Development of an Autonomous Ground Vehicle

Final Report

Team 22

April 14, 2016

Submitted To: Dr. Gupta, Senior Design Coordinator

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Acknowledgements

As a team, we would like to thank our advisors, Dr. Nikhil Gupta and Dr. Matthew Jensen, for the time and effort they put forth towards bettering our project. Without them, our research and development would be aimless.

We would like to thank the Florida Space Grant Consortium along with Dr. Chiang Shih for funding and organizing our project. Dr. Shih organized a dual university collaboration between the FAMU/FSU College of Engineering and the Florida Institute of Technology which has provided us with a valuable work experience.

Abstract

The Intelligent Ground Vehicle Competition compels engineering students to use the skills they have gained through study and apply them in real life applications. This competition requires that an autonomous vehicle navigate a course while remaining in a predetermined path. Once a prototype frame was constructed out of wood, other major components were added to adhere to the competition rules. The major processors being used are the NVidia Jetson TX1 and the Raspberry Pi2 B+. The camera being used for obstacle avoidance is the ZED 2K Stereo Camera. The motors being used are the PG27 Planetary Gearmotors with RS775 Motors and Encoders. These motors will propel the vehicle with the necessary speed to compete in the competition. The Pololu High-Power motor controller is being used to control the motors. The entire vehicle cost is under budget at $1806.85

1. Introduction

1.1 Intelligent Ground Vehicle Competition

The Intelligent Ground Vehicle Competition (IGVC) offers a design experience for students at the very cutting edge of their engineering education and started in 1993. It is multidisciplinary, theory-based, hands-on, team implemented, outcome assessed, and based on product realization [1]. It comprehensively includes the most recent technologies influencing industrial development and major subjects of significant interest to students. This Intelligent Vehicle's design and construction is a two semester senior year design capstone course and likewise an extracurricular activity from which participating students can earn design credit [1]. Roles practiced during the project development are team organization and leadership, roles such as business and engineering management, language and graphic arts, and public relations are also practiced during this period.

During the course of the project development, students have opportunities to solicit and interact with industrial sponsors who provide component hardware and advice, through which they get an inside view of industrial design and opportunities for employment [1]. An example of an AGV is shown navigating the 2013 course in Figure 1 [2].

Figure 1: An autonomous vehicle moving within the lane and about to avoid an obstacle during 2013 IGVC [2].

1.2 Competition Constraints

Below are the requirements that the intelligent ground vehicle must meet in order to consider it as a valid design and as well qualify for the Intelligent Ground Vehicle Competition (IGVC). A small semi-rugged outdoor vehicle is required for the competition, the requirements to be met includes [3]:

- Design: The vehicle must be designed such that it is mechanically propelled on its direct contact (traction) with the ground through the wheels.
- Width: Two feet is the minimum width required and four feet at maximum.
- Height: Apart from the emergency stop antenna, the height of the vehicle must not exceed six feet
- Length: The vehicle must be at least three feet long with maximum length of seven feet.
- Propulsion: The power required for propelling the vehicle must be generated onboard.
- Speed: At minimum the speed of the vehicle must be one mph and five mph at maximum.
- Mechanical E-stop location: The E-stop button required must be red in color, push to stop and one inch diameter at minimum. Even if the vehicle is moving, the button must be easily identified and can be safely activated with its location at the center rear of the vehicle with minimum height of 2 feet from the ground and four feet at most. The E-stop must not be software controlled, but must hardware based and on activation must be able to bring the vehicle to a prompt and full stop.
- Wireless E-stop: For a minimum of 100 feet the wireless E-stop must be effective. Hardware based E-stops that cannot be controlled using software is required. The wireless E-stop is expected to bring the vehicle to a quick and complete on activation.
- Safety Light: At any time when the vehicle power is turned on, an easily viewed solid indicator light must be recognized on the vehicle. A solid light which turns to flashing when the autonomous is activated and again turns solid when the autonomous mode is off is required.
- Payload: The vehicle must be able to carry a load of 20-pound securely mounted on the vehicle. The specifications of the payload is 18 inches long, 8 inches wide and 8 inches high.
- Lane following: The vehicle must be capable of detecting and following lanes.
- Obstacle Avoidance: The vehicle must be capable of detecting and as well avoiding obstacles.

- Waypoint Navigation: Vehicle must show its capability of finding a path to a single two meter navigation waypoint by maneuvering its way round the obstacle.
- Budget: The amount of money estimated for the completion of this project is 3,000 dollars.

1.3 Goal Statement

Team 22's goal for this project is to provide a reliable prototype that can be further improved upon for next year's team. Since designing and building a fully functional AGV in a span of 9 months is a difficult task, it is reasonable to believe that Team 22 can provide a prototype with some key aspects already completed. This will provide any future team with a base vehicle to improve upon.

1.4 Project Objectives

The objectives that were created for this project took into the consideration that the task at hand was difficult to complete in a single year. Therefore the objectives were made to give next year's team a head start on the project. The major objectives are as follows:

1. Select components (processors, motors, motor drivers)
2. Build prototype frame
3. Control vehicle speed using proportional differential control
4. Configure emergency stops
5. Configure a basic obstacle avoidance system
6. Configure a basic image processing system
7. Select a suitable battery

1.5 Team Dynamics and Challenges

This team is very unique in that it is the first team at the FAMU/FSU College of Engineering (CoE) to partner with the Florida Institute of Technology (FIT) to work on a single senior design project. The FIT campus is in Melbourne, FL which is about five hours away from Tallahassee, FL where the CoE campus resides. This gave the team a distinct look at how multi-team projects work just like in the industry. The biggest challenges that were faced were communication and work distribution. In order to make sure each team had tasks to perform, the work load was distributed. The CoE team was in charge of prototype frame fabrication, vehicle speed control, emergency stops, and choosing a battery that supplies enough power for the entire vehicle. The FIT team was tasked with obstacle detection, path following, and GPS waypoint navigation.

2. Background Information

Self-driving vehicles are being researched more than ever and the idea behind them is to reduce the number of traffic accidents. The two most successful examples of self-driving vehicles are the Google Self-Driving Car and the Tesla Model S. These vehicles use similar techniques to what is being applied to Team 22's AGV.

2.1 Google Self-Driving Car

This car has been around since 2009 with the Toyota Prius [4]. The vehicle was equipped with an overhead laser, sonar, and image processing system that can detect other vehicles as well as lanes. Even though the vehicle had an advanced collision detection system, a driver was still needed just in case there was an accident. The system was then upgraded to a new vehicle, the Lexus RX450h. The Lexus model began driving on freeways in 2012 and still needed a driver to assist in some scenarios [4]. The Lexus then began to navigate city streets which have much more traffic than the freeways. In 2014, Google announced its development of a completely autonomous vehicle shown in Figure 2.

2.2 Tesla Model S

The Tesla Model S integrates sensors all around the vehicle. It has forward facing sensors to detect vehicles in front, it has sensors on the sides to alert the vehicle of any objects in its blind spots, and it has sensors on the rear to detect for objects behind it. The unique feature on this vehicle is that it can parallel park itself [5].

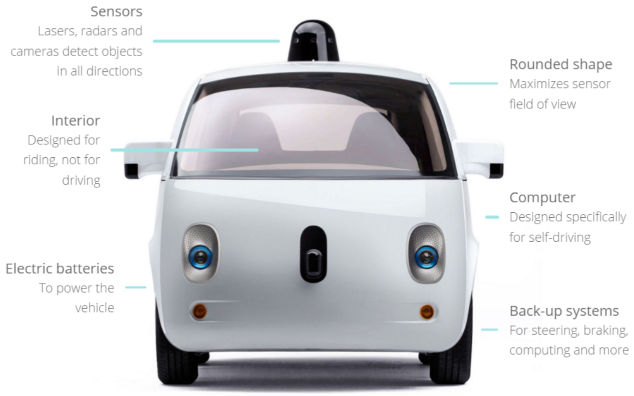


Figure 2: Google Self-Driving prototype released in 2014 [4]

3. Concept Generation

Unlike most, complete freedom over the design of an autonomous ground vehicle was given. Team 22 wanted to create a design that not only satisfied the constraints of the Intelligent Ground Vehicle Competition but also one that was innovative and sound. With no prior design being crafted, Team 22 would be able to start from scratch and create a solid foundation their successors. Before conception of the design, Team 22 had to obtain the proper knowledge on how an autonomous vehicle operates as well as what it takes to construct a good autonomous vehicle. The ideas four ideas consisted of frame fabrication, drive train, perception and processing. By using a decision matrix, seen in Table 1, Team 22 was able to pinpoint the materials, drive train to be used for the vehicle.

Table 1 – Decision Matrix

Steering	Base	Control	Feasibility	Speed	Total
Differential Steering	0	7	7	7	21
Skid Steering	0	7	5	5	17
Tank Tread	0	5	3	3	11
Steering Fans	0	3	3	5	11
Ackerman Steering	0	5	0	5	10

Body Structure	Base	Manufacturability	Weight	Availability	Total
Tube Frame	0	7	5	7	19
Sheet Material	0	7	5	5	17
3D Printed	0	5	5	3	13
Hovercraft	0	3	7	5	15

Materials	Base	Machinability	Density	Availability	Total
4130 Steel	0	7	3	5	15
Aluminum 6061	0	7	5	7	19
ABS Plastic	0	5	7	5	17
Wood	0	5	7	5	17

3.1 Proposed Frame Designs

When designing the frame for the vehicle many constraints had to be taken into account. First, the frame needed to be agile enough to maneuver around objects. Second, the frame needed to be sturdy enough to support a fully integrated electrical system as well as a 20 lb payload as per competition rules.

