\mathbf{5V/1.1k\Omega = 4.54\ mA}$

Attached below is Figure 5.2.2 showing the overall wiring diagram for the system.

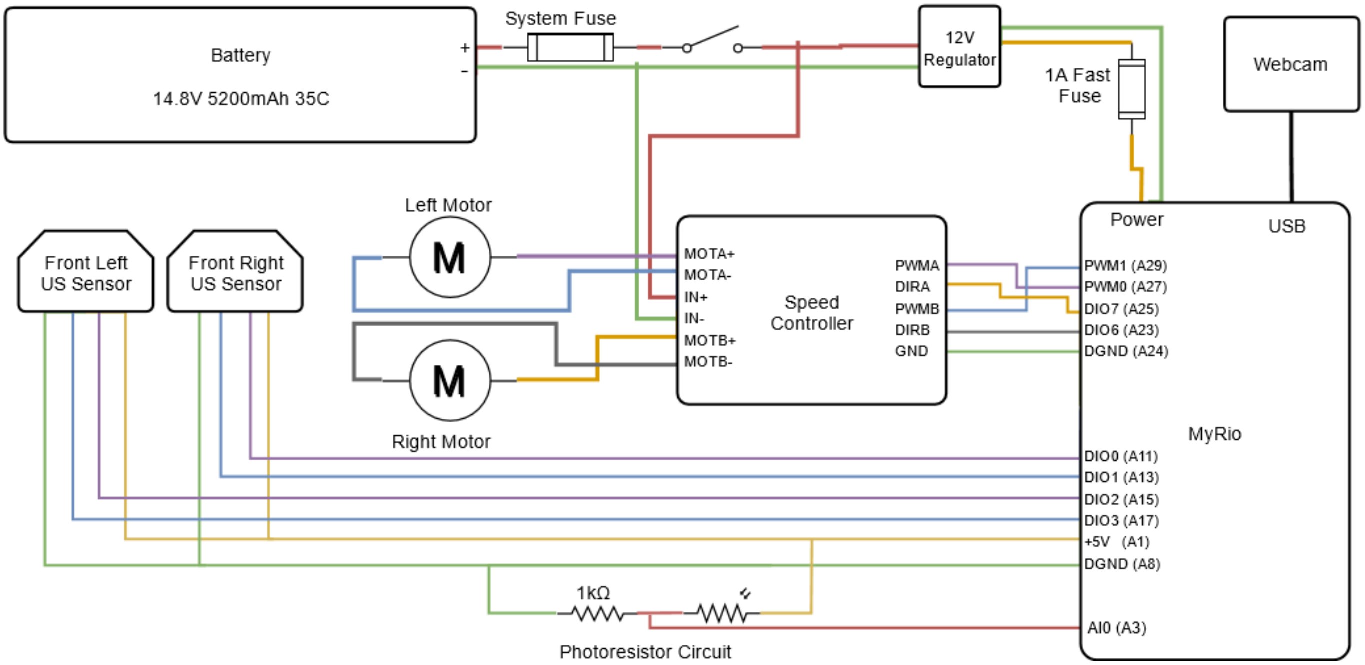

Figure 5.2.2 Electrical Diagram

This is a representation of the electrical connections on this vehicle. In accordance with the requirements all systems are protected with fusing and voltage regulation.

5.3 - Control Systems

There are two operation modes for this vehicle, manual mode and autonomous mode. Based on which mode the vehicle is operating in, the onboard control systems will be used in different ways. During autonomous operation, no user input is required and the vehicle will follow the course and avoid obstacles. In manual mode, a human operator running the LabView controller must control the operation of the vehicle. Switching between modes can be accomplished at any time from the controller with a maximum time delay of no more than 100 ms (assuming proper network connection with no drop outs).

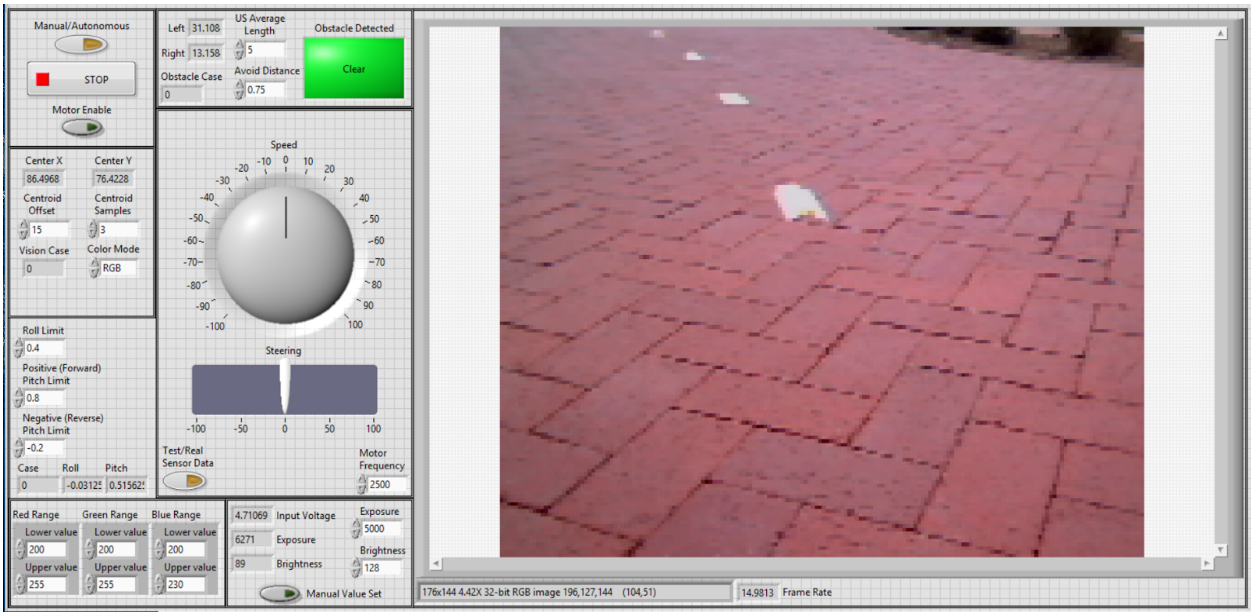

Figure 5.3.1: Controller Front Panel

This is the view that the host computer sees when controlling the vehicle. All controls and feedback display for manual and autonomous mode can be seen on this screen.

5.3.1 - Steering

Steering the vehicle is accomplished by running the motors at different speeds in order to pivot the base. As can be seen in Figure 5.3.1 above, the steering control runs from -100 to 100. This steering control is only used in manual mode, as autonomous mode uses preprogrammed values for steering and speed. In order to improve the handling of the vehicle, the steering control will gradually increase the severity of the turn as the control is set further from 0. A negative steering value represents a left turn and a positive steering value represents a right turn.

Shown below in Figure 5.3.2, all three cases for steering are shown. When steering is set to 0, the speed value is passed straight through to both motors so they run at the same speed and the vehicle continues in a straight path.

When steering is less than 0, the vehicle is turning left, so the left side motor is slowed. This is case 1. Speed is passed directly to the right motor, and modified by the equation below for the left motor.

$$L = Speed\,[1 + \frac{Steering}{100}]$$

This equation shows that at -100 steering, the left motor will stop completely, and the right motor will pivot the vehicle in place. At -50 Steering, the left motor will run at half the speed of the right motor, and at -25 steering, the left motor will run at three quarters the speed of the right motor. As the steering approaches -100, the left turn will be sharper and more pronounced.

The third case, case 2, for right steering is similar to the left steering case above. In order to turn right, the right side motor is slowed. The equation is shown below.

$$R = Speed\,[1 - \frac{Steering}{100}]$$

This equation shows that at 100 steering, the right motor will stop completely, and the left motor will pivot the vehicle in place. At 50 Steering, the right motor will run at half the speed of the left motor, and at 25 steering, the right motor will run at three quarters the speed of the left motor. Similarly, as the steering value approaches 100, the right turn will be sharper and more pronounced.

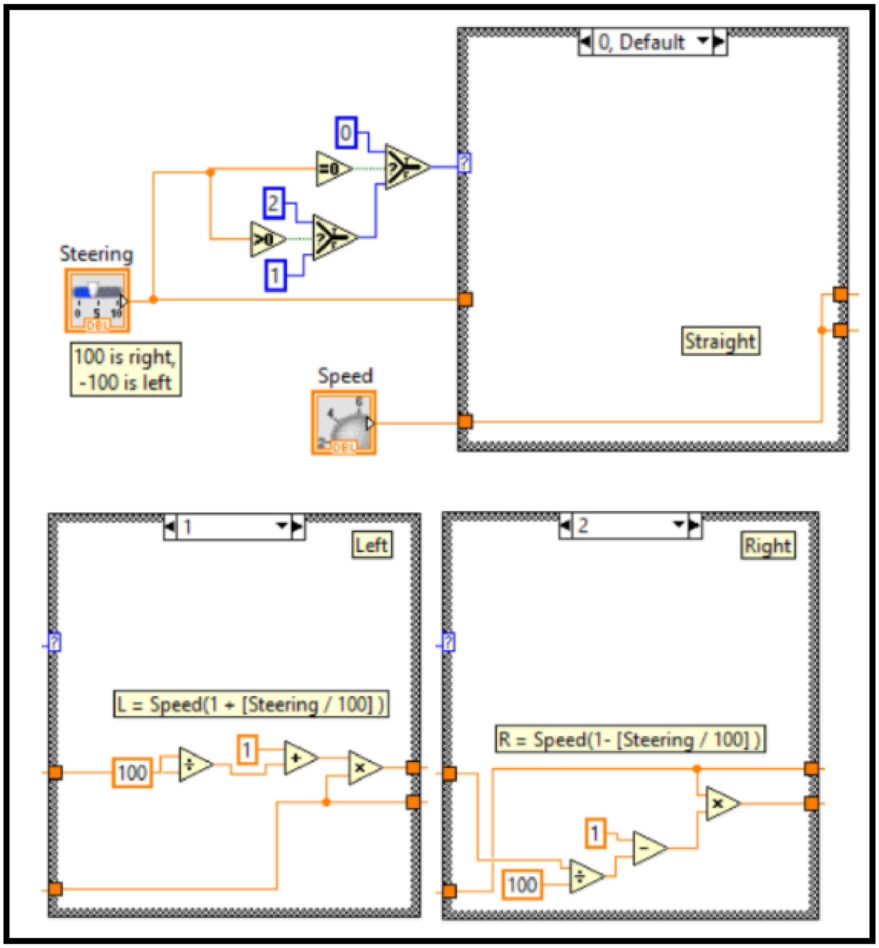

Figure 5.3.2 Manual Control with Steering Cases

Shown above is the LabView code to control the motors of the vehicle in manual mode to enable steering the vehicle.

5.3.2 - Path Following

In order to fulfill the requirement that the vehicle is able to follow a path of yellow route arrows on the path, an algorithm was developed to take input from a front mounted USB webcam and translate the image into control signals for the vehicle motors. In order to stay under bandwidth limitations of the controller, the webcam captured images at 176*144 resolution at 15 frames per second. Calculation E.3 in Appendix E explains why these values were chosen.

To translate the image into usable control signals, each pixel in the image is analyzed against user controlled RGB color code ranges. A binary image of the same size as the original is created, where every pixel that falls within the ranges is set to 1, every pixel that falls outside of any of the ranges is set to 0. After the binary image has been created, a centroid of the ‘1’ pixels is taken, and output as an [X,Y] pair. Figure 5.3.3 below shows a side by side of an original image and the edited binary image with centroid.

