# Goat Cart
# The Autonomous Golf Cart

Major Qualifying Project Report
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# Abstract

The MQP improved on the computer vision and object detection systems, installed a server-controlled throttle, and added safety features and kill switches, for an existing autonomous vehicle based on a 1995 golf cart. Our team upgraded existing power systems to make the cart self-sustaining, even when in motion. The team upgraded wiring gauges and used terminals, shrink wrap, and solder to secure connections between components. All additions were properly mounted for safety and ease of access. This platform is prepared for future teams to develop software, add better control on steering and braking, and use the autonomous vehicle for various user applications.

# Acknowledgements

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Without all of your contributions, this project would not have been possible.
We sincerely thank all of you.
-Goat Cart, 2016-2017

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# List of Acronyms

3D - Three-Dimensional (as in 3D-Printer)
ABS - Acrylonitrile Butadiene Styrene (Thermoplastic Polymer)
AGM - Absorbed Glass Mat (Battery Type)
ATX - Advanced Technology Extended Motherboard
CAD - Computer-aided design
CNAS - Collaboratively Navigating Autonomous Systems
CNC - Computer Numerical Control
DARPA - Defense Advanced Research Projects Agency
Digipot – Digital Potentiometer
EBS - Electronic Braking System
ECU - Electronic control unit
EPC - Encoder Products Company
GPS - Global Positioning System
IC - Integrated Circuit
LIDAR - Light image detection and ranging
MATLAB - Matrix Laboratory
M3 - Format for stating Metric Size 3 (as in Bolts or Hex Nuts)
MDF - Medium Density Fiberboard
MPH - Miles per Hour
MQP - Major Qualifying Project
NAPA - National Automotive Parts Association
PID - Proportional-Integral-Derivative
PLA - Polylactic Acid (Plastic)
PWM - Pulse-Width Modulation
ROS - Robot Operating System
RTP - Real-time Transport Protocol
SAE - Society of Automotive Engineers
USB - Universal Serial Bus
WPI - Worcester Polytechnic Institute

# 1 Introduction

## 1.1 Motivation

Autonomous vehicles have extensively discussed in recent years, both positively and negatively. When we started on the project, the U.S. Department of Transportation released their first ever policy on automated vehicles [1]. With the first ever recognition from the White House on autonomous vehicles, we found that their motivation aligned with ours. The US Department of Transportation (DOT) Federal Automated Vehicles Policy highlights two main motivations for self-driving vehicles' safety and innovation.

In regards to safety of autonomous vehicles, 94 percent of crashes can be tied to a human error [2]. An important aspect of autonomous vehicles is taking away human choices and room for error since everything would be computer based. This would significantly increase safety on roads as autonomous vehicles could benefit from data and experience drawn from thousands of other vehicles in order to make what decisions.

With respect to innovation, autonomous vehicles could change the way people look at transportation as a whole. People with disabilities, the elderly, or those who just don't enjoy driving could now have access to a vehicle that transports them places. Cities could look at the ways they are providing public transportation and look at how to automate that as well. Autonomous vehicles could also potentially reduce air pollution and save energy if efficiency and green saving measures are taken into consideration. The possibilities of autonomous vehicles are endless.

As we took on this project, we knew that it would be the fourth iteration of work that previous MQPs have built upon. Each year, teams have gone through struggles as well as progress with respect to the cart. Being able to bring the cart into a state where future teams would not struggle based upon previous work left behind was a big motivation for us as a team.

## 1.2 Issues

The MQP team this year focused on a list of problems in order to help the project continue to grow towards becoming an autonomous vehicle. The first problem we focused on was the power system since the cart had yet to be self-sustaining, meaning that in order to fully function it had to be plugged into an outlet. Next, we wanted to tackle the issue of safety. The cart wasn't designed with any kill switches in case a problem arose while on the move. The cart had some implementation of autonomous components but they require to be completely reworked whether for safety or lack of correct components. The throttle and braking Arduinos were both removed when last year's team left, making both those components unusable. The steering required safety features in order to prevent over turning, and a better code for obtaining greater control of the steering. There was also the issue of not having any sensors available for object detection on the cart, preventing it to from steering away from obstacles. The documentation for the work done in previous years was poor and also made false claims about the state of the cart. The code provided is uncommented, hard to follow, and issues commands to the components on the cart. The components were also poorly mounted, resulting in problems when the cart was being moved. The last issue is the poor wiring between components and batteries. Most wires were the incorrect gauge, improper mounting terminals were used, and parts were exposed, unprotected, and not secured in place.

## 1.3 Report Organization

Our report is structured into eight chapters. If this report is to be read in its entirety, you will get an insight on how this project progressed from start to finish during the 2016-2017 school year. After the introduction, we go into the background of what exactly makes a vehicle autonomous, what have the previous three year MQPs done to the cart, as well as what condition the cart was in when we received in. This sets up us being able to talk about our proposed approach next where we explain what we would want to do to the cart. In Chapter 4, we discussed how we took our proposed approach and made it into a reality, as well as what aspects stayed the same from our proposed, what aspects got added, and what aspects were removed from our proposed approach. From there it leads to the second half of the report which is the results that we gained from our project as well as the conclusion for our project. In the conclusion, we lay out future work for future teams and what we believe should be the next steps for this project. We end the report with references used throughout as well as appendices referenced during the paper.

## 1.4 Project Contributions

This project's ultimate goal is to get the Goat Cart into a roadworthy condition, where it can move forward on its own, detect basic obstacles, and be equipped with safety features. We wanted to be able to enhance the cart such that future teams would not have to reverse engineer any aspects of it, and they also would not need to get rid of any features added onto the cart.

The contributions to this project include:

- Implementing traffic cone detection for vision

- Creating a series power system
- Creating a parallel power system
- Replacing the gas pedal with a digital potentiometer
- Installing two physical and one wireless kill switch
- Adding music-activated, user-programmable LEDs

The outcomes of this project contribute to the future work of the Goat Cart MQP. Our work on the golf cart over the past year prepares future teams the resources and materials necessary to be able to pick up the project and continue on the work to further advance the Goat Cart.

# 2 Background

## 2.1 Levels of Autonomy

The term “autonomous vehicle” carries a number of commonplace definitions, depending on what group is in charge of their development, manufacture, or deployment. A autonomy classification system was published in 2014 by SAE International [1], an automotive standardization organization. This standard was adopted by the US in 2016. The SAE International automated vehicle standard specifies five levels of autonomy, numbered zero through four. An explanation of each level and its defining characteristics is contained in the next few sections.

### 2.1.1 Level 0: No Automation

Level 0 is the lowest level in the standard, and refers to a system where the driver is responsible for every aspect of the driving task. This level may include vehicles where no warning systems are available, or vehicles with passive warning systems like backup cameras or lane-departure alarms. While these two warning system examples are capable of helping the driver analyze their surroundings, they provide no mechanism to “drive” the car itself -- the driver is expected to perform the driving task entirely on their own. This is the cheapest and by far most common level of vehicular autonomy, although this proportion is decreasing as advanced, active safety features become more popular.

### 2.1.2 Level 1: Driver Assistance

The next tier is Level 1, which refers to a system where assisting technologies take charge of specific portions of the driving task. This may include autonomous systems for steering (active lane-drift assist), acceleration (dynamic cruise control), or braking (impact embrace), but with the important caveat that the system must only perform these tasks under well-defined, driver-assisting circumstances. The system still expects that the driver is completing all remaining requirements of the driving task, and that the autonomous systems only act to aid the driver, not make decisions on their own. For example, current self-parking technology has the capability to back into parking spots, pull into parking spots, or parallel park on a busy street.

### 2.1.3 Level 2: Partial Automation

Partial automation is where a vehicle would have multiple components or requirements of the driving experience automated. Dynamic cruise control, as well as anti-line drift assist fall into this category, as proper autonomous operation requires computer control of multiple throttle, braking, or steering subsystems. Automatic braking also serves to provide speed regulation when approaching minimum distances between consecutive cars. While these technologies can be used to self-drive for short distances in unchanging road conditions, it would not fall under recommended operating procedure, as the driver is often required to keep their hands on the steering wheel regardless. The level of inference and reasoning about the surrounding environment, at this stage, is generally insufficient to fully navigate or drive a vehicle autonomously.

### 2.1.4 Level 3: Conditional Automation

Level 3 refers to conditional automation, which implies the autonomous capabilities of the vehicle are sufficiently advanced such that the driver can safely engage in other activities. The vast majority of commercially available automobiles in this tier utilize LIDAR technologies, as opposed to optical, camera-based techniques. LIDAR sensors spin quickly to generate a projected understanding of the surrounding environment, which is a rather complex task due to concerns such as Doppler effects, future environment prediction, and other requirements. However, this additional understanding of the vehicle's operating state allows compliance with right-of-way, obstacle trajectory anticipation, and reaction to unexpected or unpredicted events within a timely manner. Speed limit and street light signs can be observed and properly obeyed, via finely-tuned recognition and categorization algorithms. Given these additional capabilities, the driver can perform reasonable, non-driving activities during standard vehicular operation, with the caveat that they be capable of taking back control in a short time frame.