Design 1: The first design of the frame, seen in Figure 3, consisted of multiple tubes interconnected. This initial design was constructed purely for reliability testing of the aluminum 6061 material. Team 22 was able to fully grasp idea of what it takes to construct a sturdy vehicle as well as the correct size need to per competition constraints. With a general idea of the material, team 22 could now brainstorm as to the placement of the other components and the drive train needed to run the vehicle. This design requires a lot of modification and proved to be overly complex.

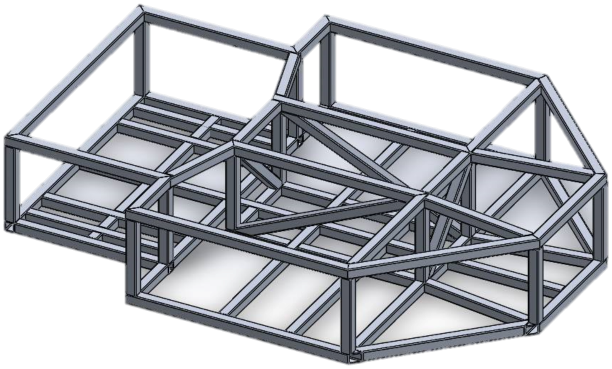


Figure 3- Frame design concept 1

Design 2: The second design of the frame, seen in Figure 4, is significantly different then the first. Instead of the complex frame initially constructed, Team 22 decided to fabricate a simpler frame that still had the strength needed to accommodate necessary components. The shape of the frame was modified from a pentagon and rectangle to a more squared design. This design consisted of a single castor wheel in the rear for added support that will be connected directly to the frame. Two front wheels will be connected directly to two motors to achieve differential steering. The payload will also be centered in the vehicle for balance. The frame still provided the necessary strength and agility but it also had several drawbacks. This design proved to be extremely difficult to modify on board components if a malfunction occurred, it also left little to now room for the electronic system with the payload being centered. The single castor wheel in the rear would also not be able to support the payload strength, which would cause stability issues and potential result in a slower vehicle. With additional sensors being mounted onto this frame the angles at which the frame was constructed will obstruct the field of view for those sensor which in turn would not produce the maximum visibility needed to accurate detect objects and lines.

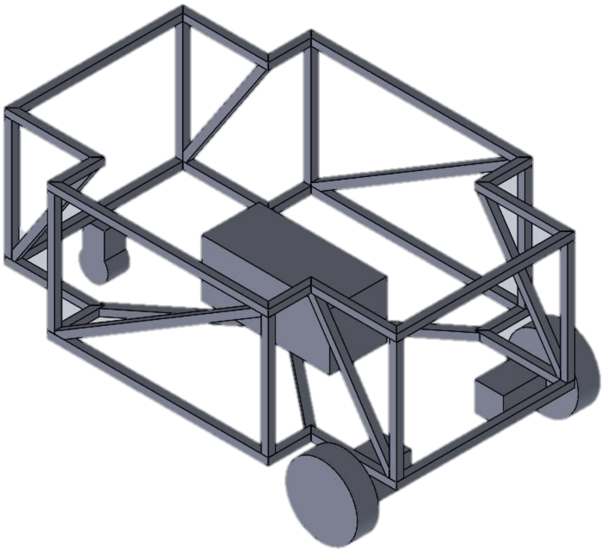


Figure 4 – Frame design concept 2

Design 3: The third design, seen in Figure 5, is significantly different then the first two designs. The shape of the frame was again modified from a square shape to an octagonal shape, with two treaded wheels in the front for the drive train and also two castor wheels in the rear for additional support. The payload is now place furthest to the rear above the castor wheels. An electronic component box is placed at the front of the vehicle for the full electrical system. This design allowed easy wiring to motors and added space for the sensor mounts. The frame is lightweight and agile. The angles at which the frame is constructed will allow a full field of view for all sensors to accurate detect objects and lanes. The frame still provides the necessary durability needed but a problem still arises with the payload, even with two castor wheels the load would still be to heavy to be supported in the rear.

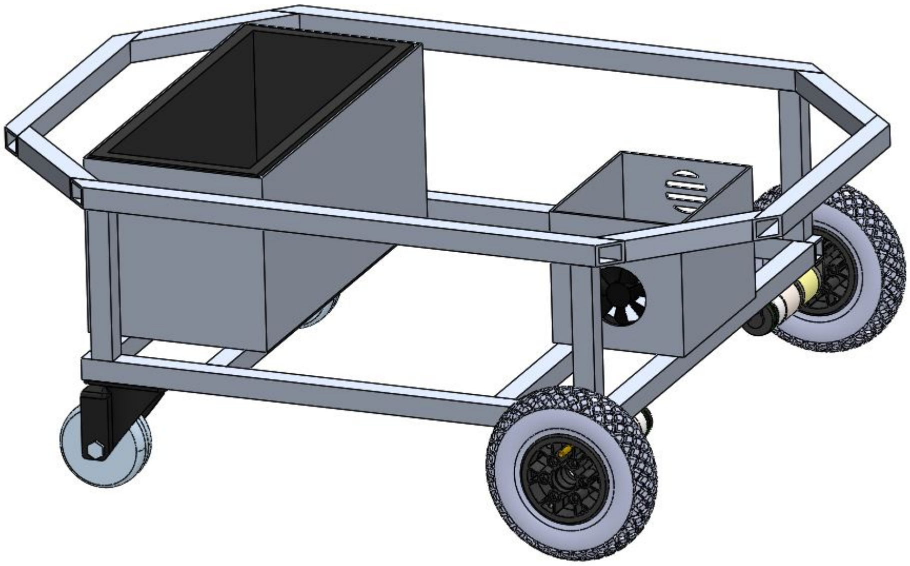


Figure 5 – Frame design concept 3

Design 4: The fourth design, seen in Figure 6, altered not only the shape but also the materials used. The shape of the frame was again modified to be as simplistic as possible. The payload is now placed in the front of the vehicle where the larger wheels can now support it without any strain on the motors. The electronic box is placed in the rear still allowing for easy wiring. A vertical piece of wood is placed at the rear to house the emergency stop push button as well as the 3D depth sensor. The resulting frame was strong and allows for easy modifications of onboard devices. The advantage of the frame is directly related to the constraints of the frame design. The frame may not be as lightweight as the above designs but it is light enough to still be agile for obstacle avoidance.

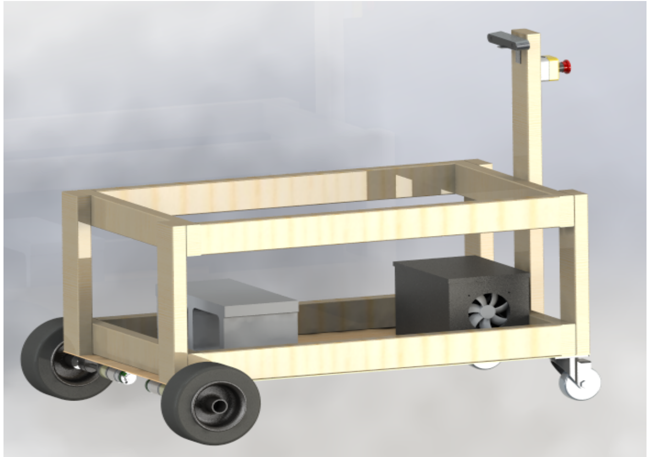


Figure 6 - Frame design concept 4

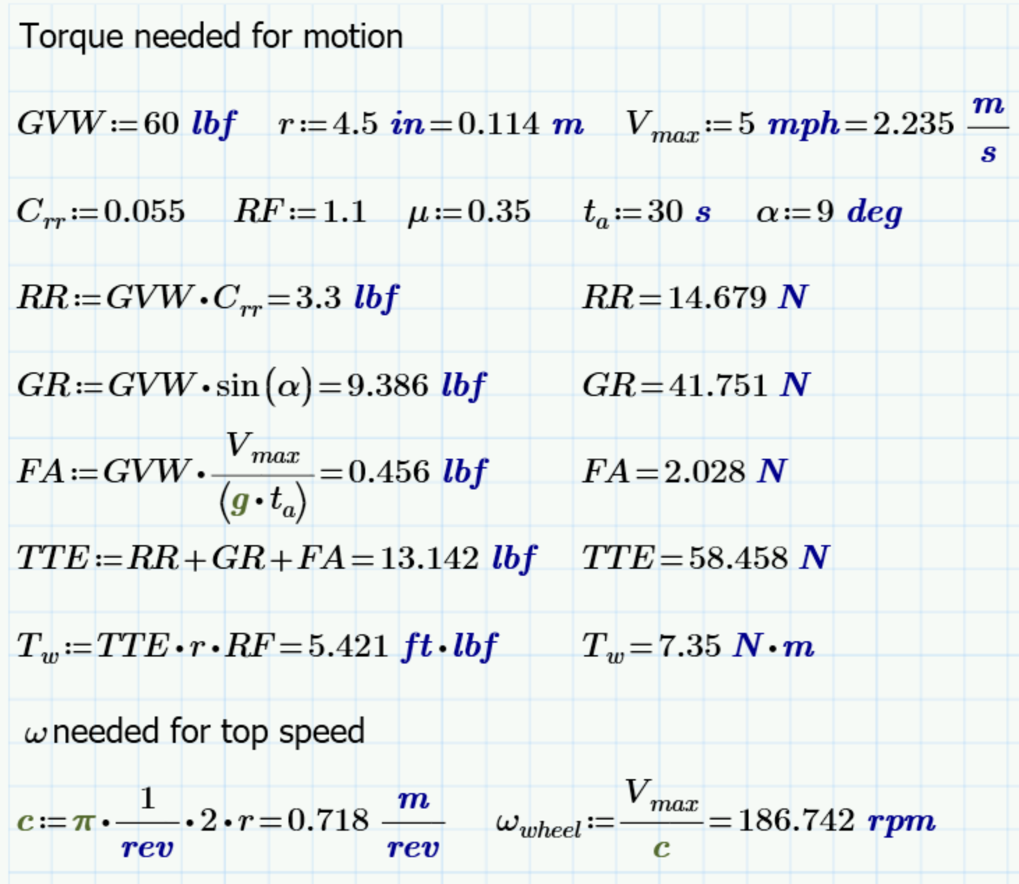
3.2 Selection

When selecting the optimal design for the frame, original design constraints had to be considered. Each design had its drawbacks and advantages but after thoroughly considering what makes a smart car successful, Team 22 decided to take a different approach. Team 22 decided that a successful vehicle for competition will be less contingent upon the frame fabrication but more about the electrical system within it; therefore the decision was made to use the fourth design. It proved to be the most accessible for component swapping as well as sturdy enough to handle the large payload and still be agile.