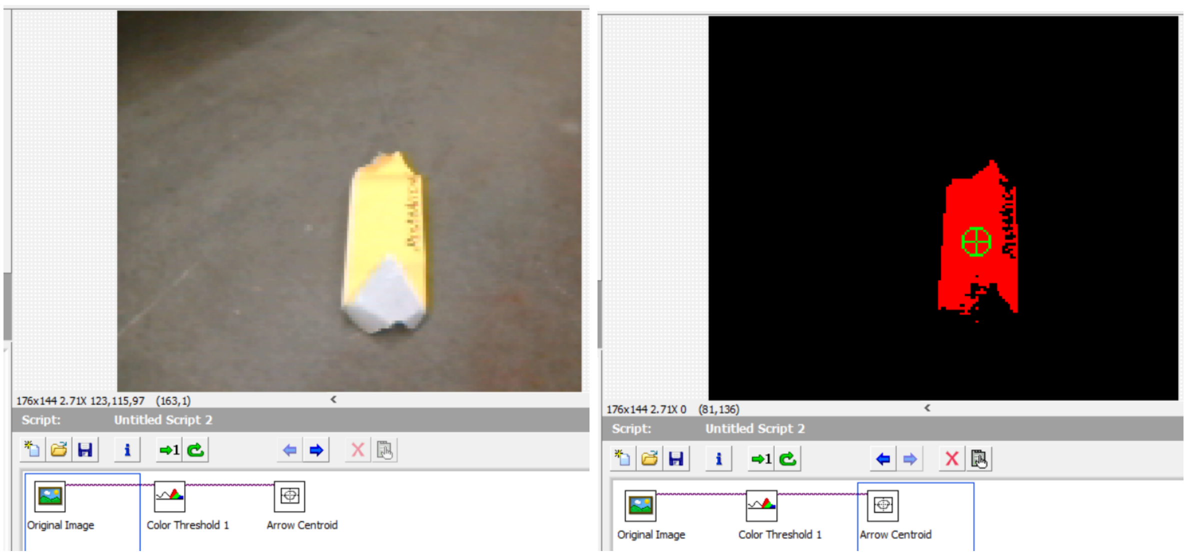

Figure 5.3.3: Original Image (left) with Calculated Binary Image (right)

After the image has been analyzed, there are four vision cases based on the X position of the centroid. These cases are summarized in Figure 5.3.4 below. If the centroid is on the left of the image, the vehicle turns left. If the centroid is in the middle of the image, the vehicle continues straight, if the centroid is on the right of the image, the vehicle turns right. Finally, if the centroid is exactly in the middle of the image, no yellow pixels were found, and the vehicle has lost the path. In this case, the vehicle will turn left until the path is reacquired.

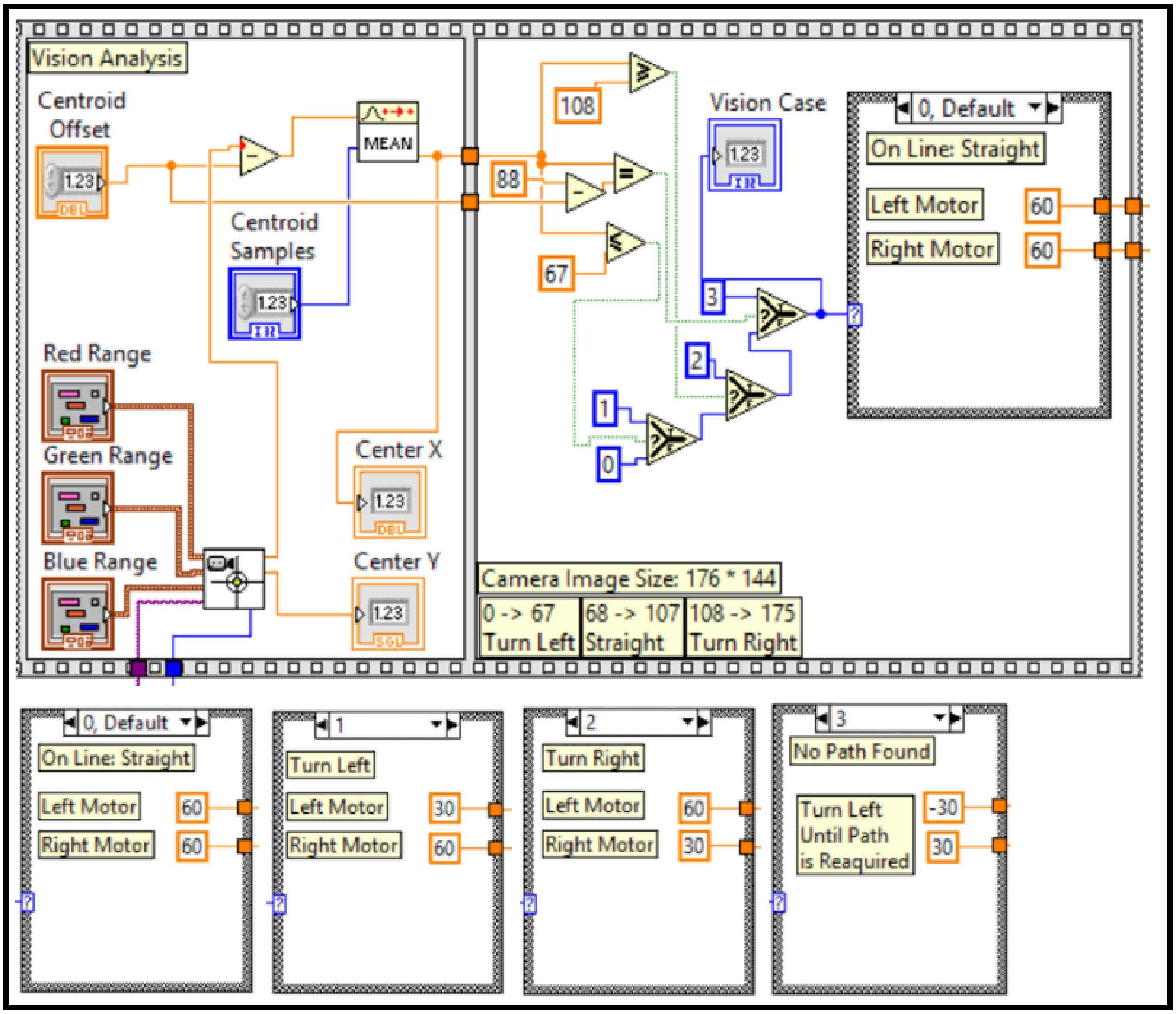

Figure 5.3.4: Vision Analysis

Vision Analysis section of the Main VI, where the centroid is taken from the Image Analysis VI and transformed into four vision cases. Each of these cases is shown at the bottom of the figure.

In the figure above, there are two additional controls that have not been explained. The centroid offset subtracts a set amount of pixels from the X centroid. This is useful for example if the course favours one turning direction or the other. In the test course used, the majority of the turns were right turns. By setting a centroid offset of around 15 pixels, the vehicle will err towards the right side of the path. This places it inside of the turn, where it is easier to see ahead to the next arrow then if the vehicle were outside the turn.

The centroid samples control is simply an averaging filter that is setup to reduce noise and false positive readings from the image. By taking an average of the last 5 centroids for example, one incorrect reading will not cause the vehicle to turn erratically. This improves path following and reduces zig zagging or excessive correction that would result without any averaging.

5.3.3 - Obstacle Avoidance

To meet the requirement to detect and avoid obstacles, two HC-SR04 ultrasonic sensors are mounted to the right and left of the camera. Each sensor is offset 15° from center. This is so that it can be distinguished whether obstacles are on the right or left side of the vehicle.

With two sensors, there are four obstacle avoidance cases. These cases are summarized in Table 5.3.5 below. A 0 represents the distance being above the threshold, while a 1 represents the sensor showing a distance closer than the avoid distance.

Table 5.3.5: Obstacle Avoidance Cases

Left Sensor	Right Sensor	Case	Action Taken
0	0	0	No obstacle detected. Perform path following.
0	1	1	Turn Left
1	0	2	Turn Right
1	1	3	Stop. Rotate right without forward motion

Complete LabView code to run the ultrasonic sensors can be found in Figure C.5 in Appendix C. Complete LabView code to run the obstacle case selector can be found in Figure C.3 in Appendix C.

5.3.4 - Pitch/Roll Correction

The most error-prone sections of the course come when the vehicle has to ascend or descend stairs. Mechanically, the vehicle will succeed if obstacles are approached straight on with less than a 15° angle of attack. If the approach falls outside of this however, there needs to be a way to recover, as simply continuing at full power will lead to failure to complete the obstacle or rolling the vehicle.

In both manual and autonomous modes, the X and Y axes of the onboard MyRio accelerometer are read continuously in order to detect any abnormal roll or pitch of the vehicle. The diagram for this component is shown below in Figure 5.3.6. The MyRio on our vehicle is positioned so that the positive Y direction points in the direction of forward motion. A large value on the X axis, positive or negative, means that the vehicle is in a roll condition. A positive value on the Y axis means that the vehicle is descending stairs, while a negative value on the Y axis means that the vehicle is ascending stairs.

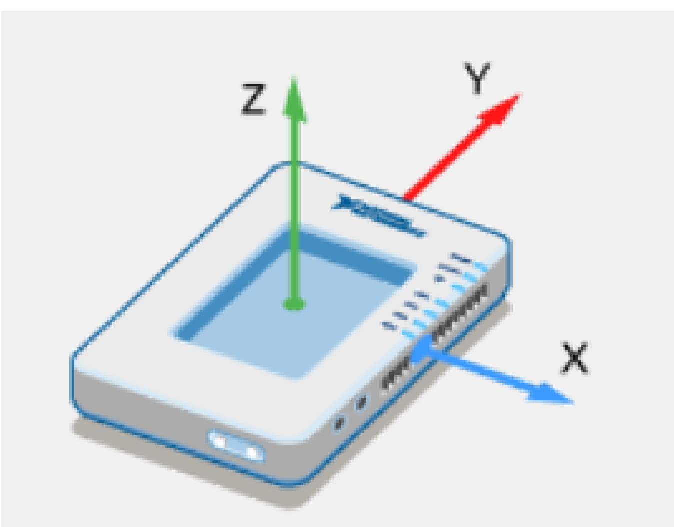

Figure 5.3.6: MyRio Accelerometer

The onboard accelerometer in the MyRio, which is used to help control the vehicle when ascending and descending stairs.

Combining the readings from the X and Y axes, six cases were identified. In each of these cases (except for the default case 0), one or both of the motor control signals is overridden to effect the operation of the vehicle and prevent rolling or obstacle failure. These cases are summarized in table 5.3.7 below.

Table 5.3.7: Pitch/Roll Control Cases

Roll	Pitch	Case	Condition	Action Taken
None	None	0	Normal Operation	Pass current values through, no change.
Positive	Negative	1	Ascending Rolling Right	Stop left motor until right motor catches up and roll is corrected.
Negative	Negative	2	Ascending Rolling Left	Stop right motor until left motor catches up and roll is corrected.
Positive	Positive	3	Descending Rolling Right	Set right motor to 40% and left motor to 60%. Vehicle will be forced to turn to the right, correcting the roll.
Negative	Positive	4	Descending Rolling Left	Set left motor to 40% and right motor to 60%. Vehicle will be forced to turn to the left, correcting the roll.
None	Positive	5	Descending With No Roll	Set both motors to 60%.

When descending stairs, stopping the vehicle results in tipping forward. This is why case 5 is needed for decent but not ascent, as there is no risk to the vehicle in ascent if there is no roll. Every descent case forces the vehicle to continue forwards at speed to prevent rolling forwards.

Complete LabView code for this process is shown in Figure C.2 in Appendix C.

