Development of an Autonomous Ground Vehicle

Design in Manufacturing, Reliability, and Economics

Team 22

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Submitted To: Dr. Gupta, Senior Design Coordinator

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Table of Contents

Table of Figures

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Introduction

The goal of Team 22's senior design project is to build an autonomous ground vehicle (AGV) that would successfully compete in the Intelligent Ground Vehicle Competition (IGVC). In order for the final AGV to be competitive with other teams, design for manufacturing, reliability, and economics were taken into consideration. If proper manufacturing techniques are implemented in the design then the AGV's cost and quality will be greatly improved. Some important manufacturing techniques are: reducing vehicle parts, using standardized components, ease of fabrication, and the minimization of assemble steps. Along with manufacturing comes the reliability of the AGV. The vehicle must be able to withstand numerous runs and even small collisions since it will be travelling at a relatively fast speed. Designing for economics is also a critical factor in the design process. Staying within budget and keeping the AGV cost to a minimum will help make the vehicle more financially competitive with other vehicles. Team 22 has designed a vehicle in which all of these design aspects have played a major role.

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 our advisor, Dr. Gupta, we fabricated a prototype frame for the AGV from plywood and 2x4 planks that were made available to us by our advisor. 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. And to provide a floor to our frame for us to mount to a sheet of 1/8 inch plywood was attached to the bottom. In total the frame took approximately one hour to manufacture. The frame assembly Solidworks model may be seen below in Figure 1a as well as in an exploded view in Figure 1b.

Figure 1a: Solidworks rendering of the 2x4 pine frame for the AGV

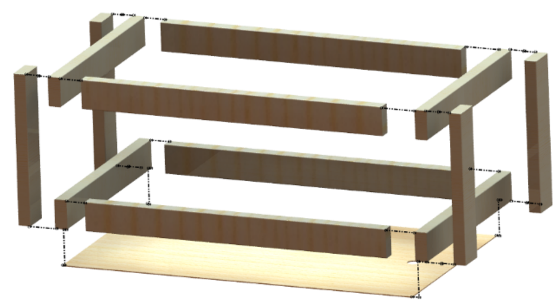


Figure 1b: Exploded view of the AGV frame

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 can be seen below in Figure 2a and the exploded view of the assembly can be seen in Figure 2b.

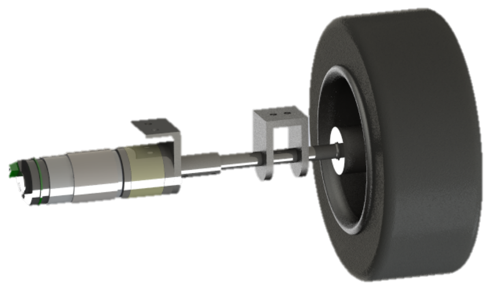


Figure 2a: Solidworks rendering of the drivetrain for the AGV

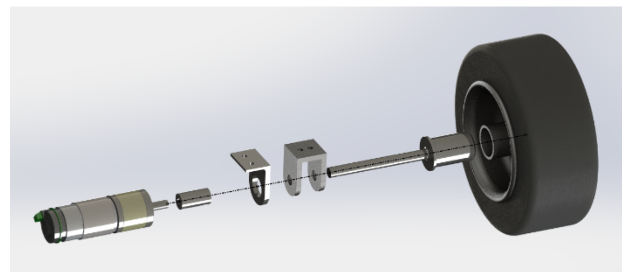


Figure 2b: Exploded assembly of the drivetrain for the AGV

After the drivetrain was manufactured and assembled the electronics housing 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 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. The 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 box took approximately two hours to fabricate including the time it took to prep the files for the laser cutter and the time it took for the glue to set. The electronics box assembly can be seen in Figure 3a and the exploded assembly can be seen in Figure 3b.