4. Final Design

The final design of the Autonomous Ground Vehicle is made up of four sub-systems: the frame, the drive train, perception, and processing. The frame is constructed from 2x4 pine planks and 1/8" plywood attached by wood screws. The frame is 39"x 24"x 18" this is to abide by the rules that the frame has to be a minimum of 3'x 2'. The drivetrain consists of the motor assemblies, the axles, the wheels, and a double bushing bracket. The purpose of the double bushing bracket is to prevent unwanted side loading to the output shafts of the motor assemblies. The perception sub-system includes the Stereo Labs ZED 2K Camera and tentatively includes five PixyCams. The ZED is used for depth sensing and will allow for basic vehicle operation while the PixyCams are for lane detection and pothole detection. The vehicle may operate in a limited fashion without the PixyCams and therefore the inclusion of them has been of low priority. The final sub-system, processing, is made up of two different microprocessors, the Nvidia Jetson TX1 and a Raspberry Pi 2, as well as a Roboclaw motor controller. The Jetson TX1 was chosen because of its number of ports and its processing power, the Raspberry Pi 2 was chosen for its ability to interface with the PixyCams.

Figure 7 depicts the calculations used to determine the required motor torque and angular velocities.



Torque needed for motion

$GVW := 60\ lbf \quad r := 4.5\ in = 0.114\ m \quad V_{max} := 5\ mph = 2.235\ \frac{m}{s}$

$C_{rr} := 0.055 \quad RF := 1.1 \quad \mu := 0.35 \quad t_a := 30\ s \quad \alpha := 9\ deg$

$RR := GVW \cdot C_{rr} = 3.3\ lbf \qquad RR = 14.679\ N$

$GR := GVW \cdot \sin(\alpha) = 9.386\ lbf \qquad GR = 41.751\ N$

$FA := GVW \cdot \frac{V_{max}}{(g \cdot t_a)} = 0.456\ lbf \qquad FA = 2.028\ N$

$TTE := RR + GR + FA = 13.142\ lbf \qquad TTE = 58.458\ N$

$T_w := TTE \cdot r \cdot RF = 5.421\ ft \cdot lbf \qquad T_w = 7.35\ N \cdot m$

ω needed for top speed

$c := \pi \cdot \frac{1}{rev} \cdot 2 \cdot r = 0.718\ \frac{m}{rev} \qquad \omega_{wheel} := \frac{V_{max}}{c} = 186.742\ rpm$

Figure 7: Key Calculations used to select motor

4.1 Manufacturing

The manufacture of the Autonomous Ground Vehicle (AGV) for the Intelligent Ground Vehicle Competition began with the frame. The frame was originally to be fabricated from aluminum square tubing, but with guidance from Dr. Gupta, a prototype frame for the AGV was fabricated from plywood and 2x4 planks that were made available by Dr. Gupta. Because of both time constraints and the fact that there would be little benefit in building a final frame the wooden prototype frame is to be our final product. The frame is constructed from 12 pieces of 2x4 pine screwed together into a box that is 43 inches long, 25 inches wide, and 18 inches tall. This size was chosen to both accommodate the rule book and to allow space for our components and the payload we are required to carry. A 1/8th inch piece of plywood was attached to the bottom to serve as a floor for the frame.

In total the frame took approximately one hour to manufacture. The frame assembly model and exploded view can be seen in Figure 8.

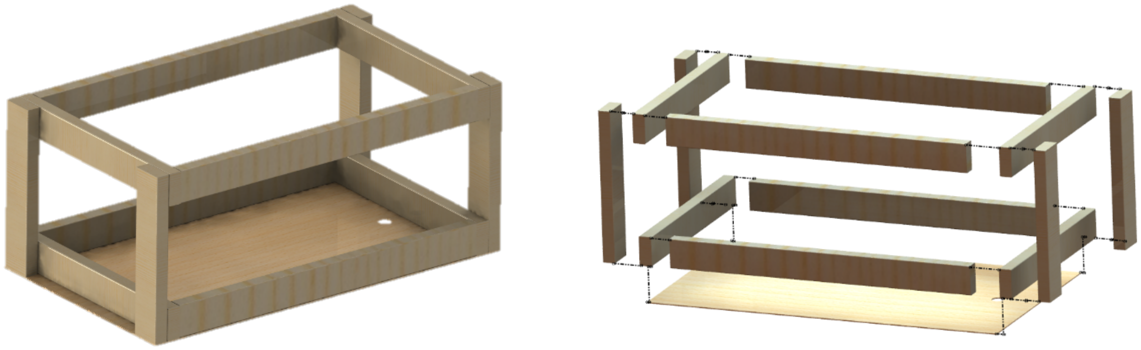


Figure 8: Frame assembly (left) and exploded view (right)

Following the manufacture of the frame the motor and wheel assembly was completed. This sub assembly consists of the motors from AndyMark that came already mounted with a planetary gear box and Hall-effect encoder, a coupler, the axle shaft, the wheel, the motor mount, and the bushing housing. The coupler is made from a piece of 0.750" mild steel shaft bored out on one half to 10mm to fit over the output shaft of the planetary gearbox from the motor assembly and on the other side bored out to 0.500" to fit the axle shaft and drilled and tapped for set screws on both sides. The axle shaft was fabricated from a piece of 1.000" mild steel shaft and a piece of 0.500" mild steel shaft. The 1.000" shaft was turned on the lathe to be press fit into the hub of the wheel and a 0.375" hole was bored in the center so that the 0.500" shaft could be turned to fit into it up to a shoulder and be welded, this was done to help center the shaft on the press fit piece before the two pieces were welded together. Following the axle fabrication the motor mount was made. The mount was drawn up as two flat plates and waterjetted from 0.250" mild steel then welded together, the waterjet was used so that all holes and geometries of the design would be accurate. Following the motor mount the bushing housing was made in similar fashion to the motor mount, utilizing the waterjet and the welder, in addition the lathe was used to fabricate the bushings used from Delrin, a hard plastic with a low friction coefficient. In total the drivetrain took approximately 4 hours to fabricate. The sub assembly for the drivetrain of the AGV as well as the exploded view can be seen in Figure 9.

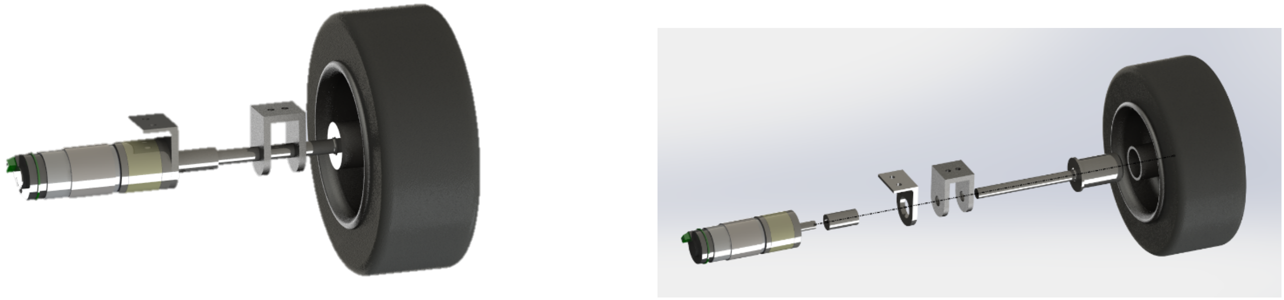


Figure 9: Assembly for drivetrain (left) and exploded view (right)

After the drivetrain was manufactured and assembled the electronics housing compartment was fabricated. It consists of a lid, a box, and a 120mm fan. The lid and box were both made from 0.125" ABS plastic sheet which was cut using a laser cutter. The walls of the box and lid were drawn up so that the pieces may be press fit together like a puzzle to ensure they would be properly assembled for gluing. One end of the box was cut with a hole in it for mounting the cooling fan to it. The cooling fan is a 120mm 79 CFM Antec brand case fan. The electronics housing compartment took approximately two hours to fabricate, including the time it took to prepare the files for the laser cutter and the time it took for the glue to set. The electronics housing compartment assembly and exploded view can be seen in Figure 10.

Figure 10: Electronic housing compartment assembly (left) and exploded view (right)

The overall assembly of the AGV includes all of the aforementioned sub-assemblies as well as a pair of four inch caster wheels mounted to the rear corners of the vehicle. The sub-assemblies were mounted to the frame by wood screws, a benefit of using the prototype frame as the competition frame. The total time it took to manufacture and assemble the AGV was approximately seven hours. This manufacture and assembly time is less than was expected, total manufacture and assembly time was expected to be close to ten hours. There are 18 parts in our total assembly counting the frame as a single part. This number of parts is in large part necessary but could be reduced slightly with the exclusion of the extended axles and bushing housing. These parts were added upon the advice of our advisor for fear of side loading on the motors causing issues. This could have been excluded because the planetary gearbox would prevent any side loading to the motor itself, however there would be a possibility of binding in the planetary gear set if substantial side loading was experienced. Figure 11 is a rendering of the mounting of all the sub-systems and the caster wheels to the frame with the exploded view of the overall assembly.