6.0 - Appendices

Appendix A: Solidworks Drawings and Subsystem Schematics

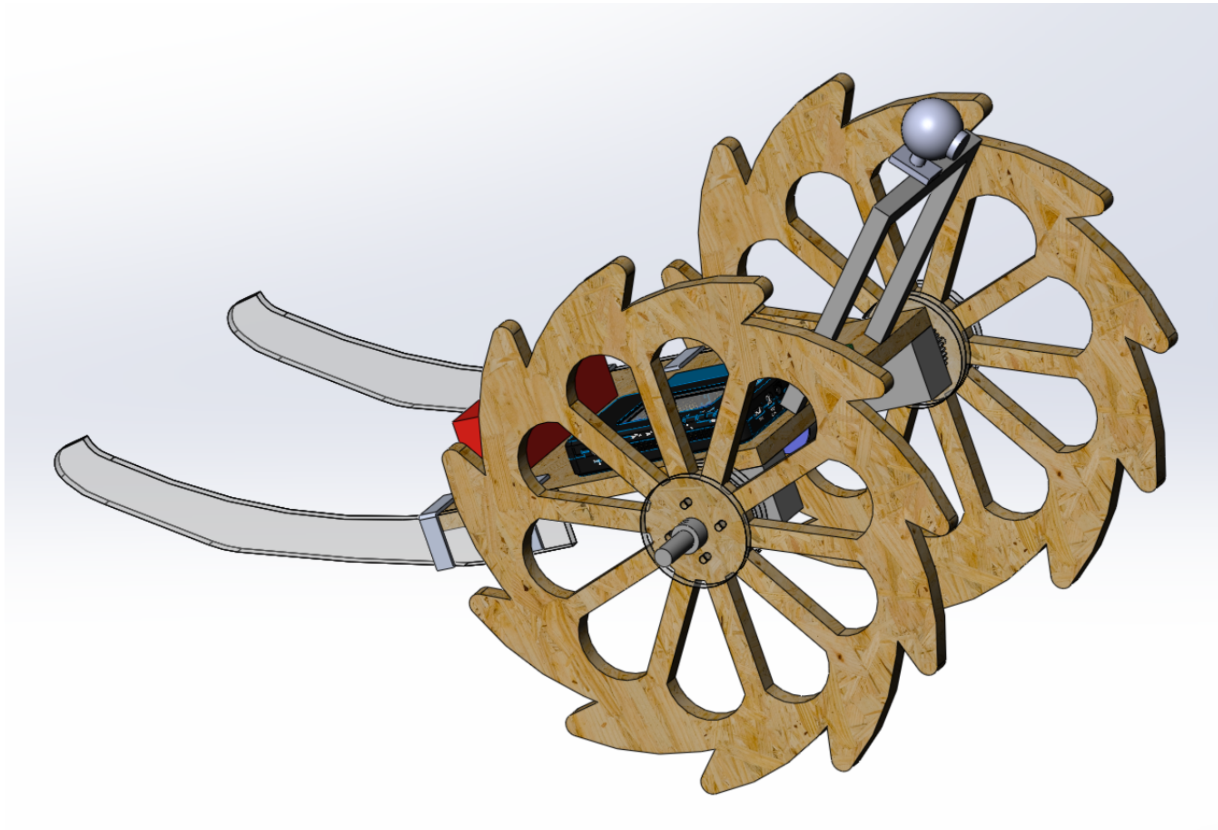

Figure A.1: Final Design Solidworks (isometric)

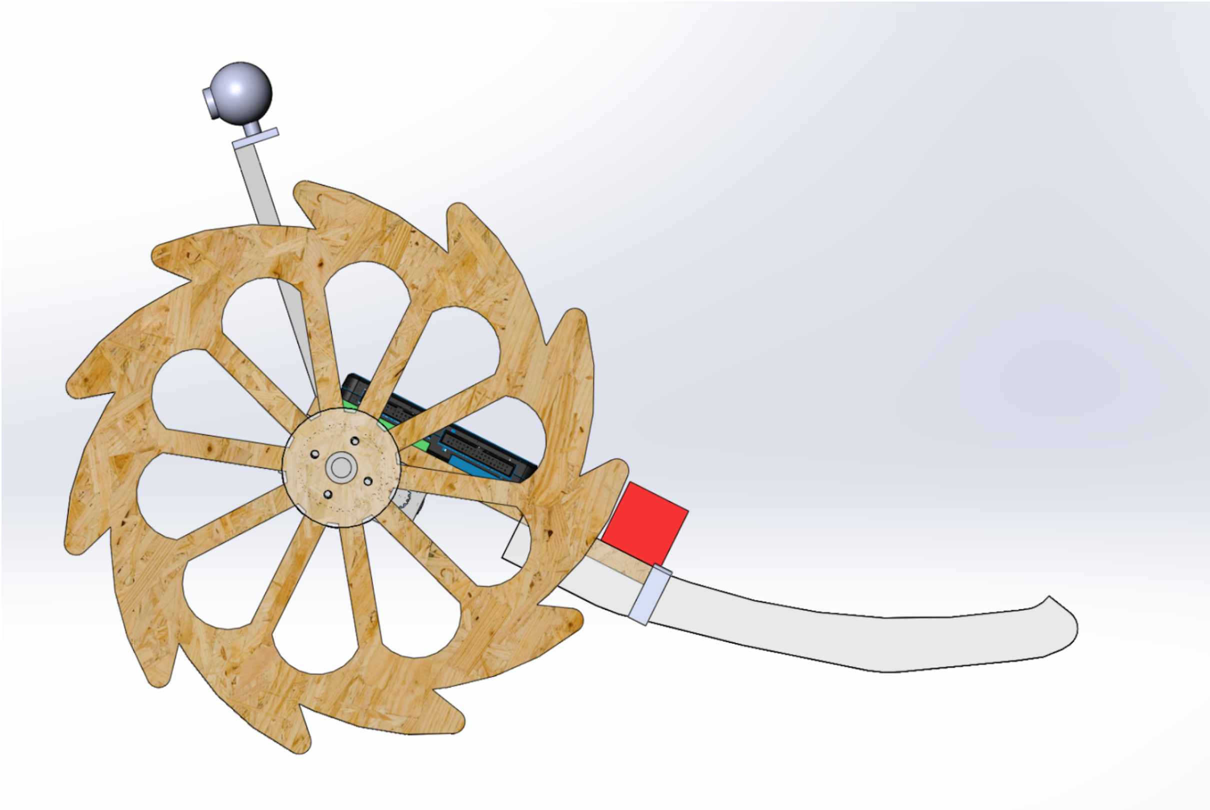

Figure A.2: Final Design Solidworks (side view)

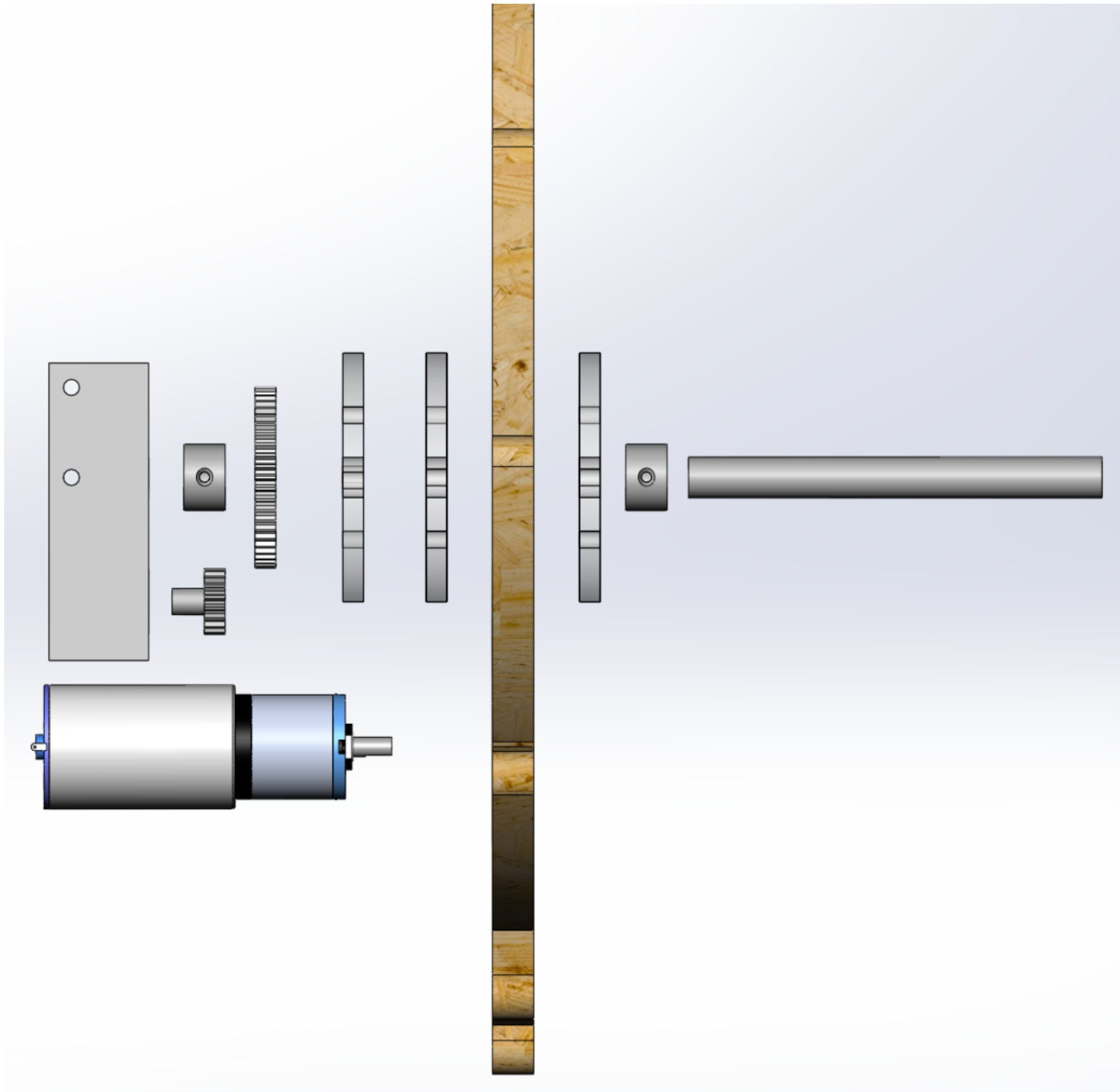

Figure A.3: Drivetrain (exploded view)

An axle collar was placed between the gear and motor mount followed by the axle gear, 2 acrylic spacers, wheel, 1 acrylic spacer and another axle collar.