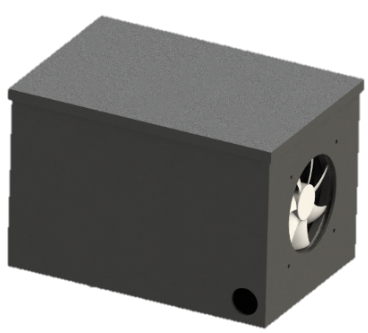
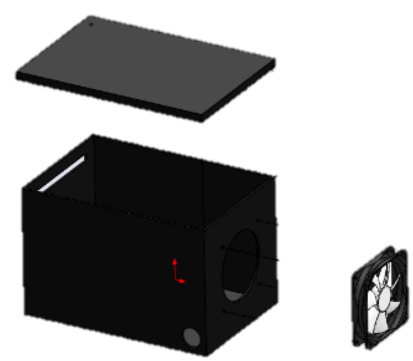
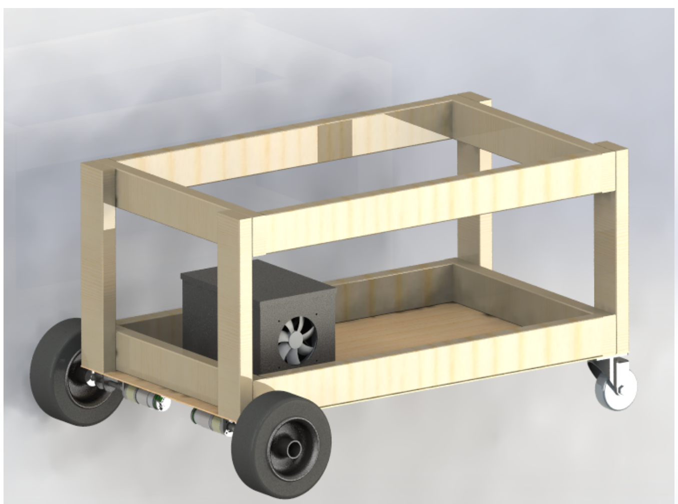


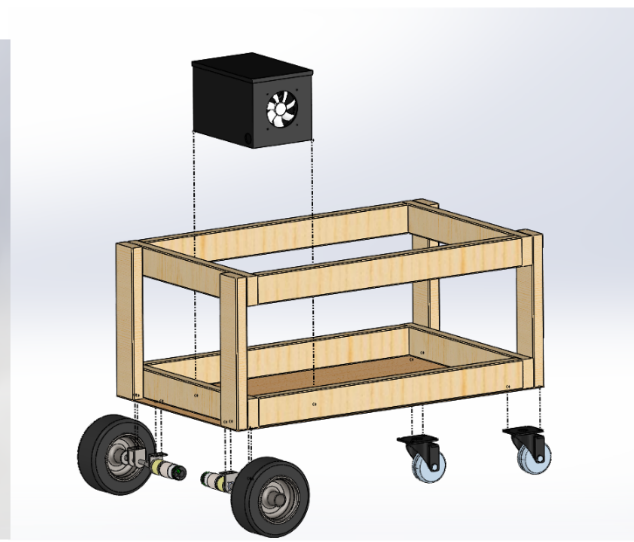
Figure 3a: Solidworks rendering the electronics box assembly for the AGV



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 Autonomous Ground Vehicle 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 4a is a rendering of the mounting of all the sub-systems and the

Figure 3b: Exploded assembly of the electronics box for the AGV





caster wheels to the frame and Figure 4b is an exploded view of the overall assembly.

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

Figure 4a: Solidworks rendering of the overall assembly of the AGV

Figure 4b: Exploded assembly of the AGV

can be seen in Figure A1 in Appendix A. 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.

Economics

The estimated cost of the AGV is $1878.35. This is an estimated value because some of the components were donated to us from the Department of Mechanical Engineering. These components are the NI MyRio, the wood for the frame, and the RPLidar. Their cost was estimated using their listed price from online sellers. Figure 5 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 would be the RPLidar taking up 13% of the budget. This component will allow the vehicle to detect and avoid obstacles which is a requirement for competition. The motors were the 3rd most costly component of the budget acquiring 9%. With 37% of the budget remaining, it is possible to adjust any components with financial comfortability.