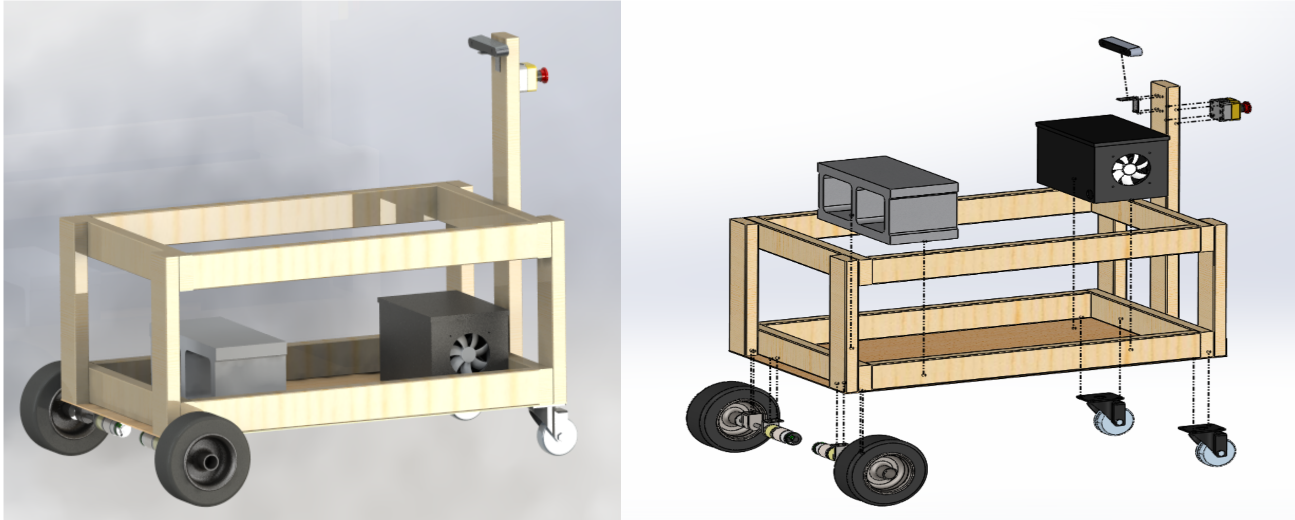
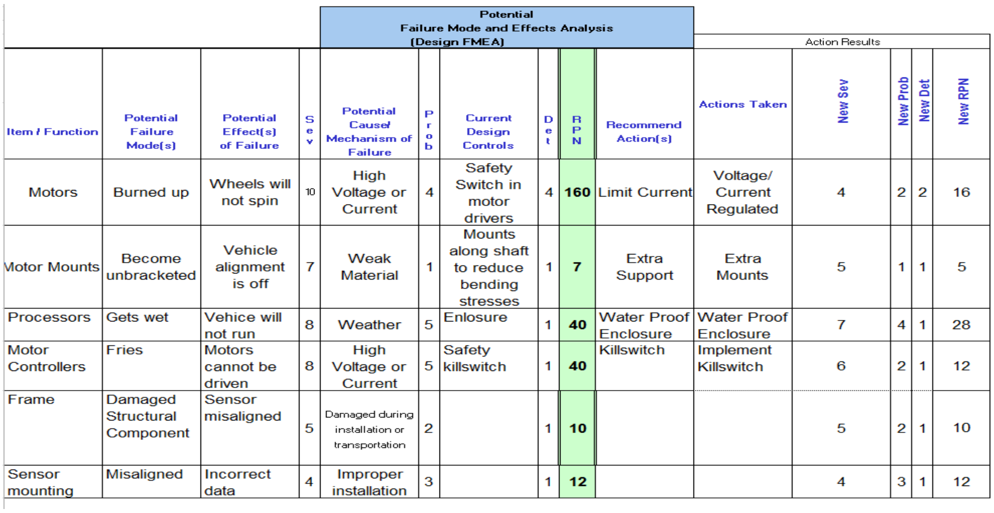


Figure 11: Prototype assembly (left) and exploded view of sub-assemblies (right)

4.2 Reliability

In examining the reliability of the AGV, many different components need to be considered. These components are the motors, motor mounts, motor controllers, microprocessors, frame, and sensors. Each component can fail at different times in the AGV's life cycle and the causes can be drastically different. Therefore, a Failure Modes, Effects and Analysis (FMEA) was conducted to identify the components most susceptible to failing and how to prevent these issues. This FMEA can be seen in Table 2. In the FMEA, a value called the Risk Priority Number (RPN) was used to determine if the component was at risk of failing. The RPN is comprised of the severity of the failure, the probability that the failure will occur, and the detectability of the failure. A component was considered to be at a high risk of failure if the RPN was over 35. The three components that exceeded this designated value were motor failure with a RPN of 160, the motor controllers with a RPN of 40, and the processors with a RPN of 40. If the motors were to fail then the vehicle would not be able to move. This is a severe failure and the precautionary measure taken was to regulate the current and voltage being supplied to the motor. With these measures being implemented the RPN reduces by a factor of 10, from 160 to 16, which is an acceptable value. The second component that had a high RPN are the motor controllers with a value of 40. To prevent overpowering the motor controllers, a kill switch was enabled so that if the motor controller receives too high of a current or voltage, then it will power off and stop the motors before any damage is done to the motor controllers or the motors themselves. This also contributes to the reduction of the motors' RPN that was previously discussed. The kill switch utilization reduces the RPN of the motor controllers from 40 to 12, well below the satisfied range. The final component at a high risk of failure is the microprocessor. The main concern for this component was the weather. The Ni MyRio 1900 can withstand a wide range of voltages and currents so it was not a major factor in causing failure. If the processor gets wet due to inclement weather then it can stop the entire vehicle from operating. A water proof enclosure was created to keep moisture away from the processor, as well as most of the other electrical components. The introduction of the enclosure reduces the RPN of the microprocessors from 40 to 28, which is under the high risk limit. With the high risk components accounted for and their RPN reduced, the AGV should run seamlessly for an unlimited number of times.

Table 2: Failure Modes, Effects, and Analysis for key components



				Potential Failure Mode and Effects Analysis (Design FMEA)						Action Results			
Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause/ Mechanism of Failure	Prob	Current Design Controls	Det	RPN	Recommend Action(s)	Actions Taken	New Sev	New Prob	New Det	New RPN
Motors	Burned up	Wheels will not spin	10	High Voltage or Current	4	Safety Switch in motor drivers	4	160	Limit Current	Voltage/ Current Regulated	4	2	2	16
Motor Mounts	Become unbracketed	Vehicle alignment is off	7	Weak Material	1	Mounts along shaft to reduce bending stresses	1	7	Extra Support	Extra Mounts	5	1	1	5
Processors	Gets wet	Vehice will not run	8	Weather	5	Enlosure	1	40	Water Proof Enclosure	Water Proof Enclosure	7	4	1	28
Motor Controllers	Fries	Motors cannot be driven	8	High Voltage or Current	5	Safety killswitch	1	40	Killswitch	Implement Killswitch	6	2	1	12
Frame	Damaged Structural Component	Sensor misaligned	5	Damaged during installation or transportation	2		1	10			5	2	1	10
Sensor mounting	Misaligned	Incorrect data	4	Improper installation	3		1	12			4	3	1	12

4.3 Economics

The cost of the AGV is $1806.85. Figure 12 shows the budget breakdown for the AGV. The majority of the budget was spent on the battery which will power the entire system. Providing power to the entire vehicle is crucial to competing. If one system loses power, then the AGV could go off course or run into an obstacle which would automatically disqualify the vehicle. The second highest expenditure were the PG27 Gearmotors with RS775 Motor and Encoder, which consumed 9% of the allotted budget. The Roboclaw Motor Controller was the third most expensive purchase taking up 6% of the budget. This controller allows for the processor to drive the motors at a desired speed.