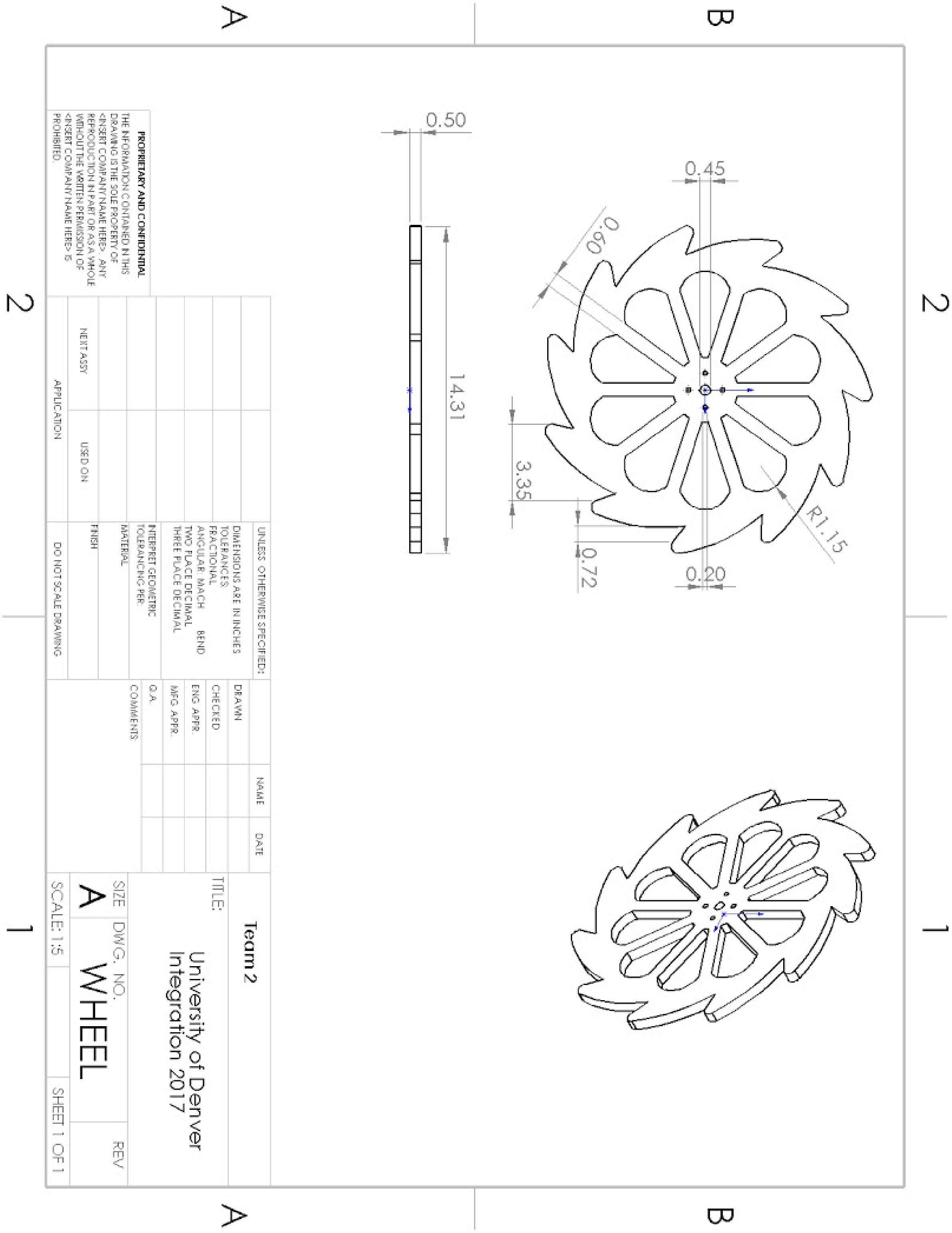

Figure A.4: Sawtooth Wheel Drawing

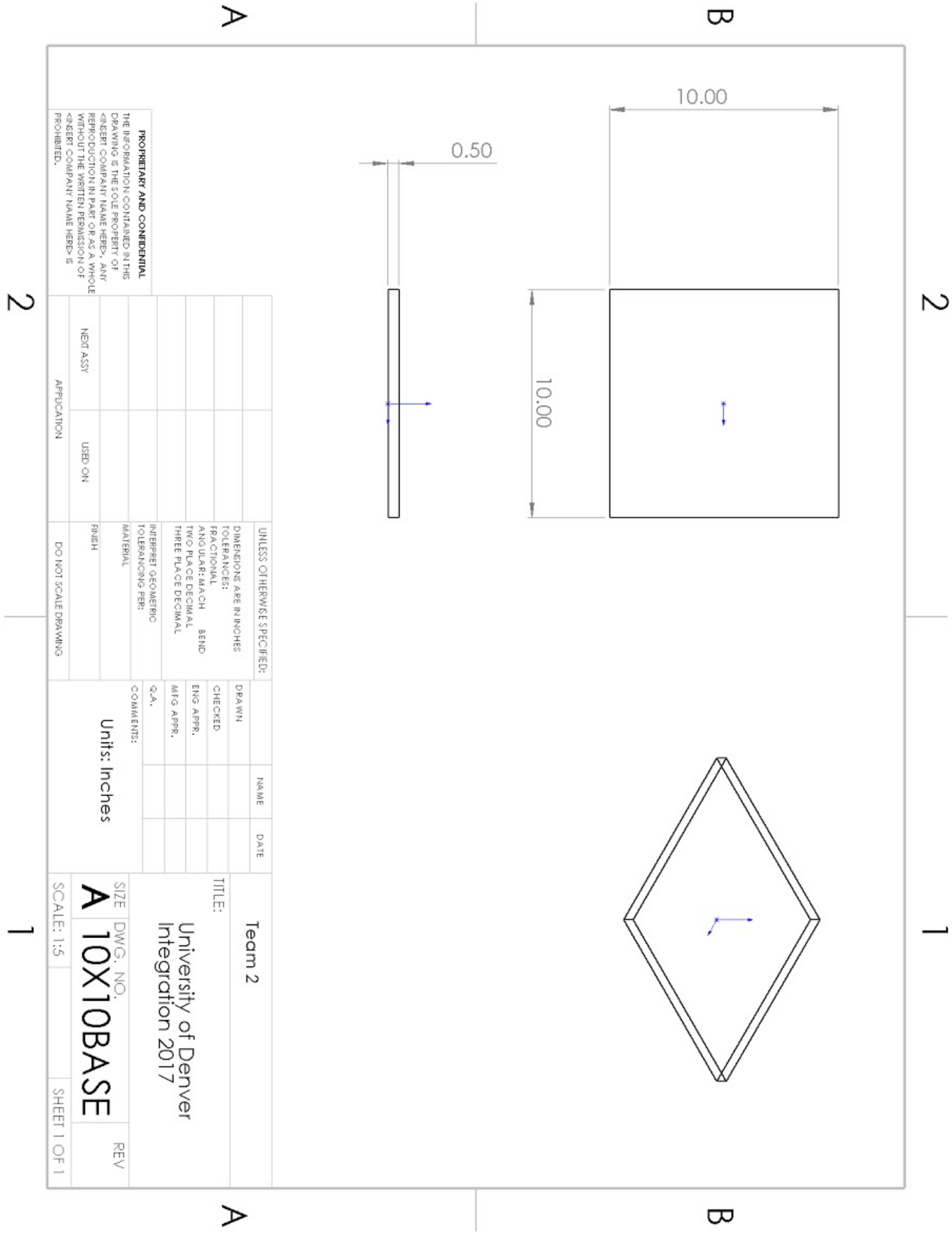

Figure A.5: Wooden Base Drawing

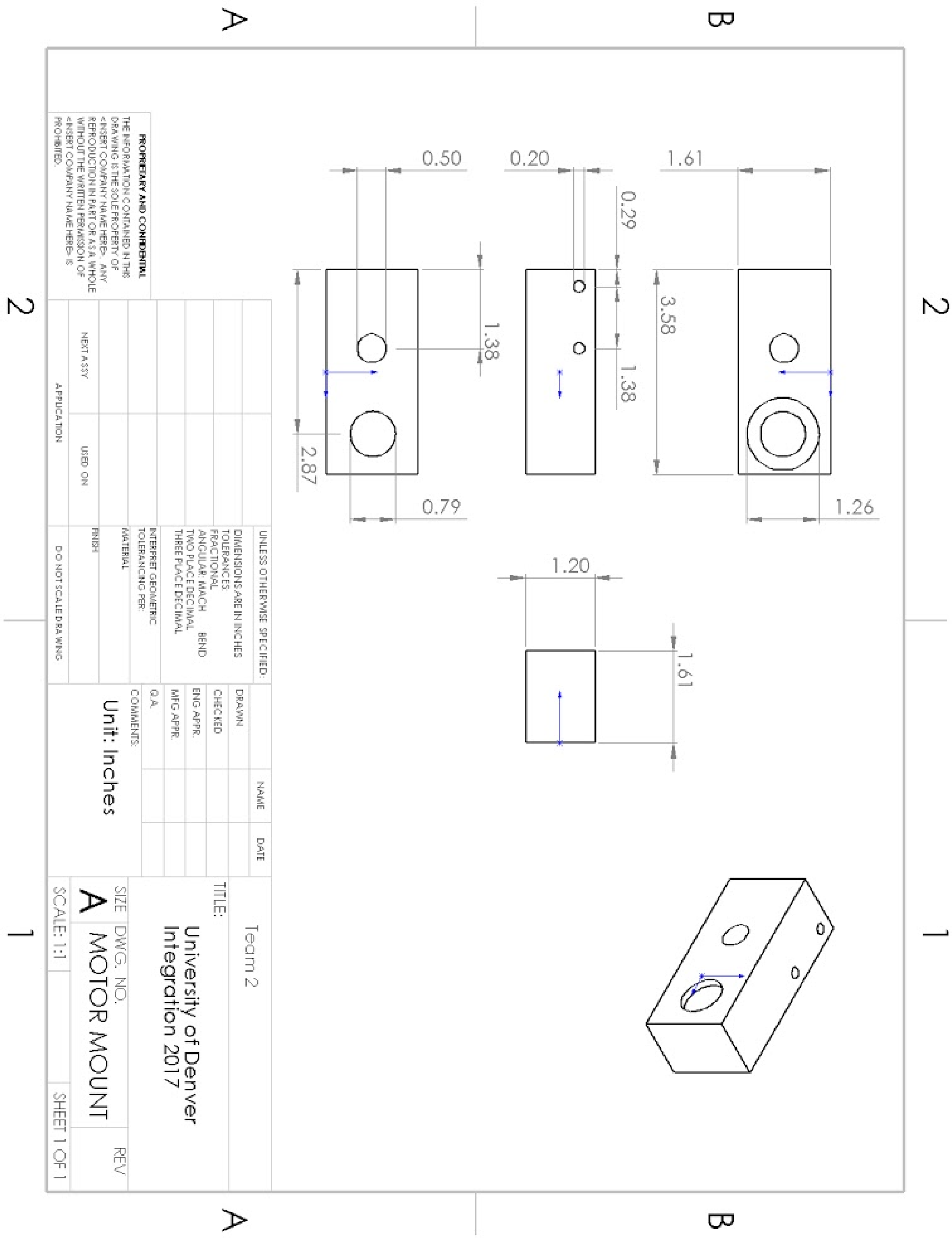

Figure A.6: Motor Mount Drawing

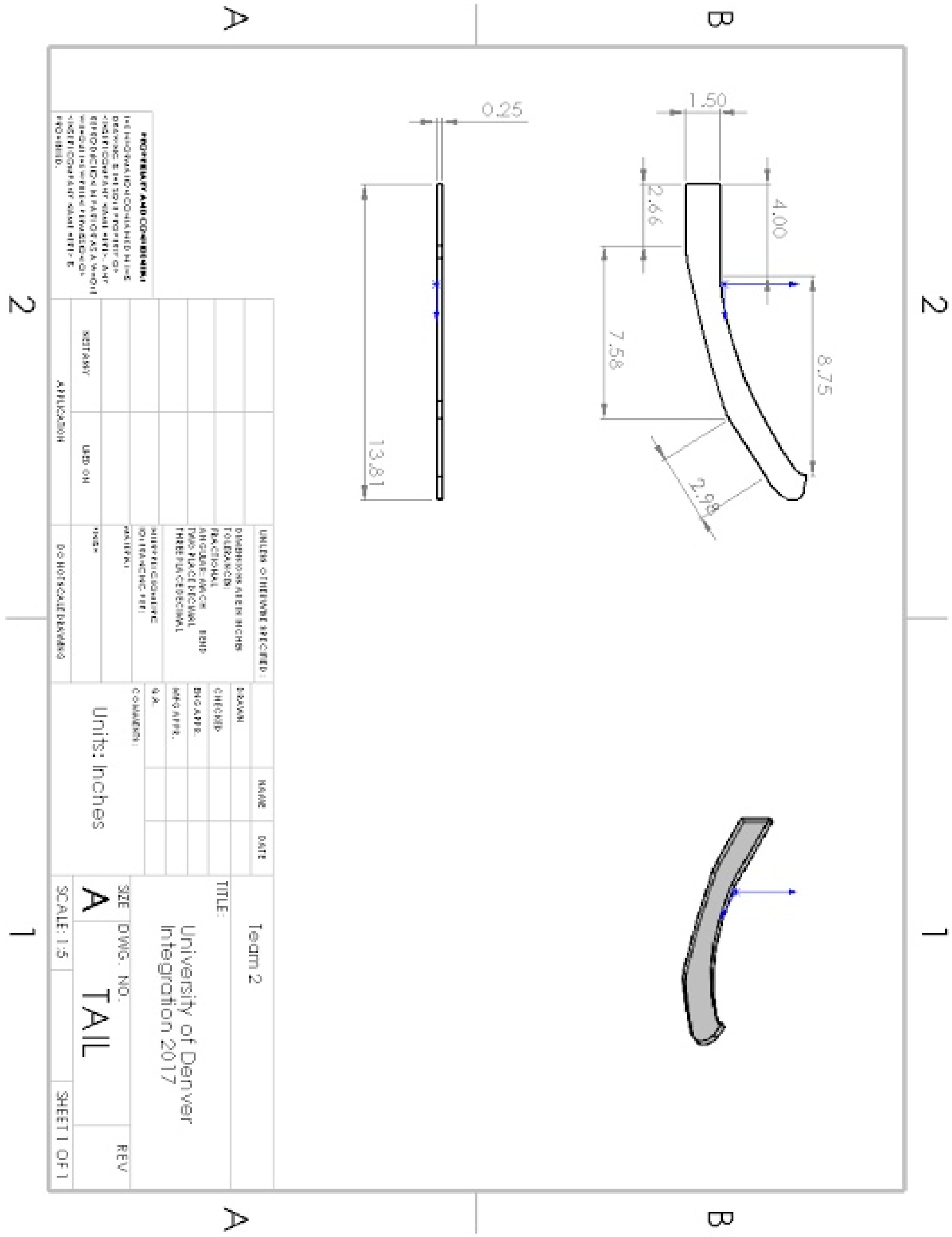

Figure A.7: Acrylic Tail Drawing

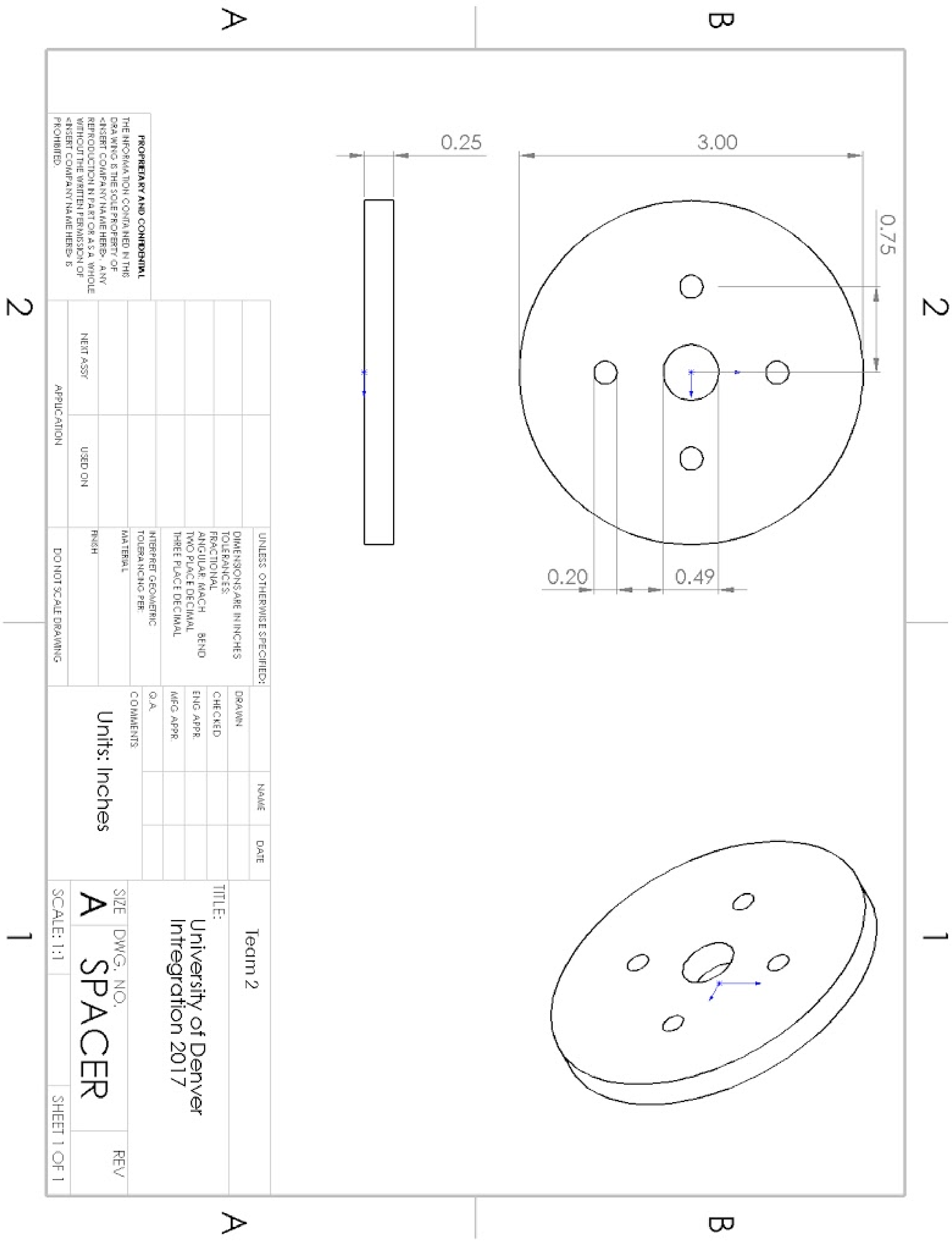

Figure A.8: Acrylic Spacer Drawing

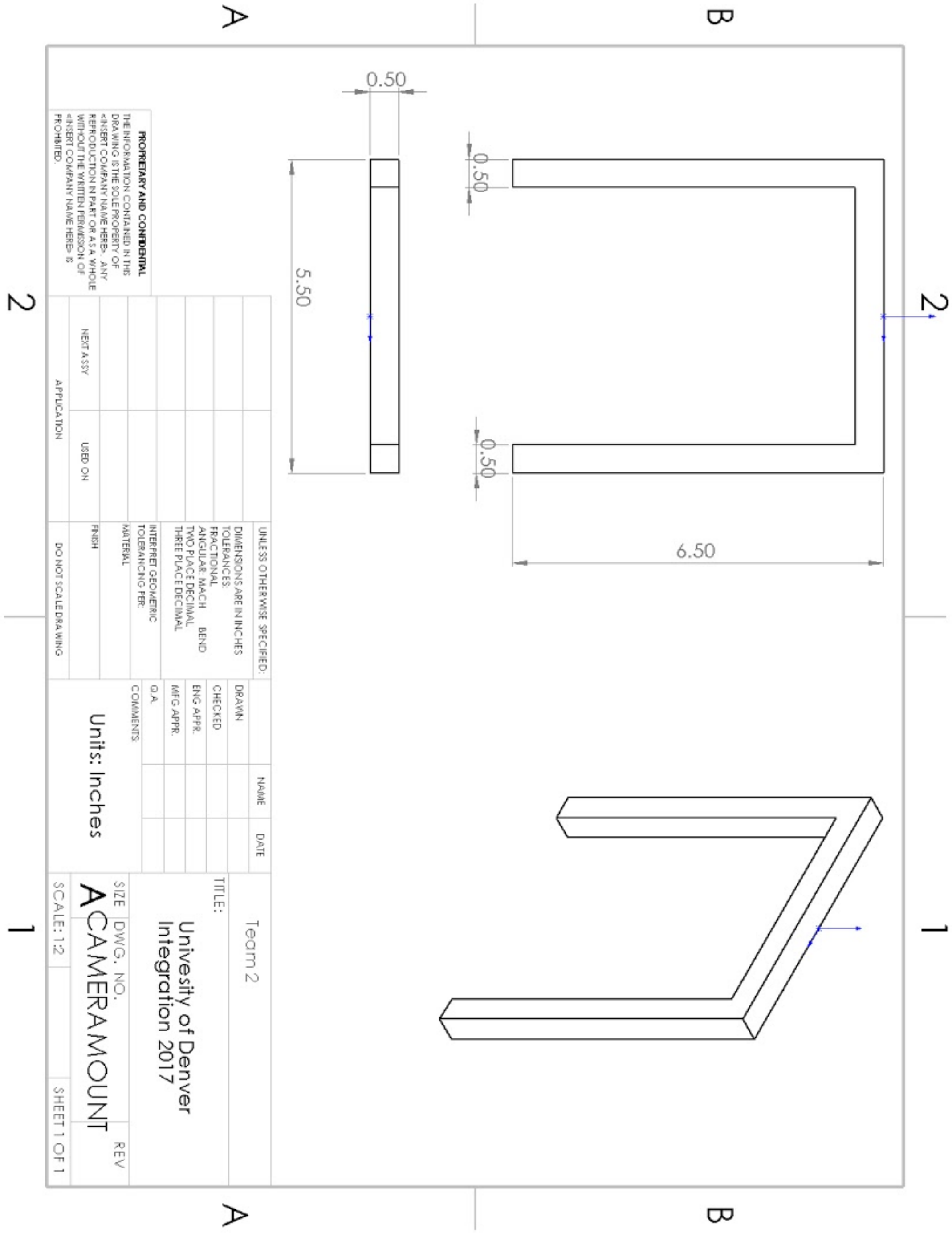

Figure A.9: Camera Mount Drawing

Appendix B: Electrical and Controls

MyRio MXP Connector A		
Pin #	**Label**	**Use**
11	DIO 0	Front Right US Send
13	DIO 1	Front Right US Recieve
15	DIO 2	Front Left US Send
17	DIO 3	Front Left US Recieve
19	DIO 4	
21	DIO 5 / SPI.CLK	
23	DIO 6 / SPI.MIS	Right Motor Direction