### 2.1.5 Level 4: High Automation

The final and highest level of autonomy in the standard is Level 4, or high automation. At this stage, the vehicle can drive itself in every capacity without a human driver's interaction or even presence. As of time of writing, this level has not been provided in commercially available vehicles, although some come close, such as Tesla's recent released models. The majority of work in this area is in research and conceptual development, either in non-public staged scenarios or in reasonable everyday traffic conditions. As the technology behind autonomous capabilities continue to improve, however, this capability could become closer to realization and popularity. A saturation point may exist where large decreases in traffic and crash statistics occur due to the growing percentage of cars that incorporate all or some of this technology.

## 2.2 Original State of the Cart

### 2.2.1 Club Car Powerdrive System 48

The version of golf cart used for our MQP is the Club Car Powerdrive System 48, equipped with a continuously variable potentiometer. This cart is broken down into four separate circuits:

- Control circuit

- Speed control circuit
- Power circuit
- The charging circuit

Each of these components will be broken down into more detail in the sections below. Each of the components can also be seen in Figure 1, which displays the electrical schematics of the cart in its original state.

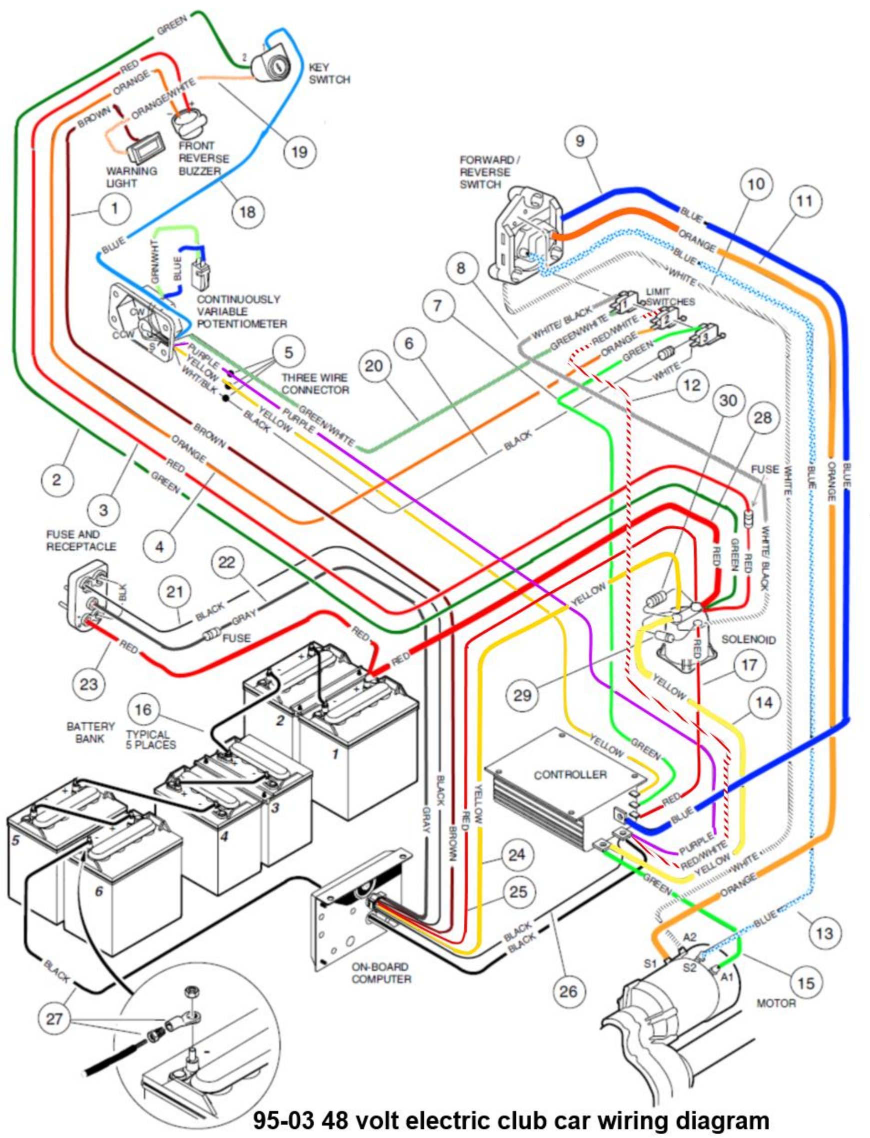


**Figure 1: Wiring Diagram for the Original State of the Golf Cart [4]**

### 2.2.2 The Control Circuit

The control circuit consists of the key switch, forward and reverse anti-arcing limit switch, accelerator limit switch, solenoid, and connecting wires. The key switch is an on off switch for the cart. The forward and reverse anti-arcing limit switch is put in place in order to avoid arcing between the forward and reverse contact. The limit switch closes only when the cart is in forward or reverse and remains open in neutral. When the accelerator is depressed it closes the limit switch completing the circuit when the cart is in the on position and in either forward or reverse. With the circuit complete the solenoid coil is activated and closes the solenoid power contactors and activating the controller.

### 2.2.3 The Speed Control Circuit

The speed controller consists of a solid state three-wire potentiometer. With the cart in forward, the resistance starts at 0 ohms meaning the cart is at rest and can reach up to 4940 ohms which means the pedal is fully depressed and the cart is at full speed. When in reverse, a limit switch is activated in order to half the top speed when backing up.

### 2.2.4 The Power Circuit

The power circuit consists of the solid-state speed controller, solenoid contacts, forward and reverse switch, motor, batteries, and all power wiring. The solid-state speed controller provides and controls the golf cart's acceleration by controlling the voltage input and is activated by the contact within the solenoid. The forward and reverse switch changes the direction of vehicle movement by changing the direction of electrical current through the motor, and thus the direction that the motor turns. The cart is driven by a 48-volt motor that's powered off of six eight volt batteries connected in series.

### 2.2.5 The Charging Circuit

The charge circuit consists of the on-board computer, battery charger, DC charger plug, charger receptacle, receptacle fuse link, and the 8-volt batteries. The on-board computer is to control the battery charger. It monitors the state of the batteries continuously in order to know how much energy has been consumed and controls how much energy is needed to replenish the batteries effectively and safely. The on-board computer is also capable of recording cart diagnostics and indicating when the batteries or charger has encountered a problem. The battery charger, DC charger plug, and charger receptacle are all used in order to recharge the batteries by plugging into an AC wall outlet. The receptacle fuse link is put in place in order to protect the charger and the batteries.

### 2.2.6 Summary

The 48V golf cart uses four separate circuits that make up the electrical components of the golf cart. The control circuit consist of the key switch to turn the cart on and off, the limiting switch in the forward and reserve in order to prevent arcing, and the accelerator that activated the controller. The speed controller circuit that uses a continuous potentiometer to control the cart's speed. The power circuit that controls the voltage from the batteries going into the motor in order to control the acceleration. The charging circuit controls battery usage, recharging the batteries, and protecting the electrical components of the cart. Additional information on the golf cart can be found in the maintenance manual in Sections 20A and 20B of the golf cart maintenance manual [4].

## 2.3 Overview of Previous MQPs

### 2.3.1 Year 2014: Collaboratively Navigating Autonomous Systems

The first iteration of the Goat Cart MQP occurred in the 2013-2014 academic year. The project was started as an idea to get the homogeneous collaboration among autonomous robotic systems. This MQP wanted to make a multi-robot system where each robot shared data among each other to make decisions through various sensors. The system that they wanted to create would include a golf cart and four drones. The golf cart was meant to follow planned paths based upon a user input and avoid obstacles as it navigated. The four drones were to fly to waypoints along the user planned path and identify traffic cones for the golf cart to avoid.

In order to achieve their goals, the team had to first retrofit the golf cart to have the steering, braking, and throttle be accessible by a computer. In order to get the steering accessible by a computer, the team installed a 150lb. linear actuator. Another linear actuator, this time a 110 lb. one was installed for the braking system as well. In order to interface with the brake, a Sabertooth 2x60 Motor Controller was installed as well as the Teensy 3.0, which both are still in place on the cart today. The Sabertooth controls the speed and direction of the braking system and does this by accepting commands from the Teensy which is getting them from the server. For the throttle, this team put in place a potentiometer. They also placed on a switch that would allow the users of the cart to choose between autonomous and manual mode as at the time, that was a desired concept. The completion of how the cart looked after the 2014 year can be seen in Figure 2.