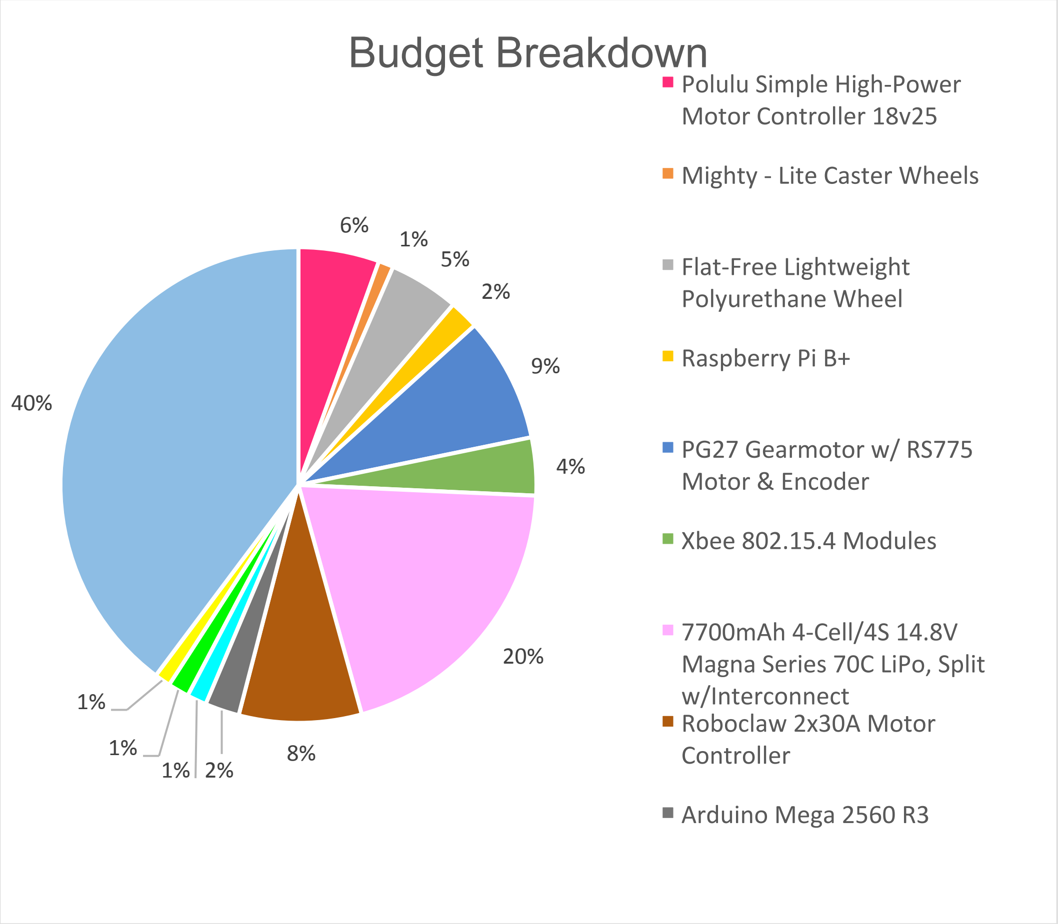


Figure 12: Breakdown of $3000 budget

To see how this AGV compares to previous competitors, Figure 6 shows the prices of the vehicles that won in years past. The University of New South Wales, Australia won in 2015 with a vehicle cost of $2,480 [6]. In 2014 Oakland University, the host university, won with a vehicle cost of $11,049 which was substantially higher than other competitors [7]. The 2013 winner was California

State University Northridge and they won with a vehicle that costs $4,279 [8]. Team 22's AGV is most comparable to the University of New South Wales AGV with a price difference of $601.65.

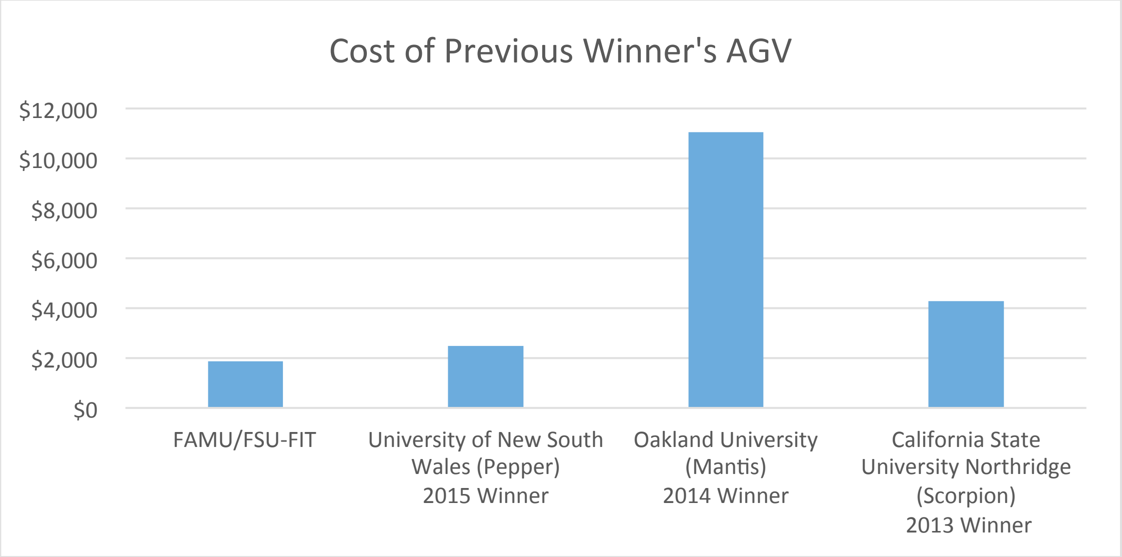


Figure 12: Previous Winner's Cost Comparison

4.4 Operation Manual

4.4.1 Functional Analysis

The course created for the robot to navigate depends mainly on two concepts: the concept of depth and color sensing, and the concept of object recognition. Sensors have advanced to the point where it is now economical to do the first concept with a sensor alone. The sensor chosen, a ZED 2k Stereo Camera from STEREO Labs, offers both color and depth sensing in amazing definition. ZED offers depth and color sensing officially up to 15m in any lighting and precipitation conditions. ZED builds a 3D point cloud of the area with color and depth identified. Using a PCL, a software library for transforming 3D point clouds, that information can be turned into a 2D map from which obstacles may be identified. That information is then saved into a growing database of information on obstacles present in the course and used by the algorithm to identify the best path through the course. The data is retrieved using C++ and CUDA libraries stored on the NVIDIA Jetson board.

The actual representation of data is kept as minimal as possible. The robot only knows three kinds of data: obstacles, GPS waypoints, and flags. A line is an obstacle, a fence is an obstacle, a barrel is an obstacle; this determination means that the robot needs to know nothing other than the locations of obstacles and waypoints. Every time the robot takes a snapshot of its surroundings, it catalogues the obstacles and then places them in its current existing map. The robot starts with paths to all of its destinations marked out, as paths become infeasible (an obstacle is added to its known map) the robot deletes and modifies paths. Once an updated map is reached, the robot then adjusts to calculate the known path to its next destination.

With the path known the robot then plots a course to that point in real time and navigates to that point. The data is passed through ROS, an open source operating system for robots through a serial port on the NVIDIA Jetson and to two Pololu Motor Controller which handles one motor each. A case diagram is shown in Figure 1.

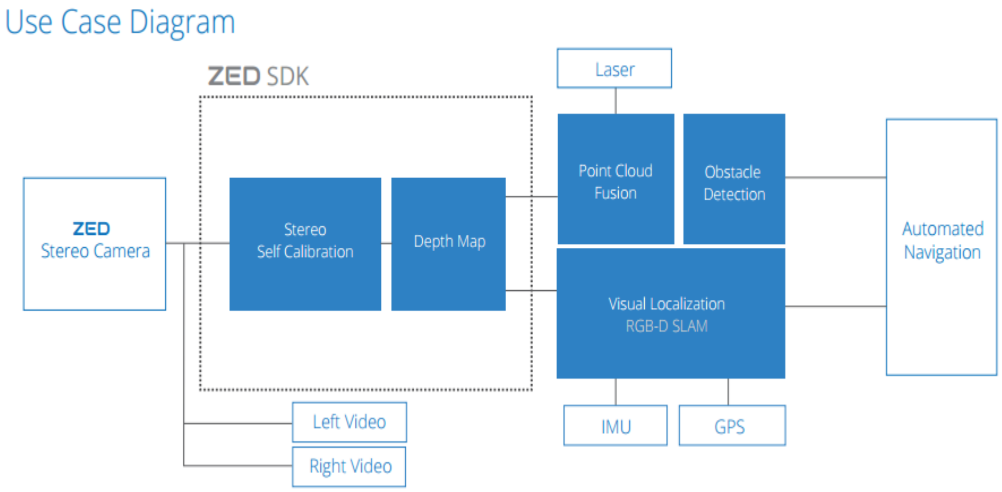


Figure 14: Case diagram of the ZED 2k Stereo Camera

4.4.2 Component Specifications

<u>NVidia Jetson TXI</u>

Figure 15: NVIDIA Jetson TX1

Table 3: NVIDIA Jetson Specifications

General	Technical Specifications
Power	Micro USB socket 5V, 2A
CPU	1.73 GHz ARM® Cortex® -A57 MP Core (Quad-Core) Processor with NEON Technology
Memory	4 GB RAM
Size	50 mm x 6.25mm x 87 mm
Weight	75g
Operating Voltage Range	5.5~19.6V

Raspberry Pi B+

Figure 16: Raspberry Pi 2 B+

Table 4 - Raspberry PI 2 Model B+ Specification

General	Technical Specifications
Power	Micro USB socket 5V, 2A
Current Consumption	700 – 1000 mA
Chip	Broadcom BCM2835 SoC
CPU	900MHz quad-core ARM Cortex-A7
Memory	1 GB RAM

Table 5- Raspberry PI 2 Model B+ Connections

General	Connectors
GPIO Connectors	40 GPIO pins (+3.3V, +5V and GND)
USB	4 USB 2.0
Video Output	HDMI
Ethernet	10/100 BaseT Ethernet socket
Memory Card Slot	SDIO

ZED 2K Stereo Camera

Figure 17: ZED 2K Stereo Camera

Table 6 - ZED 2K Stereo Camera Specifications

General	Technical Specifications
Size	33 x 30 x 175 mm
Weight	159g
Operating Voltage	5.5V
Power	380 mA
Field of View	110°
Depth Range	15m

Pololu High-Power Motor Controller

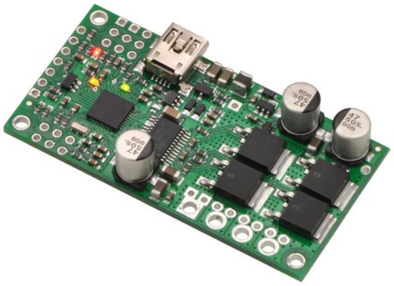


Figure18: Pololu High Power Motor Controller

Table 7 - Pololu High-Power Motor Controller Specifications

General	Technical Specifications
Size	2.3 x 1.2 x 0.4 in
Weight	12g
Maximum Operating Voltage	30V
Minimum Operating Voltage	5.5V
Continuous output current per channel	25A
Maximum PWM frequency	21.77 kHz
Motor Channels	1
Control Interface	USB; non-inverted TTL serial; RC servo pulses; analog voltage