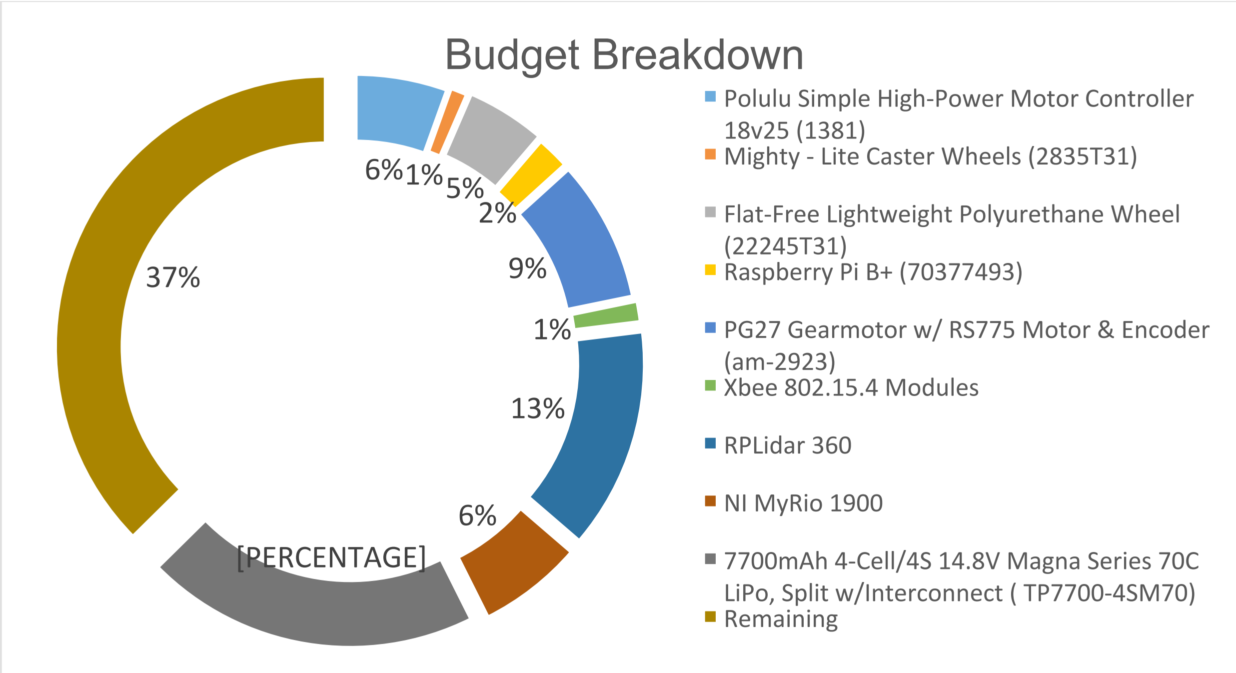


Figure 5: Breakdown of $3000 budget

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 [1]. In 2014 Oakland University, the host university, won with a vehicle cost of $11,049 which was substantially higher than other competitors [2]. The 2013 winner was California State University Northridge and they won with a vehicle that costs $4,279 [3]. Team 22's AGV is most comparible to the University of New South Wales AGV with a price difference of $601.65.

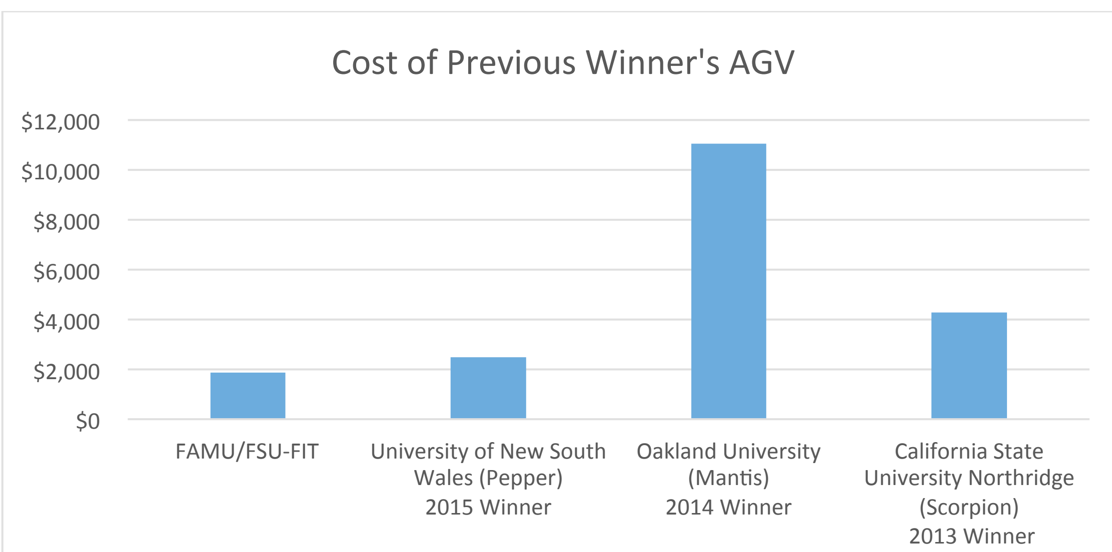


Figure 5: Previous Winner's Cost Comparison

Conclusion

Team 22 was tasked with designing and building an autonomous ground vehicle from scratch in order to compete in the Intelligent Ground Vehicle Competition. While keeping in mind the design requirements, Team 22 utilized the design for manufacture, reliability, and economics. This ensured that the AGV would be easy to assemble and fix if necessary due to the simplistic, yet robust manufacturing process. Keeping components in proper working conditions allowed the AGV to run numerous times without failure. Selecting the optimal components for the AGV enabled Team 22 to design an economically affordable AGV.

References

[1] “IGVC Results 2015.” *IGVC.* Web. 29 Mar. 2016. http://www.igvc.org/results/r2015.pdf

[2] “IGVC Results 2014.” *IGVC.* Web. 29 Mar. 2016. http://www.igvc.org/results/r2014.pdf

[3] “IGVC Results 2013.” *IGVC.* Web. 29 Mar. 2016. http://www.igvc.org/results/r2013.pdf

Appendix A

				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

Figure A1: FMEA of Major Components