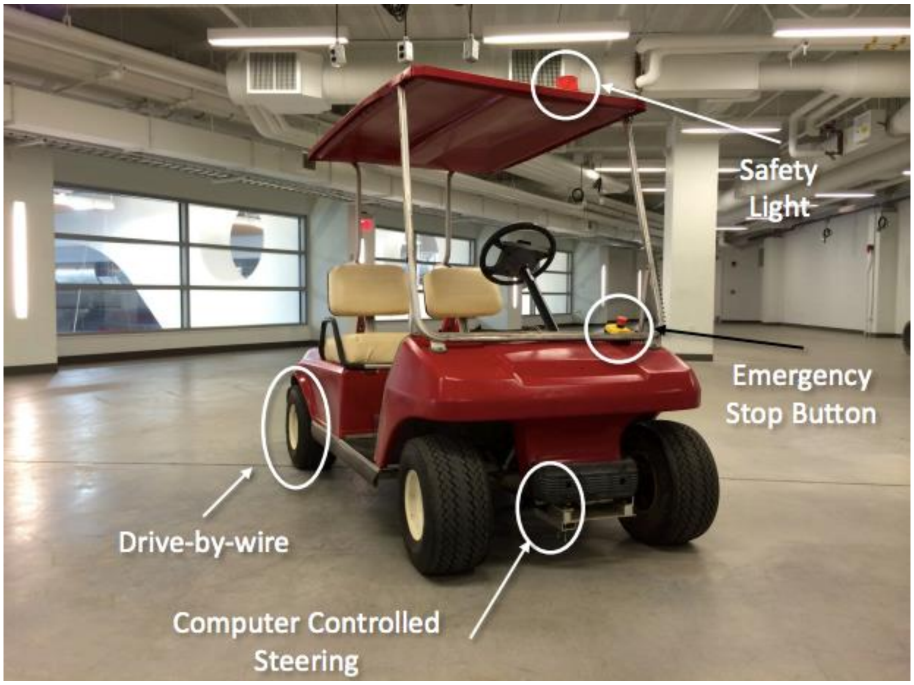


**Figure 2: Golf Cart after 2014 MQP Completion Date [5]**

With software, the team was able to retrieve and send data to and from the drones using ROS (Robot Operating System), a programming language for robotic software applications. Data was also able to be transferred between ROS and MATLAB which allowed for processing and making decisions. The drones were also able to detect cones which were considered hazards for the golf cart.

After the completion of the first year, this team's vision for the future years was to get better drones that are more precise in their flying as that would help get more precise measurements of the path for the cart as well as obstacles encountered. They also would want future teams to improve the steering as at this time frame it took seven seconds for the cart to turn from fully left to fully right which is not applicable in real world situations. In terms of the throttle, they envisioned future teams created a PID loop in the throttle control software so it can take into account the current speed, current throttle position, and desired speed and acceleration in order to make future decisions. Their advice for future teams was to take on smaller pieces of the project at a time as they took on too much in the first year and were not able to complete any of their tasks fully.

### 2.3.2 Year 2015: Robocart: Autonomous Ground Vehicle

The second iteration of this MQP took a different approach from that of the first team. Instead of working together as a team, they split into three different subsections: System Design [6], System

Framework for Machine Vision [8], and Electromechanical Foundations Design [7]. One major change in this year from that of the first is the drones for path planning, starting with the 2015 year and going forward, the scope of the MQP changed to only looking at the golf cart and making the golf cart fully autonomous.

The electromechanical foundations design subsection focused on upgrading the physical cart to meet the system requirements. The team found that the steering installed from the previous team was inadequate as the linear actuators were not mounted properly and they also put an inordinate amount of stress on the system. The linear actuators were also not back-drivable which posed a safety issue if the cart ever needed to be veer away from obstacles. The new automated steering system that was designed would have a steel plate mounted to the dashboard with a motor controlling a steering column. The configuration of this new steering system can be seen below in Figure 3. Along with the automated steering system, a new automated braking system had to be implemented as well. They used a van door motor to pull a bearing along the threaded rod until it collided with a shaft collar that was attached onto the rod. When that happens, the rod is pulled towards the front of the golf cart, which in turn pulled on the brake cables. The manual use of the brake was left in as well for an additional feature. A new feature was also added where the brakes automatically would engage when the cart lost power.

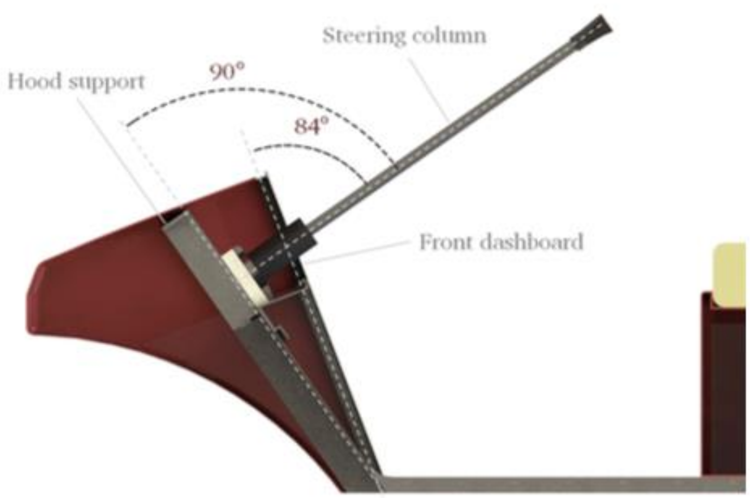


**Figure 3: 2015 Automated Steering System [7]**

The final physical component implemented on the cart in the 2015 year was a Raspberry Pi Mount. This would add extra safety for the protection of the Raspberry Pi's and their cameras that were to be used for vision. The mount that was designed can be seen in Figure 4.

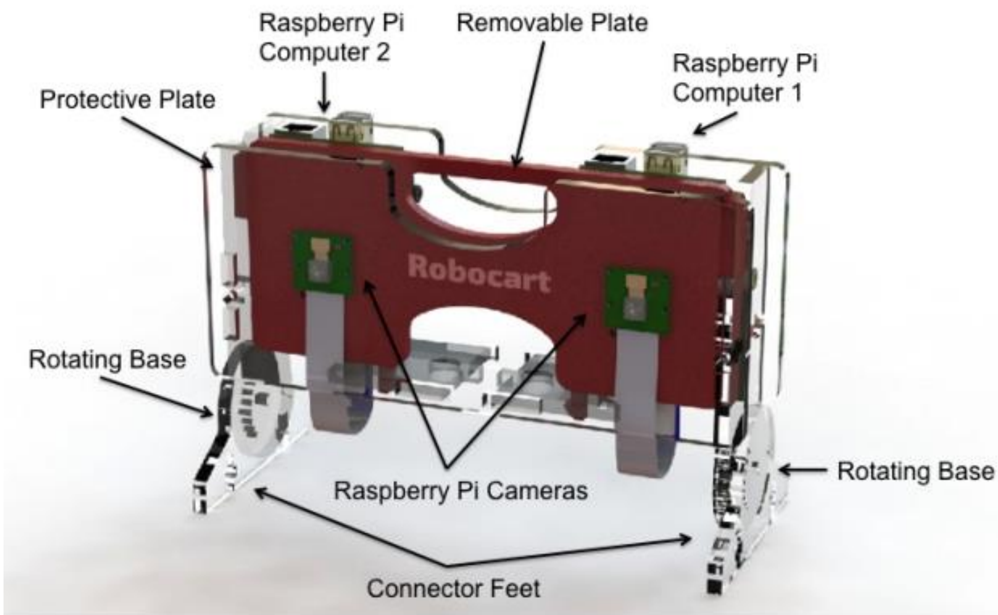


**Figure 4: Machine Vision Mock-up Mount for Golf Cart [8]**

With the protection of the Raspberry Cameras in place, the System Framework for Machine Vision sub team focused on implementing vision to have the cart be autonomous. The design the team worked on was to have a central server receive the image data from the cameras over RTP (Real-time Transport Protocol). A ROS node running on the server relays the RTP video streams to a ROS topic, which both local ROS nodes running on the server and ROS nodes running on other locations of a network that the server is on can subscribe to the ROS topic for video data. Calculations based on the video data were to be made from each ROS node. The code from this year was never actually put onto the golf cart, it was tested using a laptop's webcam. Using a laptop's webcam, the team was able to distinguish between what a road was and what grass, this was done as a proof of concept to show that the method described above could work if implemented.

The final sub team of the 2015 year focused on System Design. They looked at the integration of the components as well as the idea of this project as a MQP. Five critical areas were examined as future steps for this MQP and ways for MQPs to be more focused instead of as broad scope as 2014 and 2015 were. The five recommendations were:

- An MQP focused on power systems
- An MQP focused on usability, safety, and ergonomics
- An MQP focused on path planning and algorithm development
- An MQP focused on developing graphical user interfaces
- An MQP focused on systems engineering, integration, and testing

They believed that by addressing these five areas throughout separate MQPs, each area would get the focus it needed in order to be successful.

### 2.3.3 Year 2016: Autonomous Ground Vehicle Prototype via Steering-, Throttle-, and Brake-by Wire Modules

The main goal of the 2016 team was to obtain control of the three main subsystems of the golf cart: steering, braking, and throttle control systems. They established six main components that would need to be integrated to accomplish this, they are:

- Power system
- Brake-by-wire
- Server
- Throttle
- Steer-by-wire
- Stereoscopic cameras

One of the main issues that the team found was that the batteries from the cart were starting to bulge as well as have corrosion on the terminals, which both are a sign that the battery needs to be replaced. The corrosion and bulging can be seen in Figure 5. The batteries were not original to the 1995 golf cart, but were ones from 2002. The team researched different types of batteries and found that the best type would be Duracell 12V-29HM. Its reserve capacity is 225 mins @ 23 amps and has a capacity of 86.2569Ah. Although this was decided as the best battery for the project, the team decided on buying three Duracell 12V-27DC batteries, and two Duracell 12V-29HM. The 12V-27DC battery has a reserve capacity of 220 mins @ 23 amps and a capacity of 76.6728 Ah. The rationale as to why these amounts were bought was not explained. The battery trays on the cart were rusted as well as had battery acid on them, so the team also built brand new battery trays out of wood that were then installed.