PG27 Planetary Gearbox with RS775 Motor and Encoder

Figure 19: PG27 Planetary Gearbox w/ RS775 Motor and Encoder

Table 8 – PG27 Planetary Gearbox w/ RS775 Motor and Encoder Specifications

General	Technical Specifications
Weight	1.6 lbs.
Gearbox Reduction	26.9:1
Voltage	12 V DC
No Load Current	0.6 A
Stall Torque	6.3 ft-lbf
Stall Current	22 A

Table 9 – Encoder Specifications

General	Technical Specifications
Pulses per revolution	7
Operating voltage	5 V

Xbee 802.15.4 Module

Figure 20: Xbee 802.15.4 Module

Table 10 – Xbee 802.15.4 Module Specifications

General	Technical Specifications
Operating Frequency	2.4 GHz
Range	300 ft.
Transmit Current	45mA
Receive Current	50mA
Operating Voltage	3.3V
Data Rate	250 kbps
Receiver Sensitivity	-92 dBm

4.4.3 Operation Instructions

- **Start – Up Instructions**

In preparing for driving, some preliminary checks must be done to ensure the vehicle can move in a safe fashion. These checks involve doing a visual and manual inspection of all components. The frame must be free of defects such as holes, cracks, and erosion of materials that could limit the functionality of the vehicle. The two front tires must be spun by hand to ensure full free rotational status of the motors. Wiring from the motors and encoders must be traced to their initial point to confirm all connections are properly made and that there are not faulty wires that will short circuit or cause any damage to other components. If any of these occur, wires must be properly disconnected and replace prior to operation. All battery sources must be inspected to ensure they not only contain a full charge; but they also do not have any corrosion due to excess discharge. The safety light must be tested to certify full functionality as well. Following the above procedure, a battery source must be connected to the motor controllers to supply power to the motors, microprocessors and the cooling fan within the electronic box. At this point, all necessary components will have been assembled. After assembly, the vehicle is now ready to be turned on. A solid indicator light will used to verify the vehicle is on. All systems within the vehicle must now be booted and tested to verify that each sensor is receiving power from their respective microprocessor and receiving and transmitted accurate data. Once all systems have checked out, it is now time to operate the vehicle.

- **Autonomous Mode Instructions**

The vehicle will remain stationary until the autonomous mode is triggered via push button. Only then will the light go from solid to flashing. While in this mode the vehicle will be moving hands free; the sensors will help to maneuver the vehicle around objects and detect lane patterns.

- **Shutdown Instructions**

The vehicle can be taken out of autonomous mode two ways: mechanical emergency stop or wireless emergency stop. As soon as the vehicle comes out of autonomous mode the light will go back to solid. The mechanical emergency stop is a red push button located on the vehicle that will bring the vehicle to a quick and complete stop. On the other hand the wireless emergency stop, which will be held by the judges, once activated will send a signal to motor controller that will completely stop the vehicle as well. After the vehicle is stopped, all batteries must be disconnected and stored in the temperature regulated area for immediate charging. This is detrimental for the lithium ion polymer to prolong the usage of these batteries. Any systems changes must be made after disconnection of batteries to avoid short-circuiting components.

4.4.5 Troubleshooting

A number of problems can be encountered while operating this vehicle, which include but are not limited to:

- **Sensors not receiving data**

  1. Check connections to microprocessors

    a. Unplug and re-plug wires to microprocessors
        i. Re-ground all wires
        ii. Plug wires into different input and output ports
    b. If the sensor is plugged into a USB hub, unplug the hub and then plug it in again.
        i. Connect the sensor to another port on the microprocessor
        ii. Plug the hub into a different USB port on the same computer.
        iii. Make sure that a powered hub is being used that is appropriate for the device.
2. Check the power
    a. Make sure the correct amount of power is supplied to the device. For information about proper power supply, see the documentation that was included with the device.
3. Reset the power to the device
    a. If the device has a power switch, turn the device off.
    b. If the device has removable batteries, remove the batteries and reinstall them. Make sure that they are positioned correctly.
    c. If the device has a power switch, turn the device on.

- **Vehicle not turning on**

1. Check that the batteries are fully charged
    a. Make sure the battery has a charge that will power the vehicle. See specifications for components to ensure correct voltage and current outputs

******Caution: Do not over charge the battery******

2. Check battery connections
    a. Check to be sure the battery connector is plugged tightly into the motor drivers. Replace wiring connections if necessary.
3. Check electrical system
    a. Exposure to water, moisture, and dirt can damage or corrode the vehicles electrical system.
4. Replace battery
    a. If battery is old and will not accept full charge.

- **Vehicle not moving**

1. Check front motors
    a. The vehicle is equipped with two front motors, make sure each motor is properly connected to their respective motor driver.
2. Check for overloading
    a. Do not exceed the necessary weight limit for the vehicle to strain motors.

- **Wireless signal lost for the emergency stop**

1. Check the connection between receiver and transmitter
    a. Make sure that is no interference between the access points.
    b. Clear any object from the path of the transmitter.
2. Check to see that all local and remote setting are enabled
    a. Make sure all remote and local settings are established.
3. Check to see if the network is in the proper range.
    a. Make sure both modules are within the properly detection range of no greater than 90m indoor/outdoor.
4. Check to ensure all data packets from were successfully delivered.
    a. Make sure API operation mode is enabled to ensure packets are sent as a whole from one module to the other.
    b. Each packet provides destination information, network diagnoses and a frame id for monitoring.
5. Refresh the wireless connections
    a. Re-establish a wireless link between modules either manually or automatically
    b. Reset to default values.

- **Vehicle behaving erratically**

1. Immediately stop the vehicle
2. Check all electrical system components
3. Re-calibrate PD control values

- **Image Processing**

1. If the simulation runs but collects incorrect data, then the algorithm in the simulation needs to be adjusted
2. If the data collected is accurate, and there is still an issue
    a. ZED is unresponsive, needs to be replaced
    b. ZED is responsive, then the data cannot be visualized
        i. Use PCL library to construct a map step by step to spot anomalies

- **Other difficulties**

For all other problems, please refer to the product guides and specifications or any other help guides. The internet provides a plethora of forums that will allow for easy troubleshooting of devices.

4.4.5 Regular Maintenance

The design of the autonomous ground vehicle incorporates both motion components as well as electrical components. As outlined in the operation section, start-up and shutdown instructions should be followed both pre and post operation of the vehicle to avoid damage or injury. The motors and battery are vital pieces to the successful operation of the vehicle and should be regularly checked. As long as maintenance is done efficiently and properly, the lifespan of the direct current motors will be favorable. It is recommended wipe off dust, dirt and oils monthly and avoid wet conditions that could cause them to rust. A noise and vibration inspection should be conducted monthly to ensure no electrical or mechanical imbalances exist. The lithium ion polymer batteries selected have considerably low discharge, which increases the shelf life or idle time of them. The batteries require delicate care to guarantee the maximum usage before replacement. Overcharging, misuse, and bad storage can cause the lifespan to decrease in the batteries and reduced capacity. It is recommended to keep them clean and dry, out of contact with random metal objects and at a safe, non-extreme temperature. If replacement is necessary, it is recommended to cycle the new batteries a few times to help recover any lost capacity while in storage.

4.4.6 Spare Parts

Safely operating the vehicle is essential to minimizing the need for spare parts, however batteries recommended to have as a spare part because there is higher risks of these being damaged and having a need for replacement. Spare wiring cables are also recommended to avoid connection lost and short-circuiting.

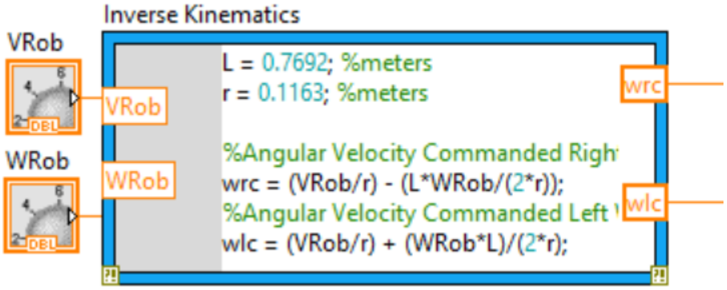
5. Design Experiment

5.1 Setup

This experiment was performed using NI MyRio, motor controller, LabView and Pololu Simple Motor Control Center. This experiment was done in order to integrate the inverse kinematic model to the Proportional – Derivative (PD) gain control of the AGV so as to fine tune its closed loop speed control.