25	DIO 7 / SPI.MOS	Left Motor Direction
27	DIO 8 / PWM0	Right Motor PWM
29	DIO 9 / PWM1	Left Motor PWM
31	DIO 10 / PWM2	
18	DIO 11 / ENC.A	
22	DIO 12 / ENC.B	
26	DIO 13	
32	DIO 14 / I2C.SCL	
34	DIO 15 / I2C.SD	
8	DGND	
12	DGND	
16	DGND	
20	DGND	
24	DGND	Speed Controller GND
28	DGND	
30	DGND	
1	+ 5V	Power Two US in Parallel/PhotoR
33	+ 3.3V	
3	AI 0	PhotoResistor Read
5	AI 1	
7	AI 2	
9	AI 3	
2	AO 0	
4	AO 1	
6	AGND	
10	UART.RX	
14	UART.TX	

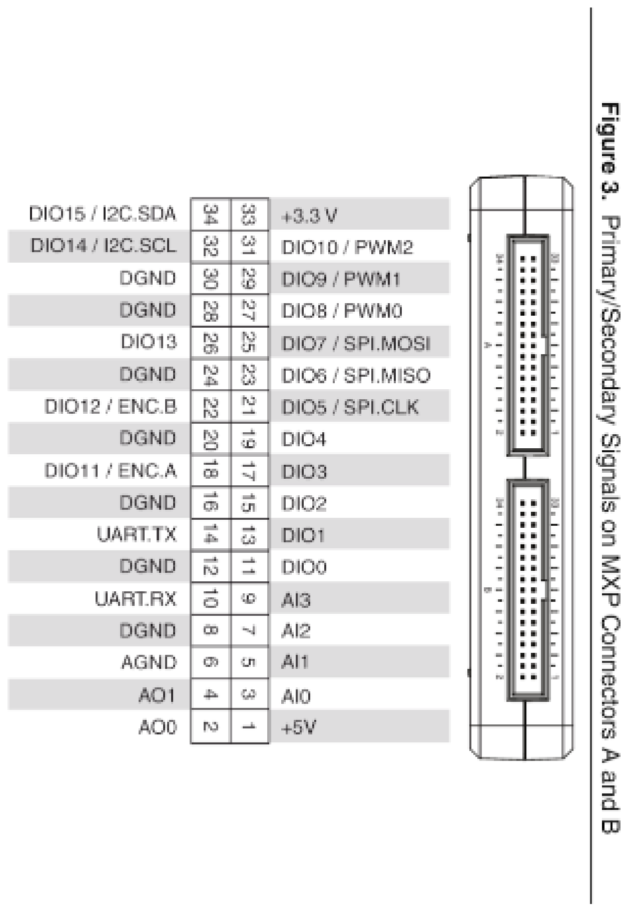

Figure B.1: MyRio Pin Connections

This figure shows the connections on the MyRio MXP breakout board that are required to run all control systems on the vehicle. The breakout board is connected to Port A of the MyRio, and no connections to Ports B or C are required.