**Figure 5: State of the Batteries in 2016 [9]**

Previously, teams have implemented parts of the project individually but never looked at bringing it together. To start this, the team needed to establish communication between the high-level information processing of the server with the low-level hardware control of each subsystem. The throttle control for the 2016 team is achieved with an Arduino and a DS1803 digital potentiometer. The team decided to recreate the brake mechanism this year and added a custom brake coupler onto it as well as a vinyl-coated steel braided cable. The new braking system installed can be seen in Figure 6.

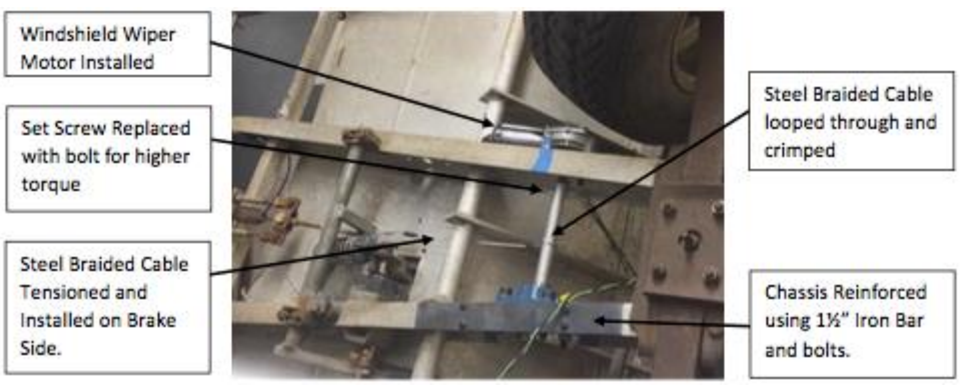


**Figure 6: 2016 Braking System [9]**

In terms of the steering system, the 2016 team found that the steering configuration that was installed by the 2015 team was out of alignment. This made it difficult for the steering as the chain and sprocket were not aligned. The 2016 team decided to just redesign the back plate that was out of alignment. In order to bring the steering, throttle, and braking together they were all tested by using the serve to communicate to each of these 3 subsystems connected to an Arduino.

In 2016, the team also took on tasks they deemed as “Addition Enhancements” to improve both the image and functionality of the golf cart. One of these enhancements was upgrading the outer shell of the cart. The team decided to paint it the official WPI red color. They also decided to add an 80/20 bar on the front of the chassis. This was to add for modular movement of both the raspberry pi cameras and any other components that might need to be added/removed often from the cart easily. This effectively got rid of the previous raspberry pi camera mounts made from previous teams. Along this 80/20 bar they also attached computer monitors that were used during testing. There were 3 monitors that detailed: raw camera data, server information, terminal console, and other valuable information. The final enhancement that was completed in the 2016 year was dealing with the server. In previous years, MQP teams attempted to wirelessly transmit raw data to the server for image processing and computation. Although this did work, the previous teams faced issues with latency and packet loss. So they decided to actually mount the server onto the cart so that is can be connected through ethernet cables. The team bought a rack for the golf cart, then hand built using 80/20 as well as 3D printed parts a hanging system for the server, this rack can be seen in Figure 7. The server would be hanging from the 80/20 from underneath the golf cart. The top of the rack was left empty.

**Figure 7: 2016 MQP Team Server Rack [9]**

This year's team did not focus on any of the software as previous teams had. Instead, there was a graduate student who worked on path planning for his thesis that worked alongside this team in order to accomplish the vision system [8].

At the conclusion of the 2016 year, the team left the golf cart in a state to prepare it for autonomous operation, this can be seen in Figure 8. Leading into the 2017 project year, the 2016 outlined future work for the MQP, this included: further integration between throttle, brakes, and steering control, create a low-level collision avoidance mechanism, as well as development of applications supporting the operation of the autonomous vehicle.

**Figure 8: State of the Cart at the end of 2016 Year**

### 2.3.4 Summary

This project of an autonomous golf cart started back in 2014 as one that had a completely different vision from where the 2016 team left it. The 2014 team created a foundation for outfitting a 1995 golf cart to begin the autonomous process. Although they did not see the cart being fully autonomous and wanted to include the use of drones, they still have parts on the cart that are in use today such as the Sabertooth and Teensy. The 2015 year decided to take the project into three different directions. From 2015, we got the basis of both the throttle and braking system implemented on the cart. The 2016 team decided to create much needed enhancements that were not thought of in the previous years. Such as replacing the batteries, attaching the server onto the cart, as well as perfecting the 2015 braking and steering systems.

## 2.4 Sensors in Autonomous Vehicles

While there are many different sensors that can be used as the "eyes" of autonomous vehicles, some of the most prominent examples are LIDAR, Ultrasonic sensors, and Computer Vision. Each of these has their own strengths and weaknesses.

LIDAR (Light Imaging, Detection, and Ranging), is a technique that uses a laser to measure distance to a target. With LIDAR, a laser is bounced off a remote target. By measuring the differences in laser return times and wavelengths, it is possible to calculate the distance to the hit. Through aiming the laser, it is possible to generate a digital representation of the target. While the representation produced is generally very accurate, there are several disadvantages to LIDAR. Most importantly, with respect to this project, LIDAR is not necessarily safe for use in a busy setting. Since LIDAR uses a laser, it can be dangerous while driving or navigating among people. Additionally, LIDAR uses delicate equipment to function and can be prone to breaking. In order to rapidly scan the surrounding environment, it uses a mirror and gimbal system. Finally, a good LIDAR system can be fairly expensive if you don't find the right system.

Ultrasonic sensors are basically an inaudible version of sonar. They produce a high-frequency "chirp" and measure the response time. Using this, they can determine the distance to a target. One issue with ultrasonic sensors is their low resolution. Since sound spreads as it travels, an ultrasonic sensor would not be capable of providing the same level of detail as other sensors. Overall, an ultrasonic sensor would work best as a proximity sensor, providing a means of automatically stopping the cart if anything got too close.

Unlike the other two sensor types, Computer Vision covers a broad variety of techniques. Computer Vision (CV) deals with using a computer to emulate the human visual system. This includes a broad variety of techniques from detecting colors to depth perception. One of the major advantages of CV is its adaptability. From the same inputs, it is possible to extract a large variety of data. You can detect specific objects, like a traffic cone or a road lane. You can detect position and orientation by using a process known as visual odometry. You can even simulate depth perception by comparing a scene from two viewpoints to extract relative depth information (Triangulation).

# 3 Proposed Design

## 3.1 Throttle

Looking through the golf cart manual for information on the throttle subsystem, the team subsequently discovered that the throttle operates using a continuous potentiometer, whose resistance is set by the state of the accelerator pedal. As the pedal was depressed, the resistance of the potentiometer would increase; this change, when viewed at the motor controller terminals, indicated that the cart should accelerate. Since the intended mode of operation was purely autonomous, the accelerator pedal and under-cart throttle enclosure would have to be removed. There were numerous options for the autonomous system that would replace this, but intended choice was a Raspberry Pi 3 that interfaced with a digital potentiometer. The server would communicate with the Raspberry Pi over a web interface, allowing the server to act as a central node that issued commands to all driving subsystems. The Raspberry Pi would then connect to the digital potentiometer via GPIO, and provide commands via SPI or I2C to set resistances. The added complexity is transparent to the motor controller terminal, which only sees variable impedance.

The other requirement present in construction of the throttle subsystem was safety concerns: if a power failure or disconnect occurred at any stage of the design, the golf cart would have to safely decelerate. Anything less than immediate disengagement of the throttle would negatively impact the safety of riders and bystanders. The proposed solution was to incorporate some type of active 'switch', which would ensure the resistance path would only be through the digital potentiometer when the Raspberry Pi was active, and ensure otherwise on power failure. This was deemed a sufficiently safe solution for proper autonomous operation of the golf cart.

## 3.2 Sensor Systems

After examining the potential solutions to provide sensory input for the golf cart, we settled upon using stereoscopic computer vision as the best approach for a variety of reasons. Primarily, because it was the most balanced approach. While LIDAR would provide an incredibly detailed view of the surrounding environment, it is both extremely expensive for our budget and involves delicate mechanisms. We did not want to find ourselves replacing gimbals if they broke. On the other hand, ultrasonic sensors provide a cheap approach to tell if something approaches closer than a certain distance. However, they do not provide a sufficient level of detail. Needless to say, we quickly settled upon using computer vision as our planned sensor type.

Stereoscopic computer vision seeks to replicate the biological process of depth perception. By comparing information about a scene from two perspectives, depth information can be obtained through examining the relative positions of objects in the two perspectives. The actual process of computing the disparity map involves several theoretical steps. First, the image is processed to remove any distortion of the input image. Next, the images undergo a process called rectification, where they are projected onto a common plane. This allows detected features to be properly compared. Finally, the two images are processed to detect features, then use these features to create a disparity map. Optionally, this disparity map can be further processed into a point cloud. This provides a 3-dimensional map of the visible scene where measurements can be determined at a known scale.