The inverse kinematics model in a robot helps to control the robot to reach a given speed configuration in a closed loop speed control. A differential drive robot imposes what are called non-holonomic constraints on establishing its position. A good example of this is that, such robot will not be able to move laterally to its axle. Therefore, for the robot to be able to move directly sidewise, Inverse kinematics is employed into the configuration, thereby motivating a strategy of moving the robot in a straight line, then rotating for a turn in place, and then moving straight again. The equation below represents the inverse kinematic model in matrix form which was used for configuring the right and left wheels' angular velocity ($\omega_{1,2}$) as a function of the overall robot linear velocity (v_R), angular velocity (ω), the wheel radius (r) and distance (L) between the two wheels.

$$\begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{r} & \frac{-L}{2r} \\ \frac{1}{r} & \frac{L}{2r} \end{bmatrix} \begin{bmatrix} v_R \\ \omega \end{bmatrix}$$



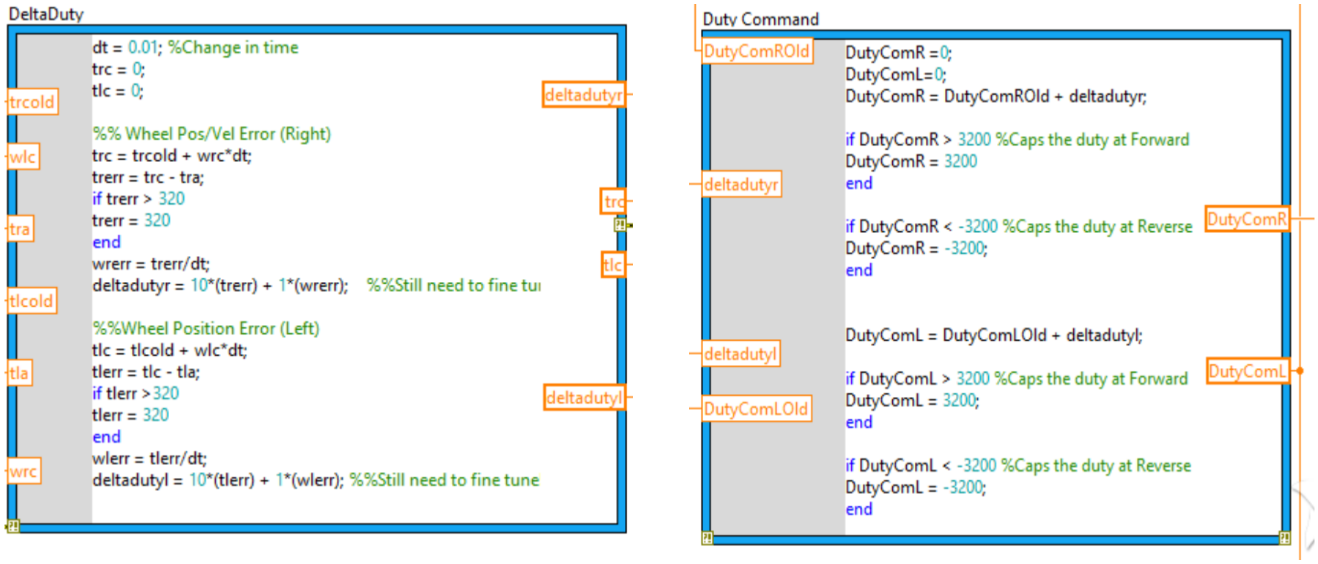
```
L = 0.7692; %meters
r = 0.1163; %meters

%Angular Velocity Commanded Righ
wrc = (VRob/r) - (L*WRob/(2*r));
%Angular Velocity Commanded Left
wlc = (VRob/r) + (WRob*L)/(2*r);
```

Figure 21: Inverse kinematics in LabView

Figure 21 above is the inverse kinematics coding written in MATLAB and implemented in LabView to determine the angular velocity at which each of the wheel is supposed to move in order for the robot to turn right or left. The output from the inverse kinematic model which are the angular velocities of the right and left wheel commanded, wrc and wlc respectively, is then plugged into the change in the duty cycle as shown in Figure 22 below.

Change in duty cycle which is termed "Delta duty" is an error function which helps to adjust the actual robot angular velocity to the commanded duty cycle. If the actual robot velocity shoots below the commanded duty cycle then delta duty, which is the error difference adds to it, so that the actual robot velocity can correspond to the duty commanded and vice versa. Delta duty is determined by adding the product of wrc and wlc from inverse kinematics and change in time (dt) to the previous value of the postion of the wheels, which is trcold for the right wheel and tlcold for the left wheel. The delta duty function still needs to be fine tuned. The output from delta duty from the right (deltadutyr) and left (deltadutyl) wheel is then plugged into the duty command. The duty command as shown in Figure 22 below helps to move the right and left wheels of robot at a given angular velocity. The duty command ranges from negative 3200 to positive 3200.



```
dt = 0.01; %Change in time
trc = 0;
tlc = 0;

%% Wheel Pos/Vel Error (Right)
trc = trcold + wrc*dt;
trerr = trc - tra;
if trerr > 320
trerr = 320
end
wrerr = trerr/dt;
deltadutyr = 10*(trerr) + 1*(wrerr);    %%Still need to fine tu

%%Wheel Position Error (Left)
tlc = tlcold + wlc*dt;
tlerr = tlc - tla;
if tlerr >320
tlerr = 320
end
wlerr = tlerr/dt;
deltadutyl = 10*(tlerr) + 1*(wlerr); %%Still need to fine tune
```

```
DutyComR =0;
DutyComL=0;
DutyComR = DutyComROld + deltadutyr;

if DutyComR > 3200 %Caps the duty at Forward
DutyComR = 3200
end

if DutyComR < -3200 %Caps the duty at Reverse
DutyComR = -3200;
end


DutyComL = DutyComLOld + deltadutyl;

if DutyComL > 3200 %Caps the duty at Forward
DutyComL = 3200;
end

if DutyComL < -3200 %Caps the duty at Reverse
DutyComL = -3200;
end
```

Figure 22: DeltaDuty (left) and Duty Command (right) functions in LabView

5.2 Results

Firstly, the velocity knobs shown in Figures 23 below ranges from negative 4 to positive 4, which also corresponds to the duty command that ranges from negative 3200 to positive 3200 shown in Figure 22 above. From the results obtained during the experiments, it was observed that when the velocity knob is set on negative 4, the duty command chart indicates a corresponding amplitude of negative 3200. The same thing was observed when the velocity knob is set on positive 4, the duty command chart indicates a corresponding amplitude of positive 3200.

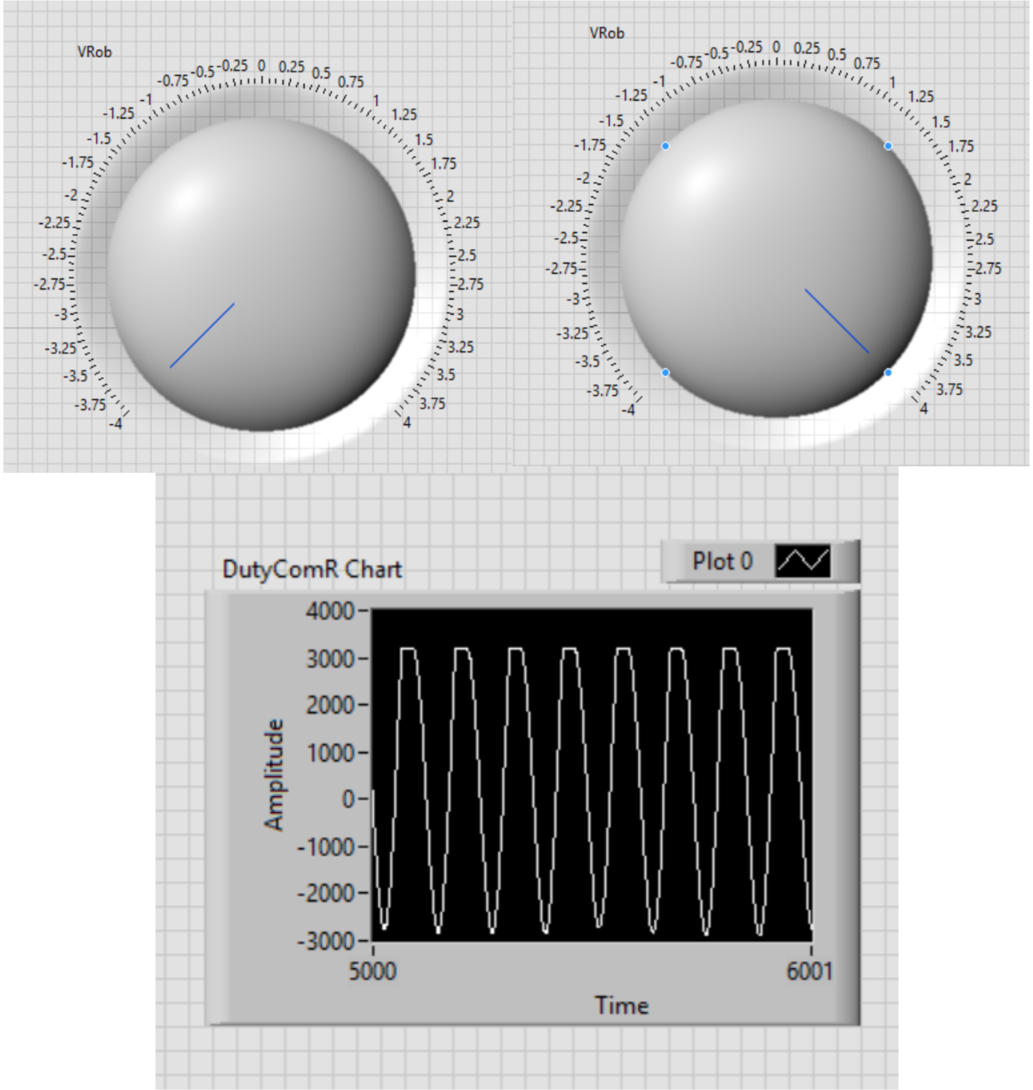


Figure 23: Commanded Speed (top) and resulting duty command (bottom)

6. Environmental, Safety, and Ethics Considerations

The autonomous ground vehicle's power is supplied from an on-board power source. The power source is not to come from any form of combustion engine as to not emit any harmful pollutants into the environment. Instead power is supplied by Lithium Polymer rechargeable batteries that provide the largest energy density for weight, which in turn produce less waste than non-rechargeable batteries since the batteries can simply be reused instead of thrown away. As well, they use less energy because recharging batteries with a battery charger is more energy efficient than the cost and energy of making new batteries. The vehicle is limited to a maximum of 5 miles per hour, which would cause minimal structural and environmental damage in the event of a collision.

The AGV also offers an on-board and wireless emergency push stop feature to ensure safety to the AGV's immediate surroundings. Since the navigation is fully autonomous, and the technology used is not unsusceptible to malfunctions, the vehicle has a hardware based emergency stop in case the vehicle goes off track, or an object that the various safety censors, such as pixy cameras and the LIDAR, cannot detect comes into the AGV's path.