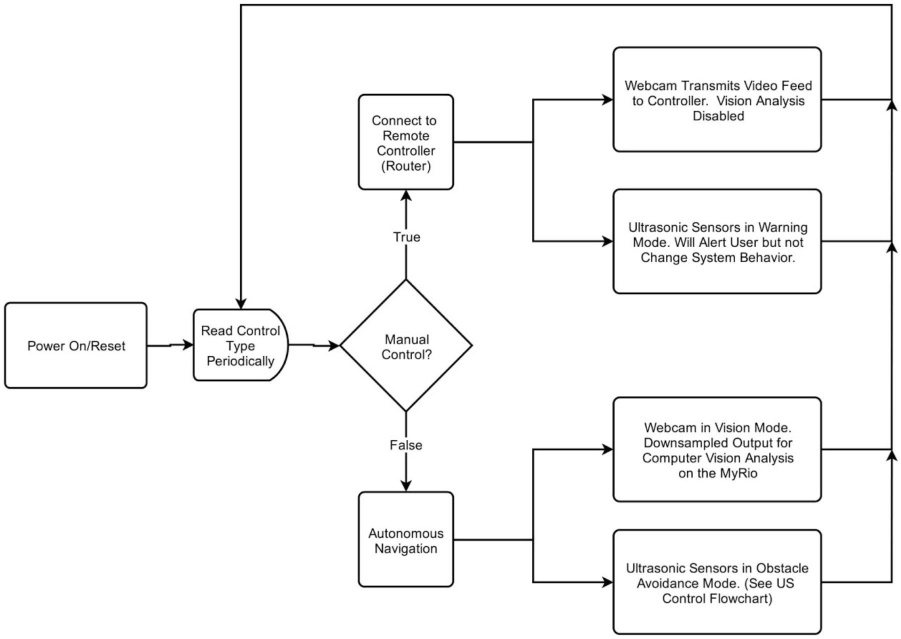

Figure B.2: High Level Control Flowchart

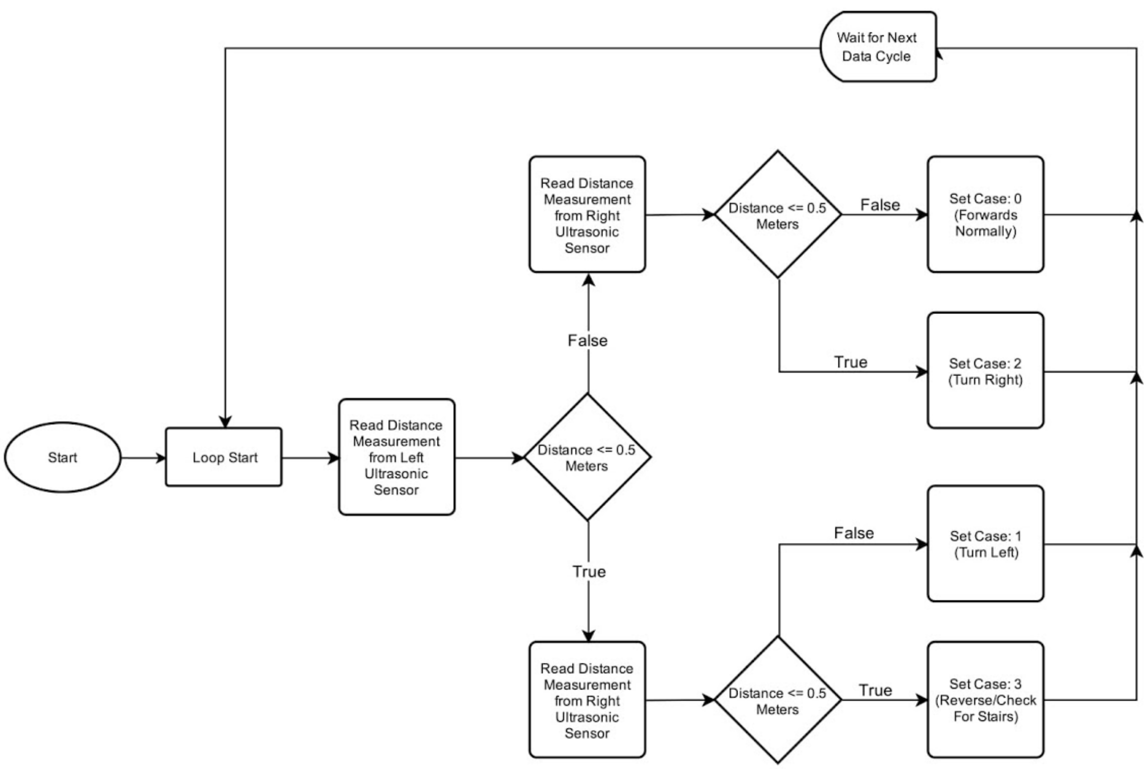

Figure B.3: Ultrasonic Sensor Flowchart

Appendix C: LabView Code

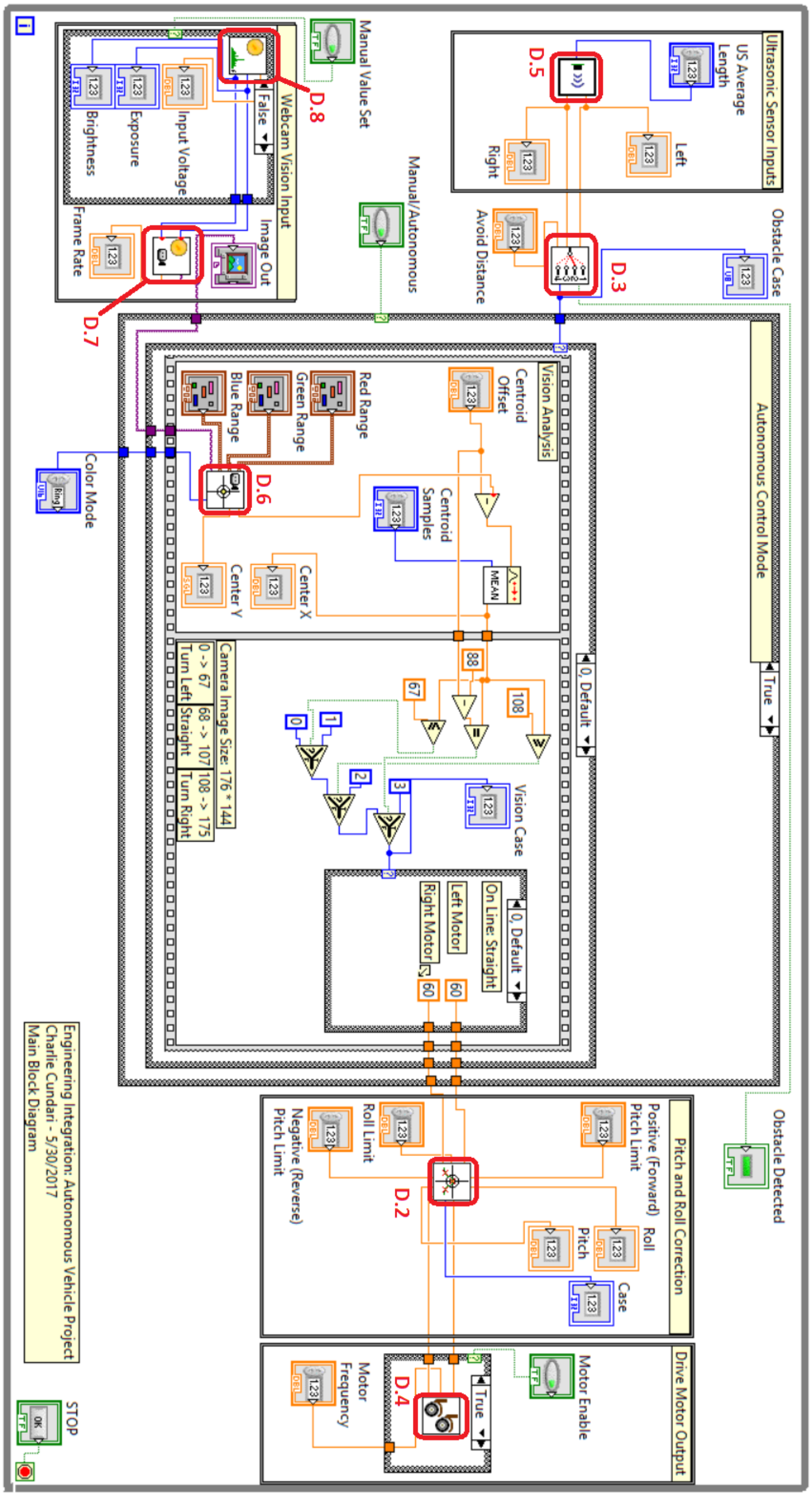

Figure C.1: Main VI Block Diagram

This is the block diagram for the main VI. This runs every other VI on the project. Each sub VI is outlined in red and is explained in more detail later in this appendix.

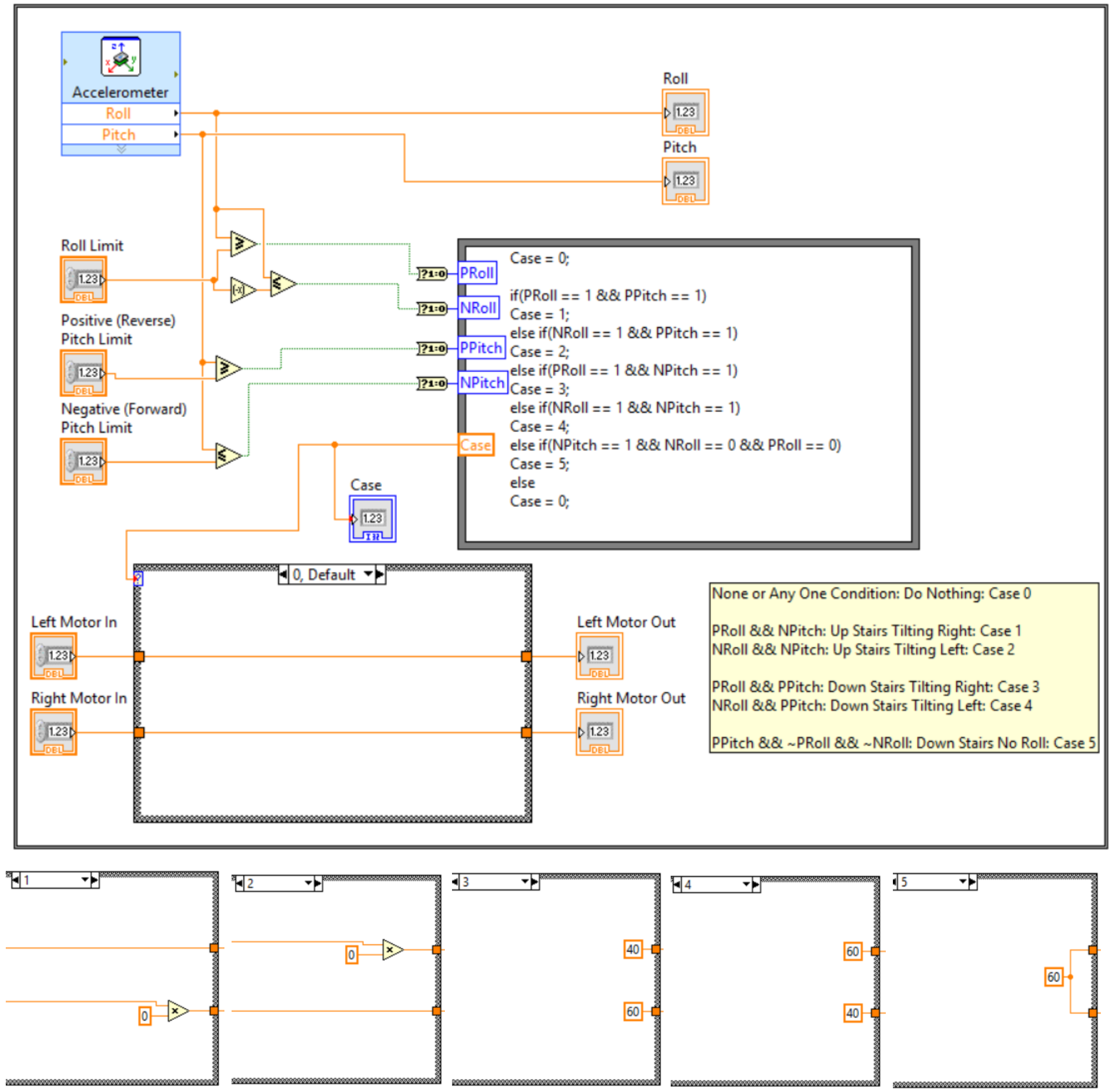

Figure C.2: Pitch/Roll Control VI

This VI assists the vehicle when ascending or descending stairs. If a roll is detected (such as one wheel climbing before the other) it will detect that and stop the motor that has already climbed so that the other wheel can catch up. Similarly, if the vehicle is pitched downwards and rolling, it will slow the lower motor, to allow the vehicle to turn and recover from its roll.