Our implementation uses two webcams to provide a real-time visual of the environment in front of the cart. The frames captured from the webcams are processed using OpenCV to produce a disparity map. This map is then analyzed to create a 2-dimensional map of potential obstacles. This map is then fed into the decision planner system that then sends directions to the various control systems in the cart, such as throttle and steering.

## 3.3 Computing

For our server, we have continued to use the original design constructed by the first MQP team. The server will essentially function as the brain of the cart. It will handle the processing of the sensor input from the webcams and any future additions. Using this input, it will also handle the decision-making process on what actions the cart must take to self-navigate. The server will then communicate with the individual computing systems that control the physical components of the cart, like throttle and braking.

While we had the server, previous MQPs had unfortunately neglected to update it. Therefore, one of the first tasks our group did with the server was updating the operating system. Additionally, the cart software was poorly organized, so we planned on implementing containers on the server. This would create a more organized and flexible implementation. Each subsystem could be separated into its own container, allowing independent allocation of resources, as well as health monitoring and ease of web interface development. Additionally, the team planned to provide continuous updates to the server as time passed, to prevent outdated libraries or software from interfering with proper operating behavior.

## 3.4 Power Systems

After looking at the work completed by the previous team, the team decided it would be best to go through the existing Power Systems on the cart and see what would be needed to get every component on the cart powered through a power source on the cart. The golf cart throughout the years has never had every single component on it run off of a power source on the cart. One of the goals of this year was to make everything run of a power source that would exist on the cart. In order to start this, we created a schematic of all the existing components that were given to us from the previous year's team, this can be seen in Figure 9. The schematic has a legend for what the color or what property a certain wire had as when given to us, the cart wiring was not uniform or organized.

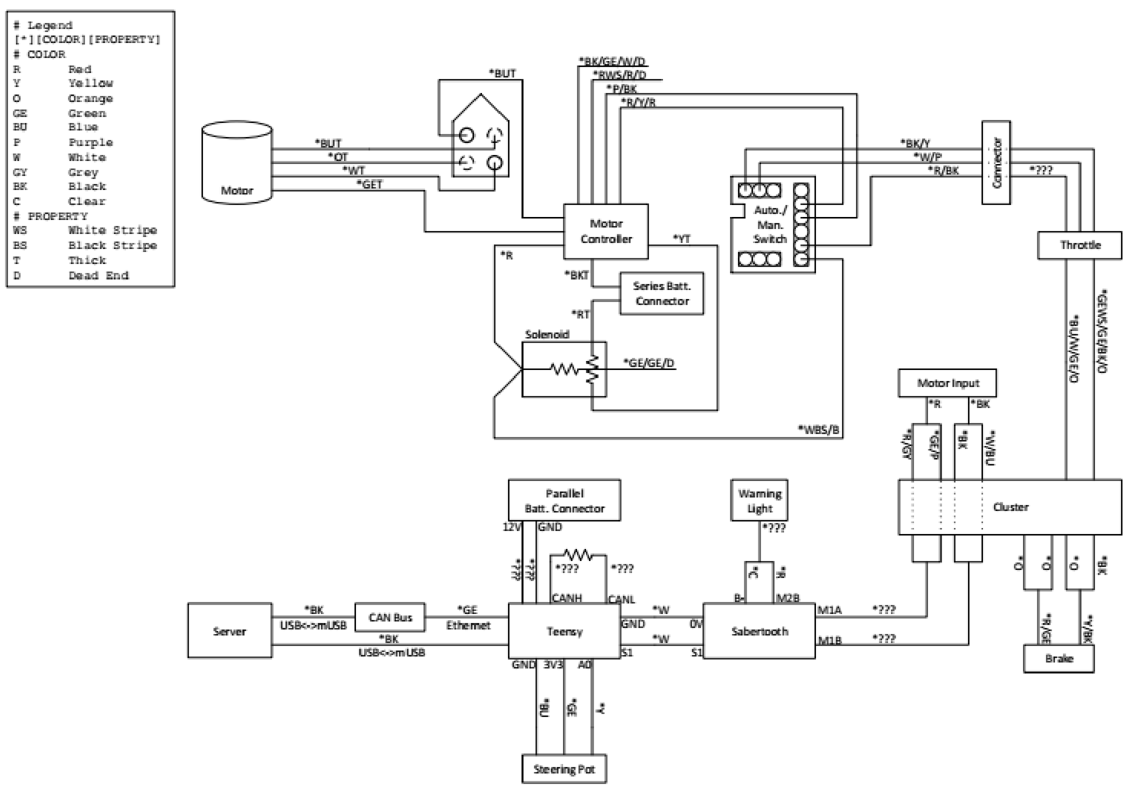


**Figure 9: Golf Cart Wiring as of August 2016**

All components on our cart we found either ran off of 12V or 48V. From the previous team, we had five 12V batteries that were only a year old. The five batteries were of two different types, with three being Duracell 12V-27DC and two being Duracell 12V-29HM. In order to get the cart to run on its own, it needed 48V, which meant four batteries. Then, to get sensors and our server to run, we needed

12V. It was decided that the best approach would be to create two separate power system sources. One would be our two 12V-29HM batteries attached in parallel to achieve a 12V source. The second would be our three 12V-27DC batteries, and we would buy a fourth 12V-27DC battery to add on and connect these in series to create a 48V source. Each of these power systems would have their own charging system as well. The proposed layout can be seen in Figure 10.

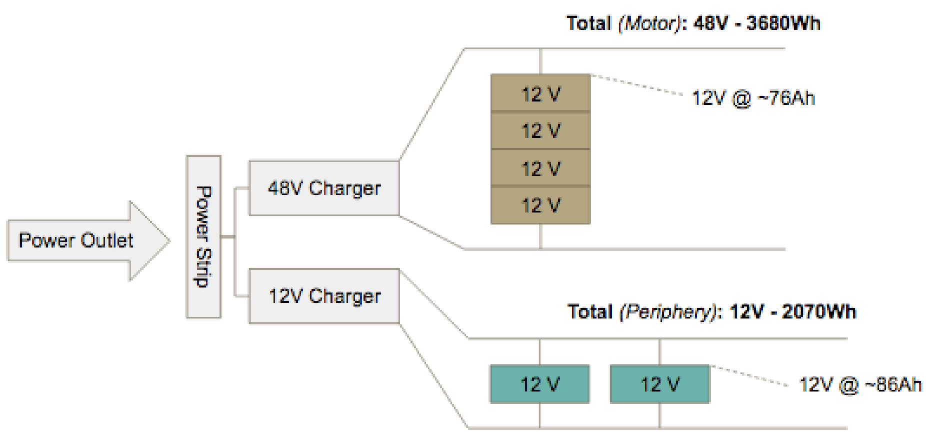


**Figure 10: Proposed Power Layout**

### 3.4.1 Series Power System

For our series system, we first would need to buy a 12V-27DC battery so we can achieve the 48V needed to run the golf cart. Previously, between all the five batteries, four were located on the battery trays built by the 2016 team and one battery was located in a battery box hanging from the cargo rack. We decided it would be best to have the four batteries for the series system to be located together on the battery trays.

The series system would power the 48V motor on the golf cart and our physical and wireless kill switches. Other iterations of the golf cart only had one charger for all batteries, and would charge one battery at a time and would need to remove the battery from the golf cart in order to do so. In order to simplify the charging of the batteries, we wanted everything that would be needed for the system to be located on the golf cart. We looked into buying a 40A 4-Bank 12V battery charger that would be able to charge all four of our batteries in the series system. The charger would be located on the cart at all times with the leads attached to the batteries at all times. In order to simplify even more, we also want to mount a power strip with a retractable cord that way the charger can be plugged in right on the cart and the power strip can be plugged into an outlet when it is stationary. The proposed series circuit can be seen in Figure 11.