7. Project Management

7.1 Schedule

The original schedule had Team 22 finishing the project just before May. Since a design process is not perfect the first time through there were set backs. The initial gantt chart can be seen in Appendix A as Figure A-1. It only covered the first semester of the project but had the team begin coding for speed control and obstacle detection on January 2, 2016. In Figure A-2, the current gantt chart shows that this did not actually did not happen until a month later on February 1, 2016. This in turn caused the entire project to be delayed by one month.

7.2 Resources

The most readily available resources that were used were the machine shop and the mobile robotics lab at the FAMU/FSU College of Engineering. Since one member of Team 22 works in the machine shop, it was easy to manufacture the prototype frame. The mobile robotics lab allowed the team to familiarize themselves with computer equipment and develop a pseudocode as a base for future development. The FabLab, which is located in Melbourne, FL, was utilized by the FIT team. They had access to a machine shop similar to the one at the CoE as well as a 3D printer which was used to create mounts for the electronics in the electronic compartment.

7.3 Procurement

The funding for this project was given by the Florida Space Grant Consortium and was $3000. After the all purchases were made, the final balance came out to be $1193.15, which is 40%. Figure 12 shows how the budget was spent in the form of a pie chart. The biggest purchase, which takes up 20% of the budget, was the battery. For a more detailed budget breakdown, refer to Figure 12.

7.4 Communications

Since this was a collaborative effort between the FAMU/FSU College of Engineering and the Florida Institute of Technology, communicating was crucial in making progress. Initially communication was done via email between the teams. Once the individual teams were familiarized with themselves, a video or teleconference was conducted once every two weeks to update each other on their progress. Towards the end of the project, these meetings became more frequent and happened once a week. Eventually a face to face meeting of the two teams was planned. Three members from the CoE travelled to FIT and worked directly with the FIT team.

As for meeting with the advisor, Team 22 tried to meet with Dr. Gupta at least once a week. Coordinating a meeting time that fit everyone's schedule proved to be difficult. The solution was to have a meeting time where the majority of the team could be present and then relay information to the other members. On weeks were a conference call was held with FIT, Dr. Gupta was present and depending on the progress, a secondary meeting was scheduled if there was a task that needed to be completed and reevaluated later.

8. Conclusion

This project was started from scratch with the idea in mind that having a team from the FAMU/FSU College of Engineering and the Florida Institute of Technology could effectively work on the same project while remaining in separate locations. This would give the members the real world experience of a design team in industry. While a major portion of this project revolved around communicating ideas, the progress that was made will lay a solid building block for future teams to carry on with. Future teams will have a prototype frame to test with and since it is made from wood, it is easy to machine to their desired use. The PD speed control will be easy to transfer to a new processor if necessary thanks to the pseudocode developed as well.

If this project continues to be a collaboration with the Florida Institute of Technology, it is recommended that at least two trips per semester are planned. The face to face meetings between the teams was very beneficial and it allows the team as a whole to unify instead of hiding behind a screen. Another recommendation is to talk to your advisor on a weekly basis. This meeting should be as a team at least every two weeks but individually each member should talk to the team's advisor once a week. As intimidating as some advisor's may seem, they are there to help and they will notice effort if effort is put forth. It is important to learn how to take criticism as well. Being wrong once does not mean the entire project is a failure, simply correct the mistake on your own or ask for help.

Looking back at this project, it would have been very beneficial if the FIT team had a class similar to the Senior Design course because they had no deadlines to follow. Their time scale and urgency was a tad more relaxed than the CoE's. Even then, Team 22 could have pushed them a little harder to finalize decisions on components. Another big problem that should have been remedied at the start is team communication. The CoE team constantly struggled with talking to each other and communicating ideas.

References

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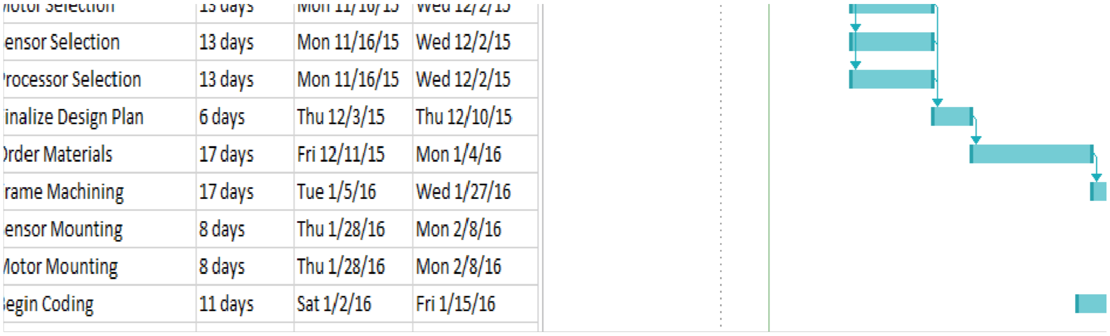
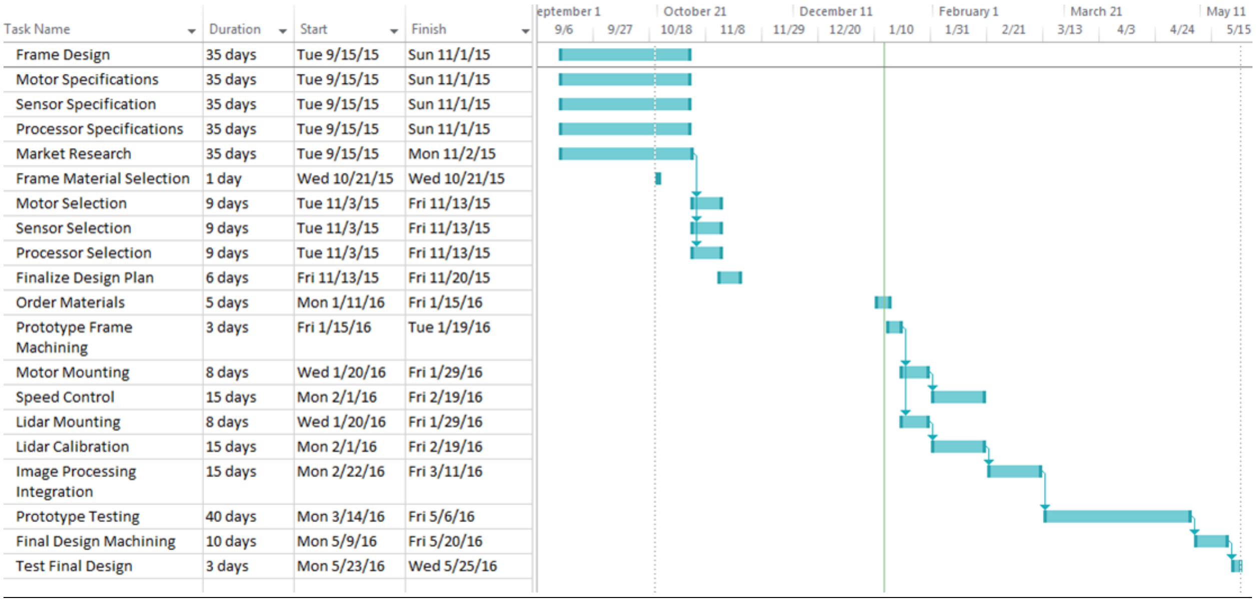
Appendix A



lotor Selection	13 days	Mon 11/16/15	Wed 12/2/15
ensor Selection	13 days	Mon 11/16/15	Wed 12/2/15
rocessor Selection	13 days	Mon 11/16/15	Wed 12/2/15
inalize Design Plan	6 days	Thu 12/3/15	Thu 12/10/15
rder Materials	17 days	Fri 12/11/15	Mon 1/4/16
rame Machining	17 days	Tue 1/5/16	Wed 1/27/16
ensor Mounting	8 days	Thu 1/28/16	Mon 2/8/16
lotor Mounting	8 days	Thu 1/28/16	Mon 2/8/16
egin Coding	11 days	Sat 1/2/16	Fri 1/15/16

Figure A-1: Initial Gantt Chart



Task Name	Duration	Start	Finish
Frame Design	35 days	Tue 9/15/15	Sun 11/1/15
Motor Specifications	35 days	Tue 9/15/15	Sun 11/1/15
Sensor Specification	35 days	Tue 9/15/15	Sun 11/1/15
Processor Specifications	35 days	Tue 9/15/15	Sun 11/1/15
Market Research	35 days	Tue 9/15/15	Mon 11/2/15
Frame Material Selection	1 day	Wed 10/21/15	Wed 10/21/15
Motor Selection	9 days	Tue 11/3/15	Fri 11/13/15
Sensor Selection	9 days	Tue 11/3/15	Fri 11/13/15
Processor Selection	9 days	Tue 11/3/15	Fri 11/13/15
Finalize Design Plan	6 days	Fri 11/13/15	Fri 11/20/15
Order Materials	5 days	Mon 1/11/16	Fri 1/15/16
Prototype Frame Machining	3 days	Fri 1/15/16	Tue 1/19/16
Motor Mounting	8 days	Wed 1/20/16	Fri 1/29/16
Speed Control	15 days	Mon 2/1/16	Fri 2/19/16
Lidar Mounting	8 days	Wed 1/20/16	Fri 1/29/16
Lidar Calibration	15 days	Mon 2/1/16	Fri 2/19/16
Image Processing Integration	15 days	Mon 2/22/16	Fri 3/11/16
Prototype Testing	40 days	Mon 3/14/16	Fri 5/6/16
Final Design Machining	10 days	Mon 5/9/16	Fri 5/20/16
Test Final Design	3 days	Mon 5/23/16	Wed 5/25/16

Figure A-2: Revised Gantt Chart