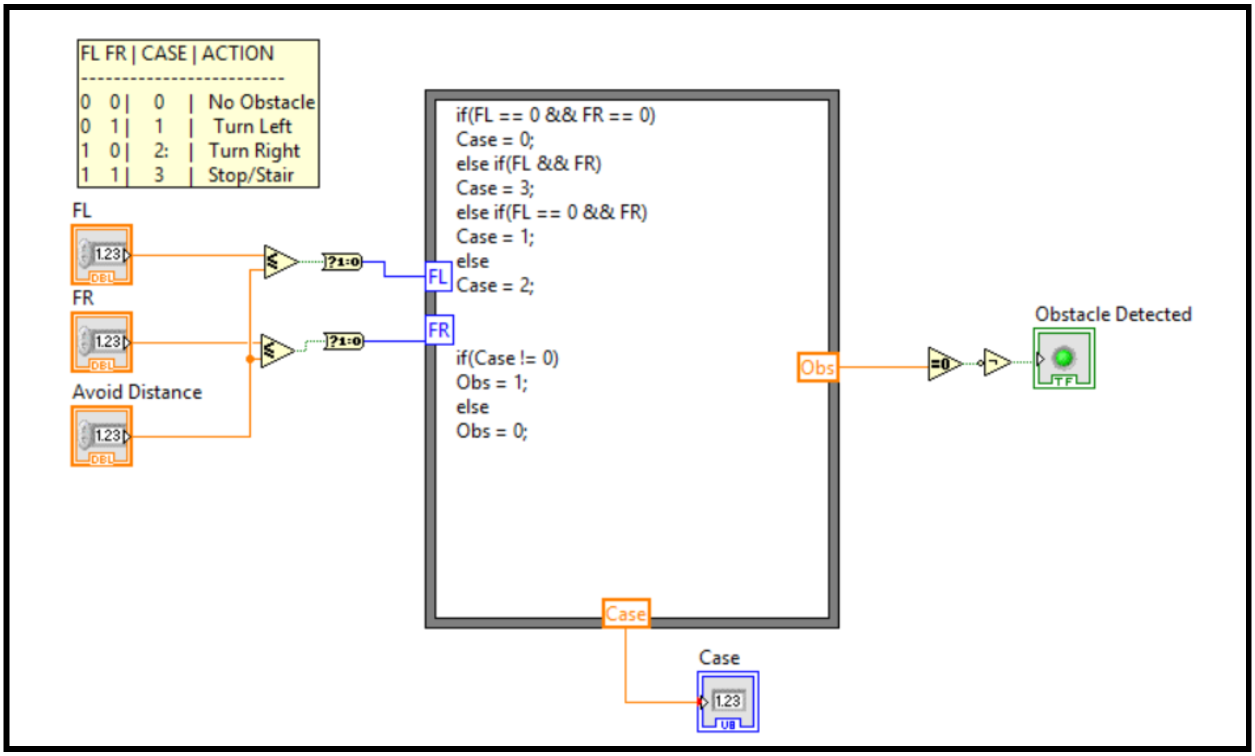

Figure C.3: Ultrasonic Sensor Case Selector VI

This VI takes in two distance measurements and outputs a case value from 0 → 3. These cases can be seen in the top left of this figure with their respective actions desired to be taken later in the program

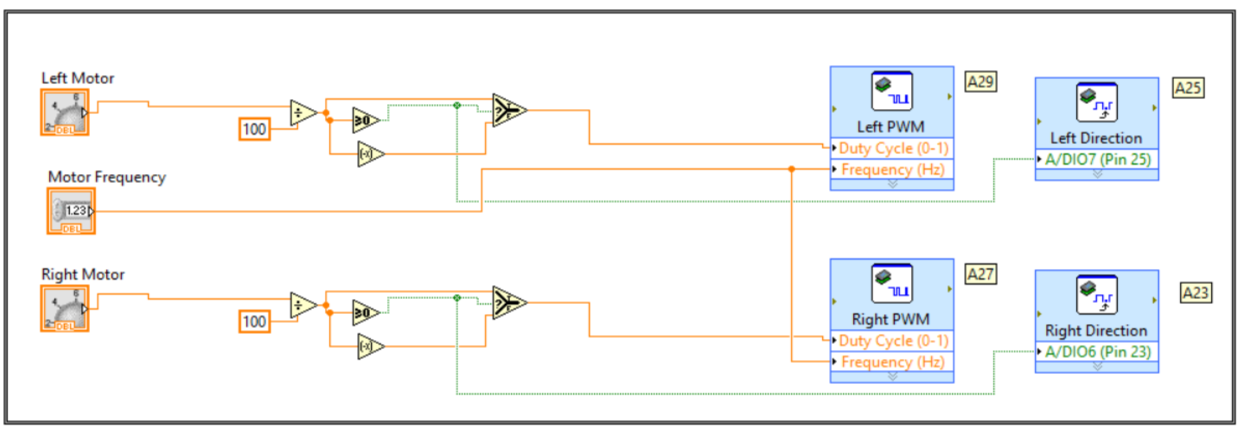

Figure C.4: Motor Control VI

This VI takes in two speeds from the control algorithm (that can be -100 → 100) and transforms them into two pwm (0 → 1) and two digital I/O direction outputs sent to the speed controller board.

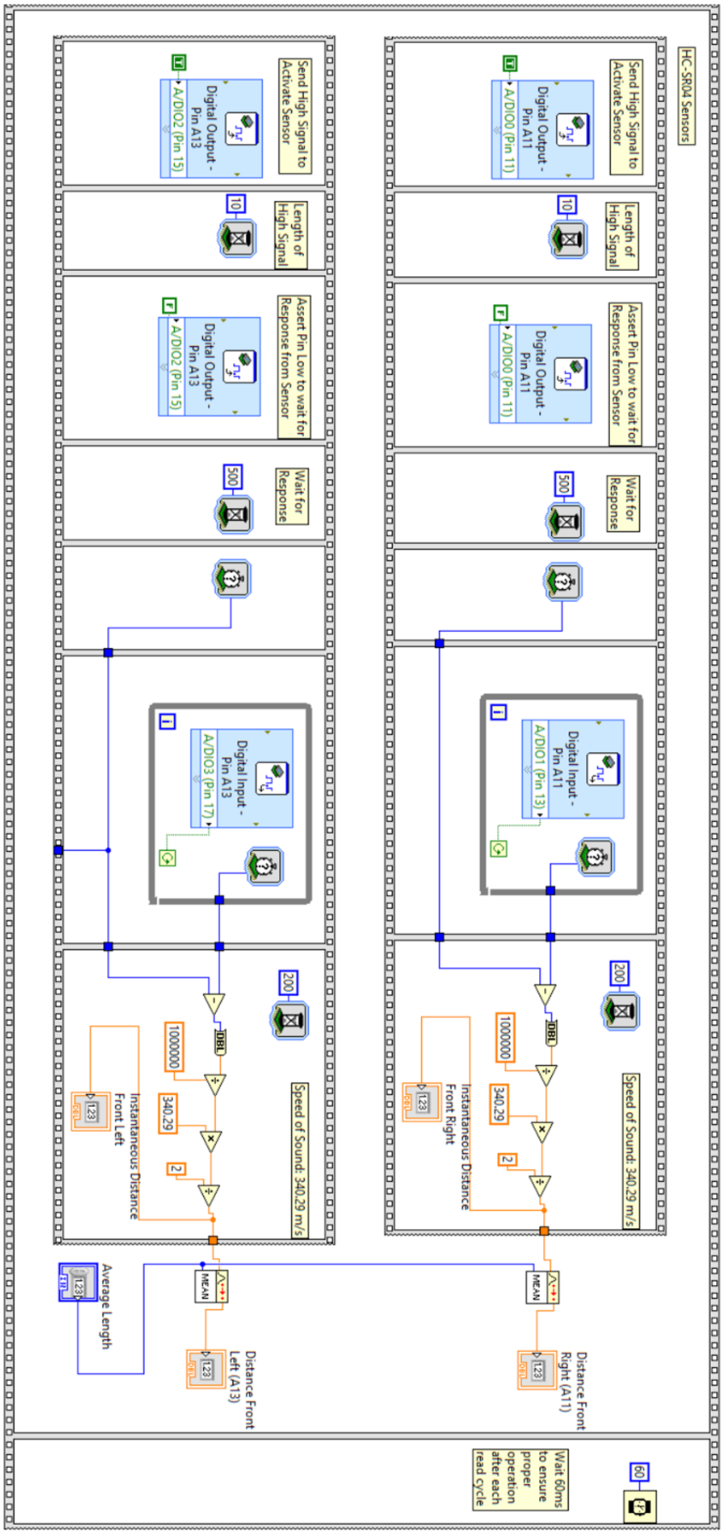

Figure C.5: Ultrasonic Sensor Data Acquisition VI

This VI runs two HC-SR04 sensors, and outputs the distance measurement from each one in meters. There is an averaging filter that controls how many previous results are averaged that can be controlled by the “Average Length” integer control.

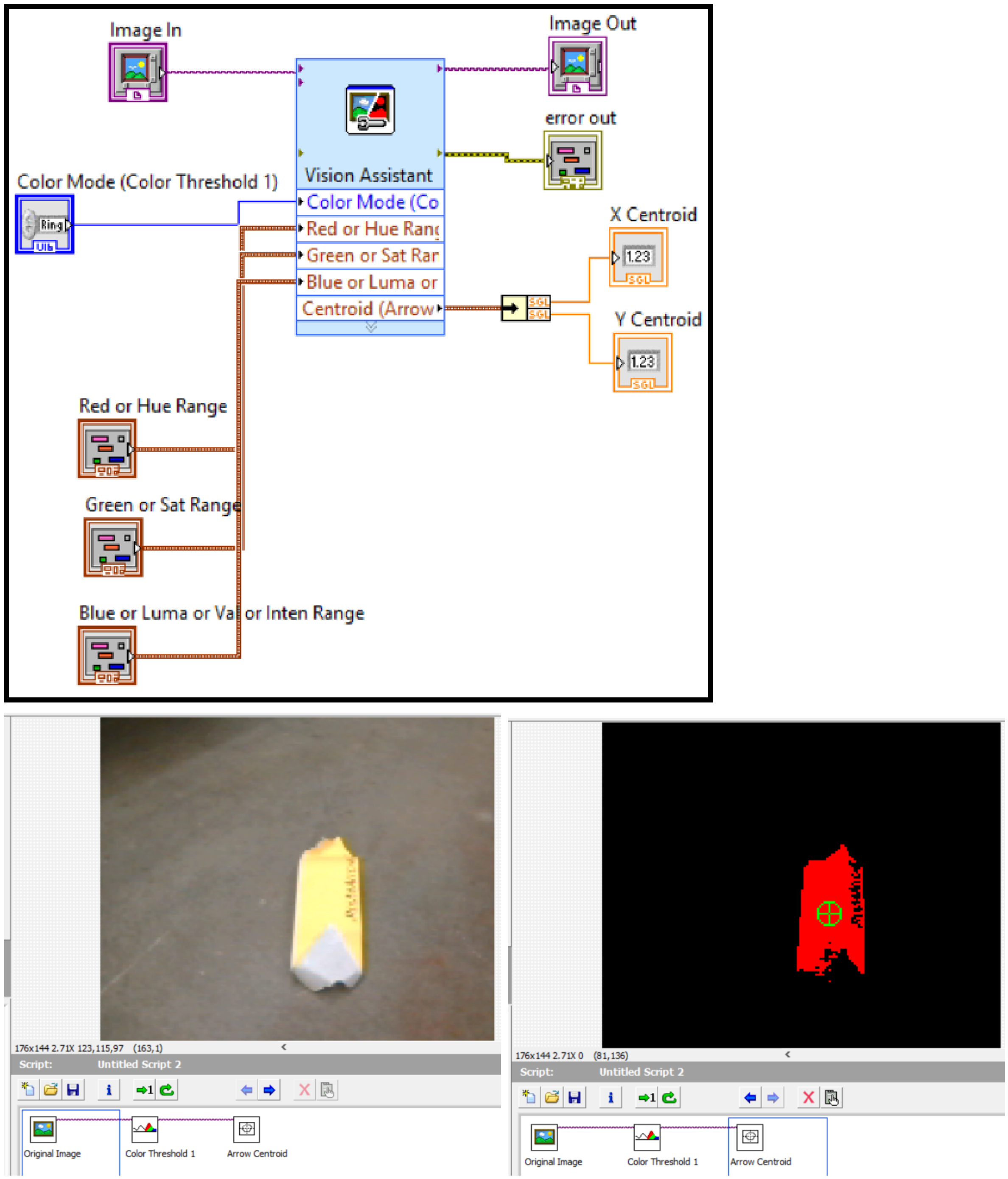

Figure C.6: Image Analysis VI

This VI takes in an image captured with the USB webcam and processes it to find the yellow arrows on the course. Shown bottom left and right are the steps contained inside the Vision Assistant module. The original image is transformed into a binary image. The binary image contains a 1 if that pixel matches the defined ranges (shown on the left as three compound controls) and a 0 if that pixel falls outside the specified range.