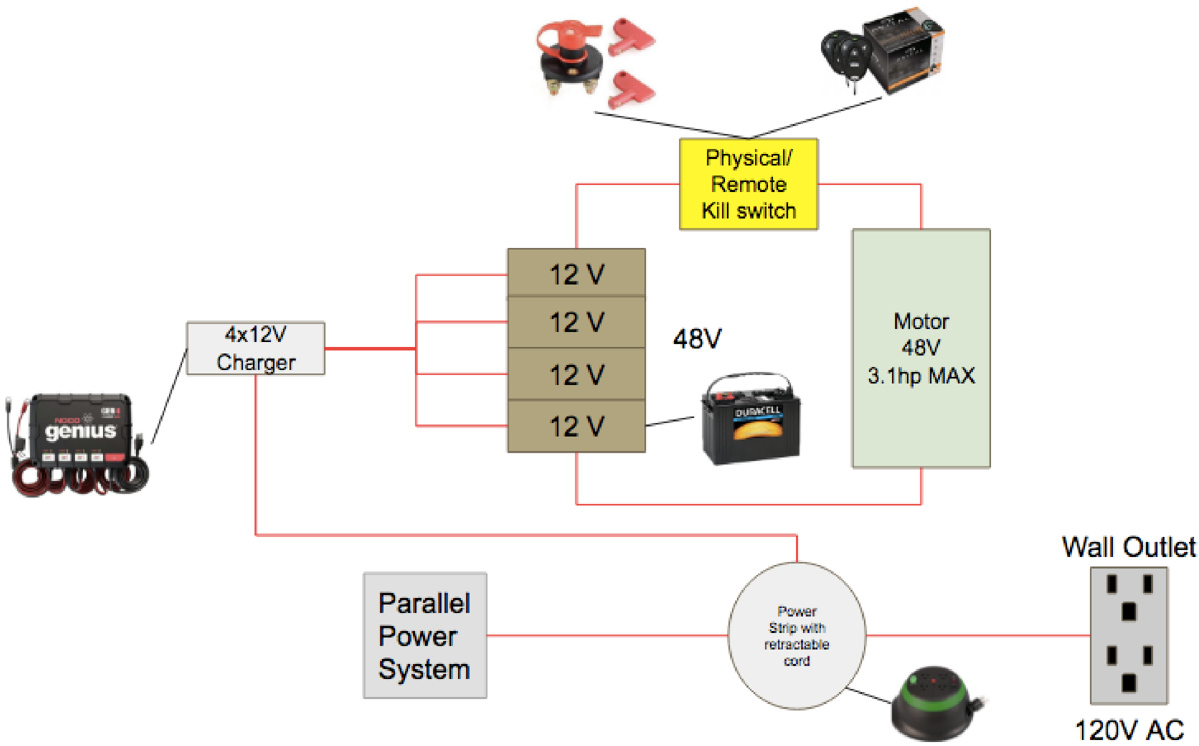


**Figure 11: 2017 Proposed Series Power System**

## 3.4.2 Parallel Power System

In the parallel system, we envisioned connecting the two 12V-29HM batteries in parallel with one another. We wanted all components that were not on the 48V system to be on this 12V system. As the series system was located on the battery trays we first needed to think about where we wanted our parallel system batteries to be located on the cart. Originally there was a battery box on the cargo box holding one battery hanging. We looked into purchasing an additional battery box and potentially hanging it on the cargo rack as well. Upon further investigation though, we did not want to put too much stress on the cargo rack as the server was already being supported by it. We decided that the best placement for the parallel system would be in the leg space of what would be the passenger seat. An additional battery box for the second 12V-29HM battery was bought to keep it protected and covered.

The parallel system would power our: warning lights, AC/DC converter, Sabertooth, and under glow lights for the cart. From our AC/DC converter we would have two items connected to it, our server and a monitor to display diagnostics. Then from our server, we would have the following connected onto it: 2 Raspberry Pi's, Speakers, 3 Cameras, GPS, Magnetometer, CAN Bus, and the Teensy. Just like the series system, we would have a 12V charger mounted onto the cart in order to be able to charge the parallel system with ease. The schematic for the proposed parallel circuit can be seen below in Figure 12.

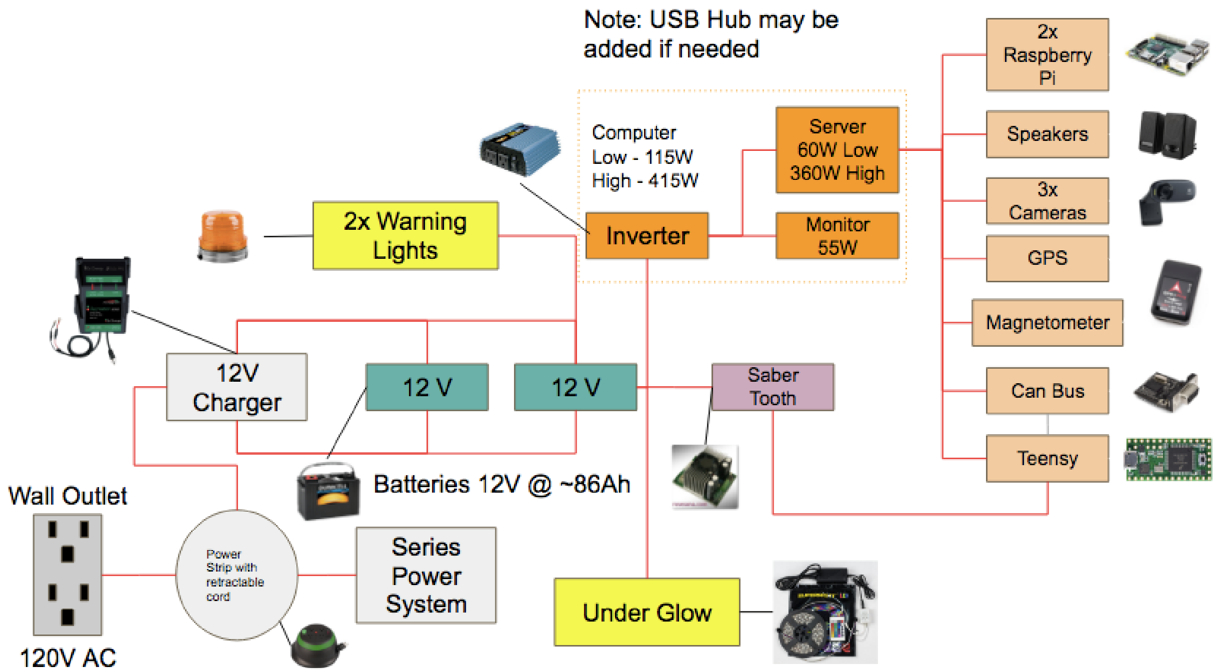


**Figure 12: 2017 Proposed Parallel Power System**

## 3.5 Golf Cart Add-Ons

Along with all the functional components that the team was looking to add to further enhance the cart, we also wanted to look at potential add-ons that would add more aesthetic and interactive appeal to the cart. Adding more aesthetic appeal would create more interest in the cart and interactive would get more people involved with the project and want to find out more.

### 3.5.1 Under Glow

The first "add on" we decided to implement onto the cart was under glow LED lights along the whole perimeter of the golf cart. We wanted to use LED lights to add some more aesthetic appeal to the golf cart as it was very worn in appearance. To achieve this, we decided to buy 5-meters of Flexible RGB

LED strips. This would allow us to be able to change the color of the cart to more than one color and let the user decide what they wanted.

### 3.5.2 Sound Receiver

An added fun component to go along with the under glow of the cart was a sound receiver. The sound receiver would connect to the LED strips and would then fluctuate the lights according to the sound that it was taking in. This feature is something that could be turned on or off based on the user's choice.  The sound receiver also led into our next add on, speakers.

### 3.5.3 Speakers

Two speakers were purchased in order to be able to create a "stereo system" for the golf cart. The speakers will be installed so that we can have a left and right speaker, more information on this can be found in section 3.1.6. When a user is in the cart, the speakers will be powered by the server and music can be controlled either off of the server or from a user's phone. Since the speakers will be installed near the sound receiver, this will allow the LEDs to fluctuate to the current song that is playing.

### 3.5.4 Hood Ornament

With the 2017 team, we decided to rebrand the original golf cart's name of "Robocart" to "Goat Cart." This decision was made to make it more relatable to the WPI community. Since our cart is the "Goat Cart," it was decided to add a hood ornament of the WPI mascot to the cart, the expected final product can be seen below in Figure 13. Using thingiverse.com, a website where users share 3D printed parts for public printing, we were able to locate an exact replica of the WPI Goat Statue located on the quad. The design was made by Denver Cohen. Using a 3D printer from one of our teammate's housemates, we were able to print the hood ornament.

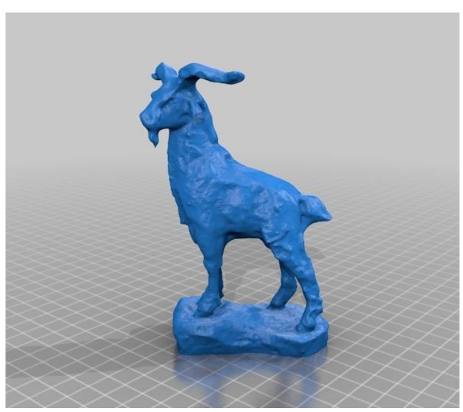

**Figure 13:  Hood Ornament Design**

## 3.6 Mounting Components

When mounting the components that make up our autonomous vehicle we have to make sure each component is in stowed away in a safe location for the user and the hardware, easy access when modifications are needed, and protects it from the weather and outdoor conditions.

### 3.6.1 Batteries

Last year's MQP team placed batteries in series in the back of the cart underneath the shell and seat. We proposed leaving the batteries in the same since it allows the batteries to be out of the users reach and keeps them safe from the elements. The team also proposes to add thick Velcro straps to the batteries to keep them from moving when the golf cart is underway. We will drill holes through the base underneath the batteries to make sure they are tightly secured by the Velcro.

The batteries in parallel will be placed in battery boxes in the legroom of the passenger seat. This may remove an extra seat but allows for safe storage and access. The battery boxes will help cover any exposed terminals to protect the batteries from any weather. Will drill holes through the boxes in order to have a safe and discrete place for the wires to snake through.

### 3.6.2 Chargers and Power Station

For the series battery charger, the team decided to bolt the charger underneath the seat directly to the frame. This way it will be safely out of reach of the user and protected from any bad weather. Using bolts will help secure the charger into place preventing it to move or fall off in any circumstance. We also chose this location since it is near where the batteries are located making it easier to get the wires to each battery.

For the batteries in parallel we want to Velcro strap the charger in place in the same area where the series batteries are located. Will use a thick Velcro strap in order to help keep the charger in place when the vehicle is on the move. This location is also ideal because it's underneath the seat and shell of the cart leaving it safe from users and protected from weather.

The power station will be mounted on the rack located on the back of the cart. We propose using nuts and bolts to fasten the power station in place. This will allow the user to be able reach the station easier in order to plug the golf cart in. One flaw of this location is that it's exposed to the weather but due to it needing to be reached by the user and limited space on the golf cart we decided this was our best option for the time being.

### 3.6.3 Battery Monitors and Cameras

To mount both battery monitors and cameras we decided the best location was attaching it to the x-bar located on top of the hood. We will attach them to the x bar using nuts and bolts in order to secure its location and prevent it from moving. This location is needed for the cameras because it is directly in front of the cart giving the cameras the best point of view. This location is also ideal for the battery monitors because it leaves the monitors in plain sight of the user. In order to protect it from weather we will build a clear acrylic box around them.

### 3.6.4 Throttle Control

Our plan to mount the throttle control is to place it on the wooden plates where the series batteries are located. We will make an acrylic case for the Arduino and the circuit in order to protect them and then use the double-sided tape to mount it in place. This location works well because it's under the seat making it easy to access but also safely away from the user. Keeping the throttle control closer to the motor controller also makes it easier to wire everything together.

### 3.6.5 Glove Compartment Components

To utilize space in the golf cart we decided to put most of the electrical components inside the open glove compartment. The Sabertooth, Teensy, inverter, and CAN bus will all be attached by using extra strength double sided tape. The glove compartment will keep the components out the weather. We will also add a clear wall in front of the glove compartment in order to keep the devices out of reach from the user and give the components extra protection.

### 3.6.6 Kill Switches

The physical kill switch will be screwed into the dash board next to the steering column. This allows the kill switch to be easily accessible by the user in case of an emergency. The electrical components will also be protected since they will be covered by the hood of the vehicle.

The wireless kill switch will be screwed into the base boards that the series batteries sit on. Screwing it in will keep the device in place and having it under the shell will protect it. Since the shell is thin it should have very little to no effect on the signal strength.

### 3.6.7 Wires

To keep the wires organized the team decided that the best approach is to use zip ties or Velcro to attach the wires to the frame. This will help keep wires easy to follow and safely out of reach of the user or any moving component. We need to keep the wires in place in order to protect them when we move the cart inside and outside the lab and when the cart is underway.

### 3.6.8 LEDs

To keep the LEDs, also called under glow, in place the team will use extra strength double sided tape. This will keep the LEDs attached to the frame of the cart and protect them from getting tangled with any moving part. If needed, we will use zip ties as well to help ensure that the LEDs will not fall off. We will purchase waterproof LEDs in order to prevent any damage due to water.

### 3.6.9 Speakers

With the sound system coming with a left and right speaker we need two locations to place the speakers. For both speakers, we will use extra strength double sided tape to keep them from moving when the cart is underway. The left speaker will be attached to the frame behind the steering column to keep the volume control close to the user and to protect it from weather since it will be under the shell of the cart. The right speaker will be placed in the glove compartment where it will be safe from the elements.

### 3.6.10 Hood Ornament

The hood ornament will be placed in the center of the hood. It will be kept in place by screwing through the frame directly into the base of the ornament. This is will keep the ornament from falling off when underway. The ornament will be made out of plastic and painted to help prevent any damage from weather.

### 3.6.11 Summary

With the addition of new components to the golf cart it's important to utilize space, keep the hardware and user safe, and have parts secured when underway. With all these boundaries met we can assure that components will last and be effective for our autonomous golf cart.

## 3.7 Gantt Chart and Team Roles

With this project being so large in scale and with such a time crunch it's important to break apart the workload in order to keep on track. The Gantt chart below breaks down the different parts of the project and the time frame given in order to complete them. We divided the team roles based on equal work load and to the strength of the members. Even with most components having contributions from all team members it's important to have a leader in order to accept responsibility and keep everyone on schedule.

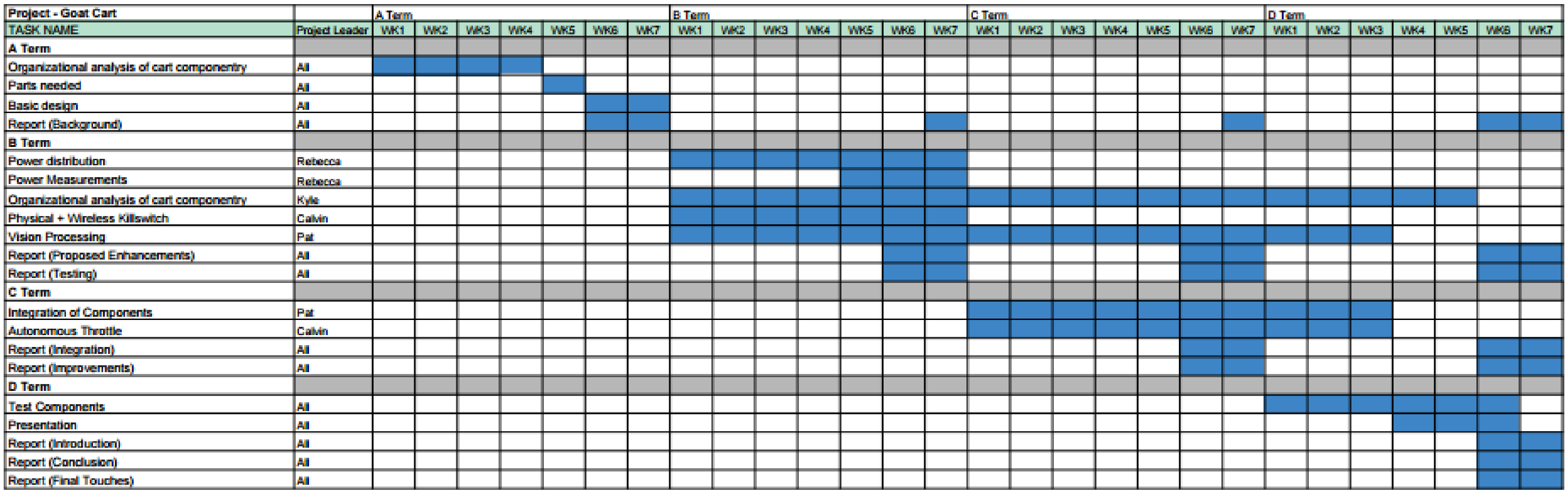


**Figure 14: Gantt Chart**

## 3.8 Testing Strategies

### 3.8.1 Power

One of the test that our team has to complete is the battery life for the batteries in parallel and series. For the batteries in parallel we will test by measuring the current being pulled from each of the components attached to the batteries. We will set the server to run with the processor and GPU running at 30% capacity. We will then mathematically estimate the battery life of the parallel system. For the batteries in series we measured the horse power of the motor and then mathematically estimate the battery life of the cart when consistently running at full speed.

### 3.8.2 Vision

A number of vision system tests were planned. For calibration, the team intended to use the previously-described checkerboard pattern to determine constants necessary for proper occupancy grid and depth mapping generation. Various left-right image pairs were also selected for potential analysis via the vision software, and the accuracy of the output would be qualitatively assessed, then altered as appropriate. The images selected were primarily of long hallways or longer distance fields of view.

### 3.8.3 Throttle

When testing the throttle, the team will send commands to the Arduino to change the value of the digital potentiometer in order to see the changes in speed. The team will also test the safety of the throttle control by cutting the power to the Arduino and the digital potentiometer to see if the motor stops when power is loss.

### 3.8.4 Kill Switch

To test the physical kill switch, we will first see if the cart will start without the key in place. Next, we will test to see if when the cart is under way if the kill switch will turn off the motor. We will conduct the same test for the wireless kill switch.

### 3.8.5 Summary

The MQP team will test the power system, vision, throttle, and kill switches on the golf cart to determine their safety and success in progressing the cart to being autonomous. The team conducted test on the battery life of the two power systems, basic obstacle detection, throttle control and safety, and the kill switches for shutting down the motor if a problem arises.

# 4 Implementation and Methodology

## 4.1 Throttle

The throttle's final stage of implementation was an Arduino Uno connected to a DS1803-010 dual I2C digital potentiometer, as opposed to the original design of a Raspberry Pi. This decision to replace the microcontroller was due to difficulty designing an interface between the Raspberry Pi and the central server. If the team had used the Raspberry Pi, additional software development would need to be performed. Either a web interface, via Ethernet, or a physical interface, via USB connection would have to be implemented. The Ethernet option would also require WiFi setup on the Raspberry Pi, which involves certificate registration and setup on WPI's wireless network.