After all pixels have been analyzed a centroid of the 1's is taken, and output on the right as X and Y centroid. These values can then be used to navigate the vehicle.

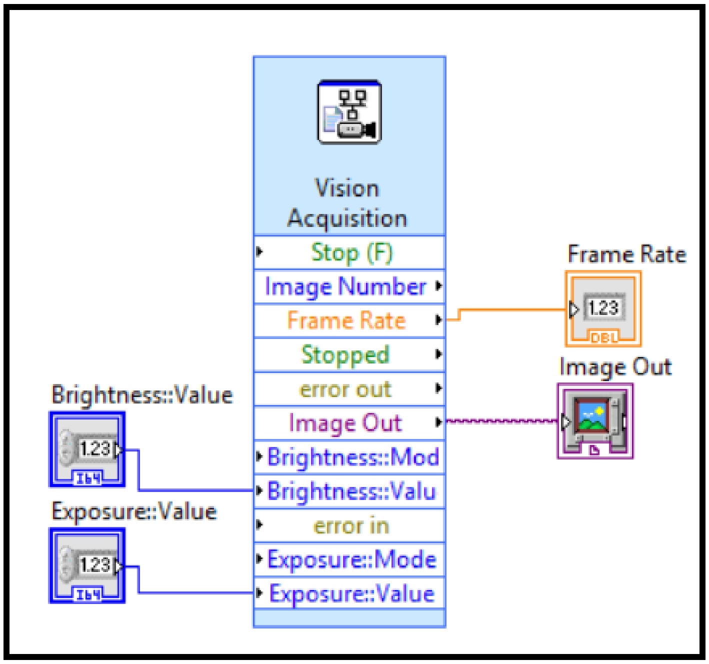

Figure C.7: Vision Acquisition VI

This VI takes an image with the USB webcam with the Brightness and Exposure values set by input controls on the left. The captured image (Image Out) is then passed to either the manual controller for viewing or to another VI that does analysis (Figure D.6).

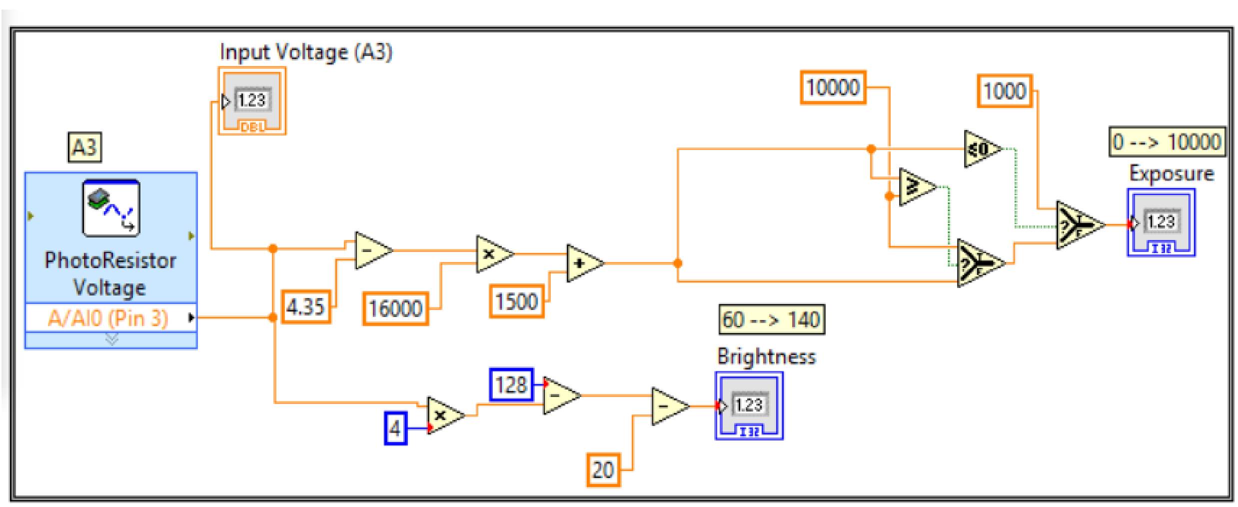

Figure C.8: Light Level Read VI

This VI reads in an analog voltage from the photoresistor circuit. It then translates the voltage value into usable brightness and exposure values for the camera in order to take accurate images for analysis

Appendix D: Bill of Materials

Bill of Materials: Team 2		ENGR 2610 - 5/30/2017					
Part Number	Part Description	Quantity	Unit Price	Total Price	Weight per part (g)	Total Weight (g)	Vendor Location
Sensors/Controls:							
SC-01	NI MyRio 1900	1	Provided	$0.00	240	240	n/a
SC-02	HC-SR04 Ultrasonic Sensor	2	$1.80	$3.60	20	40	https://www.amazor
SC-03	Logitech C160 Web Cam	1	$19.99	$19.99	100	100	https://www.cellxpo
SC-04	Sensor Mount	2	$4/in^3 @ 0.227 in^3	$1.82	10	20	3D Print
Sensor/Controls Total:		6		$25.41		380	
Electronic Devices:							
E-01	20 Ga Wire (2 Strand RED/BLACK)	25'	$0.224 / ft	$5.56	4	100	https://www.amazor
E-02	Floureon 4S 14.8V 35C 5200 mAh LiPo Battery	1	$51.99	$51.99	542	542	https://www.amazor
E-03	MyRio Power Regulator (L7812CV A-Type)	1	$0.22	$0.22	All Weights E-03 --> E-09 and E-14 --> E-16 Included in E-10 Measurement		http://www.jameco.c
E-04	12V 15A Slow Fuse (System)	1	$0.92	$0.92	-	-	https://www.amazor
E-05	12V 1A Fast Fuse (MyRIO)	1	$0.95	$0.95	-	-	https://www.amazor
E-06	12V Male Barrel Connector Adapter (MyRio Power)	1	$0.32	$0.32	-	-	http://www.cablewh
E-07	In-Line Fuse Holder	2	$1.50	$3.00	-	-	https://www.amazor
E-08	Male Fully Encapsulated Crimp Wire Connector	4	$0.07	$0.28	-	-	https://www.amazor
E-09	Female Fully Encapsulated Crimp Wire Connector	4	$0.07	$0.28	-	-	https://www.amazor
E-10	MyRio Expansion Board	1	Provided	$0.00	100	100	n/a
E-11	T-Plug Adaptor for LiPo Battery	1	$0.45	$0.45	5	5	https://www.amazor
E-12	DC Motor (#638276) 118 RPM 958.2 oz-in Planetary Gear Motor	2	$39.99	$79.98	360	720	http://www.robotshc
E-13	10A Dual Channel Speed Controller	1	$20.32	$20.32	120	120	http://www.robotshc
E-14	Adafruit Photoresistor	1	$0.86	$0.86	-	-	http://www.mouser.c
E-15	1k Pull Down Resistor	1	$0.04	$0.04	-	-	https://www.amazor
E-16	Wiring Connector Kit	1	$9.19	$4.60	-	-	https://www.amazor
Electronic Devices Total:		22		$169.76		1487	
Frame Subassembly:							
F-01	1/2 inch Aluminum Axle Rod	1 foot	$2.40/ft	$2.40	104	208	http://www.homedep
F-02	Axle Shaft Collars (1/2")	6	$0.98	$5.88	40	240	http://www.superdrc
F-03	#10 x 2.5" Bolts	4	$0.25	$1.00	All weights F-03 --> F-08 included in F-09 measurement		shop
F-04	#10 x 1/2" Bolts	8	$0.10	$0.80	-	-	shop
F-05	1/8" x .3/4" Screws	20	$0.10	$2.00	-	-	shop
F-06	#10 Nuts	12	$0.05	$0.60	-	-	shop
F-07	Washers- Small	30	$0.05	$1.50	-	-	shop
F- 08	Washers - Large	12	$0.10	$1.20	-	-	shop
F-09	Plywood for base	100 in^2	$0.01 / in^2	$1.00	500	500	http://www.homedepo
F-10	1.5 in. L-Bracket	8	$0.18	$1.44	10	80	https://www.ovisonline
F-11	Laser cut acrylic tails	2 x 19 in^2	$0.01 / in^2	$0.57	150	300	Plasticare
Frame Subassembly Total:		100		$18.39		1328	

Drive Train Subassembly:							
D-01	Motor Mount	2	4"x.75"x3" @ $.43/in^3	$7.74	200	400	Made in machine sh
D-02	Motor Shaft Gear (0.625", 20 teeth)	2	$7.99	$15.98	12.8	25.6	https://www.servocity.
D-03	Wheel Gear (2", 64 teeth)	2	$12.99	$25.98	15.6	31.2	https://www.servocity.
D-04	Medium Den. Fiberboard Laser Cut Wheels	2 x 90 in^2	90"^2 @ $0.01 /in^2	$2.70	730	1460	http://www.homedepo
Drive Train Subassembly Total:		6		$52.40		1916.8	
Budget Spent:	**$265.96**				**Total Weight:**	**5111.8**	grams
Number of Parts:	**134**				**Total Weight:**	**11.25**	Pounds

<u>Appendix E: Calculations:</u>

Calculation E.1: Torque and Gear Analysis

Givens: μ for rubber on dry concrete = .6

m = 10 lbs (1 lb = .453 kg)

Rot = 118 rpm

Tm = 6.77 Nm

r = 7.5 in (1 in = .0254m)

Nomenclature:

Ff = force of friction

Fd = drive force

Fn = normal force

Fw= force of weight

Td = torque to drive

Tm = torque of motor

d = diameter of wheel

Rot = rotations

Equations:

$Ff = \mu \; Fn = F\,d$

$T = F * r$

$M.A. = T\,d / Tm$

$W = F*d$

$T = w/\theta$

$\theta = 2\pi *rot$

Solve:

$Ff = .6*m*g$

$Ff = .6*.453*10.5*9.81$

$Ff = 26.7\ N = Fd$

$Td = Fd*r$

$Td = 26.7 * .0254 * 7.5$

$Td = 5.08\ Nm$

This is the torque required to drive the vehicle over brick.This should prove no problem for the motors used as they provide 6.8 Nm of torque.

To lift over a step:

$W = m*g *d$

$W = .453*10*9.81*6 *.0254$

$W = 7.12$ Nm
$\boldsymbol{\theta} = 2\boldsymbol{\pi} * (\boldsymbol{\pi}/2) = 1$

$T = 7.12$ Nm/ 1
$T = 7.12$ Nm

This means a torque of 7.12 Nm is needed to go over a 6" stair.

$MA = 7.12/6.77 = 1.05.$

This means that a gear ratio of 1.05 is required to lift the vehicle over the stairs. A gear ratio of 3.2 is used so the required ratio is far exceeded.

Calculation E.2: Maximum Speed Analysis

Givens: M.A. = 3.2
rw = 7.5 in (1 in = .0254 m)
wb = 118 rpm (12.35 rad/s)

Nomenclature:
rw = radius of drive wheel
wb = angular velocity of motor
wa = angular velocity of wheel
Vc = velocity of car

Equations:
$wa = wb/ MA$
$Vc = rw * wa$

Solve:
$wa= 12.35/3.2$
$wa= 4.12$ rad/s

$Vc = 7.5 * .0254 * 4.12$
Vc = .785 m/s = 1.75 mph

Calculation E.3: MyRio Wireless Bandwidth Restrictions

MyRio wireless adapter transmission mode: IEEE 802.11b/g/n (802.11b is worst case)

Using 802.11b, total bandwidth $\mathbf{B_T}$ **= 11Mbits / second**

Images to be transmitted are of size 176 * 144 pixels, with 24 bits of data for each pixel (8 bits each for R, G, B). Total image size **l = 608,256 bits**.

@30 FPS: (608256) * 30 = 18,247,680 bits/sec. This is over the transmission limit of IEEE 802.11b, thus, another mode will have to be used.

@15 FPS: (608256) * 15 = 9,123,840 bits / sec

Convert to Mbits: 9,123,840 / 1,000,000 = 9.12 Mbits/sec

Bandwidth Usage: $\mathbf{B_U}$ **= 9.12 Mbits / second**

$\mathbf{B_U < B_T} \rightarrow$ This meets the transmission requirement with bandwidth to spare for other control and feedback signals.