The Arduino code is written using a modified DS1803 I2C library, where some errors and bugs were removed from the provided code. The Arduino is programmed over USB using a laptop, but is intended to be programmed from the server at some future point in time. The digital potentiometer is wired to receive commands over I2C that set the throttle speed accordingly. In order to reproduce these results, the code and schematics for this implementation are entirely documented in the team's Github repository [11].

## 4.2 Vision

For our project, we implemented our vision software using OpenCV, a popular computer vision library. Specifically, we used OpenCV's camera calibration and 3D reconstruction APIs to process the input from two cameras and convert it to a top down view of obstacles in front of the cart. For our project, we are using two Logitech C310 webcams. When the software first starts up, we begin by obtaining the calibration data for the current state of the webcams. This is done by capturing a series of snapshots of someone holding a chessboard pattern in front of the cart at different locations and angles. By accumulating extracting the corner locations from these snapshots and with knowledge that the world-space distance between the individual corners is fixed, OpenCV can calculate the calibration information for the webcams. This process is setup to run every time the Planner application starts since the webcams are impossible to perfectly align, and thus need to be recalibrated whenever they are jostled.

After the camera calibration data is obtained, the cart takes the frames captured by the left and right webcams. It uses the calibration data obtained at startup to undistort the captured frames. Then, it computes the disparity map using the semi-global block matching algorithm [3]. The result is cropped using the intersection of the “Rectangles of Interest” (ROI) computed by the camera calibration. This leaves us with the undistorted section of the disparity/depth map.

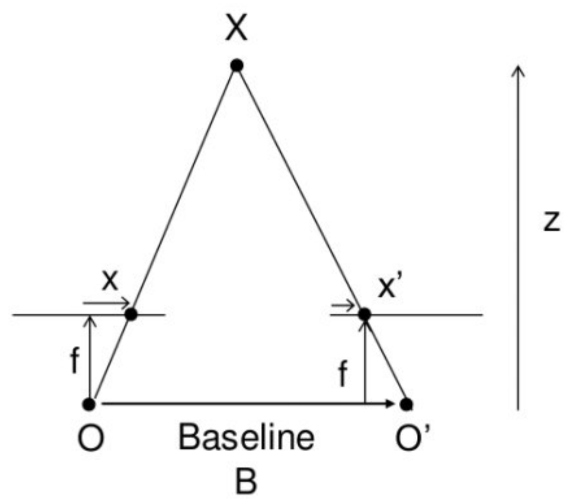


**Figure 15: Triangulation Model [14]**

Stereo matching works by extracting features from both images, as seen in Figure 15. $X$ represents the world-space location of the feature; $x$ and $x'$ represent the location of the feature on the left and right frames, respectively. The depth $z$ is inversely proportional to the difference between in the distances between feature locations and their respective camera centers. The actual process is more complicated and the various algorithms developed optimize this method to improve performance, but this is the basis.

The generated disparity map is then converted into an occupancy grid, showing obstacles in the area ahead of the cart. First, the disparity map is processed into a 3d point cloud. Each pixel of the disparity map is converted into its xyz coordinates relative to the camera. Then, the points are filtered, so all points outside a specific box in front of the cart are ignored. A 2-dimensional grid is applied to the overhead view of the box and all the remaining points are sorted into the grid cells. Then, using the total number and average height of points in the cell, the algorithm estimates whether or not there is something in the cell. The resulting grid is filtered to remove noise, leaving only clusters of cells. Then each cluster is expanded horizontally to provide padding for the width of the cart. This produces the final occupancy grid.

## 4.3 Power Systems

### 4.3.1 Series Systems

Our proposed approach for the series power system is the one that we implemented fully onto the cart, along with some minor additions. The first step to implementing the series power system was purchasing a new Duracell 12V-27DC from Sam’s Club. From there we followed our proposed schematic to implement the full system, with the final schematic shown in Figure 16. The first minor addition we made was that of an Anderson connector between the series charger and the batteries, this was added as a “quick release” and as an ultimate backup plan for if both our wireless and physical kill switches did not work. The passenger in the golf cart could simply pull apart the connector and that would cut power to the motor. The other addition that was made that was not included on the proposed schematics was a battery monitor. This battery monitor would constantly monitor the state of the series system so we could be aware of if the batteries needed to be charged.

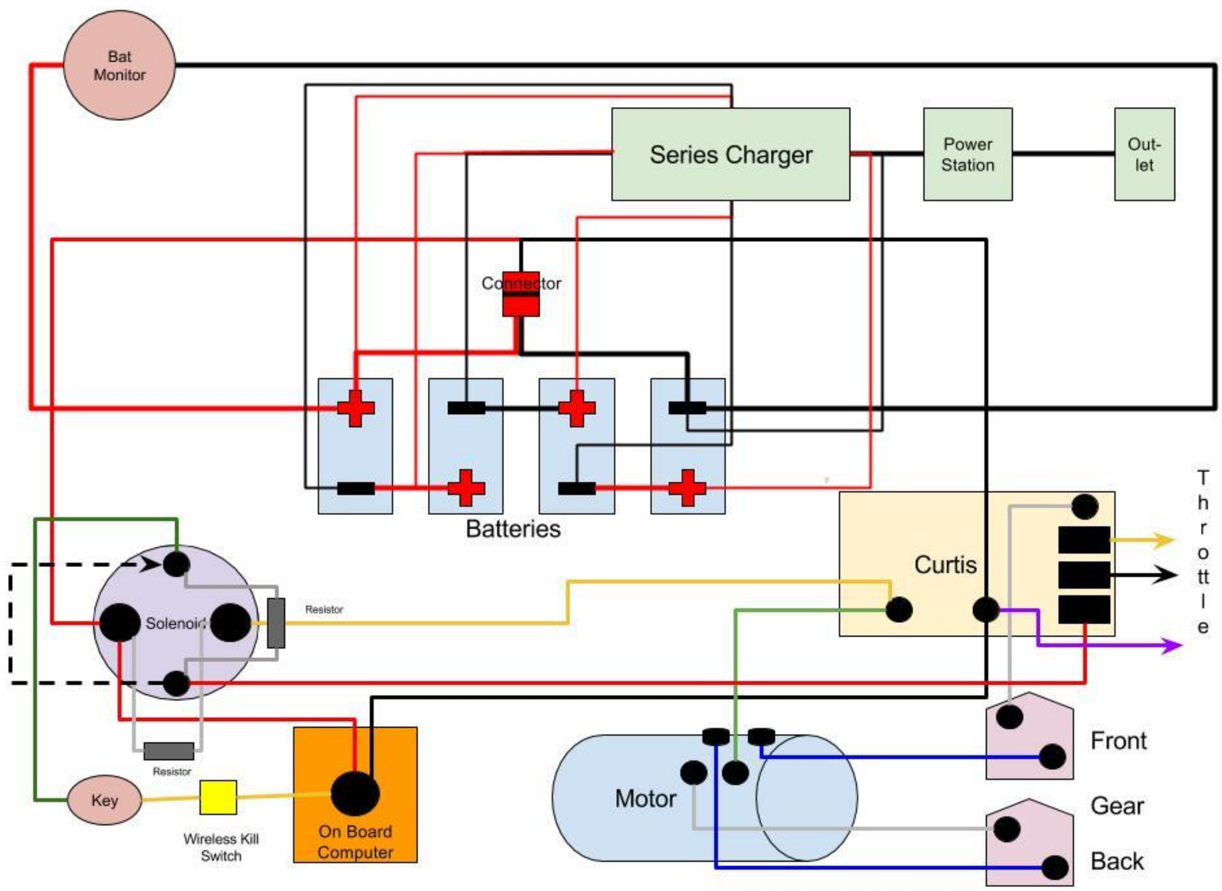


**Figure 16: Series Schematics as of May 2017**

### 4.3.2 Parallel Systems

The proposed parallel power system ended up being more complex than the one that was implemented on the cart. When we were designing our project, we had a lot of ambitious features that we wanted to be able to see on the golf cart. As the project progressed we needed to decide what was going to be considered a necessity for the cart in the current year and what was items we could for go for the current year. Originally, we were going to have warning lights, AC/DC converter, Sabertooth, and under glow lights for the cart powered from our 12V system. We decided that the two warning lights were not necessary for this current year on the cart. From our AC/DC converter we were going to have 2 Raspberry Pi's, speakers, 3 cameras, GPS, magnetometer, CAN Bus, and the teensy powered from it. We ended up not needing the 2 Raspberry Pi's, we had one Arduino for the throttle control and this was powered off directly from the server as opposed to being a part of the parallel system. We also did not end up with 3 cameras, only 2 cameras made it into the implementation of the project. A GPS and magnetometer were also not deemed necessary for this year as our vision was not going to be that complex to need it, but future years should look into implementing a GPS and magnetometer for vision navigation. All other items we said would be implemented in the 12V system were implemented. Two items we added that were not in the proposed parallel system were a computer monitor so you can use the server while you are on the golf cart, and a battery monitor that would monitor the state of the parallel system. The final parallel schematic can be seen in Figure 17.

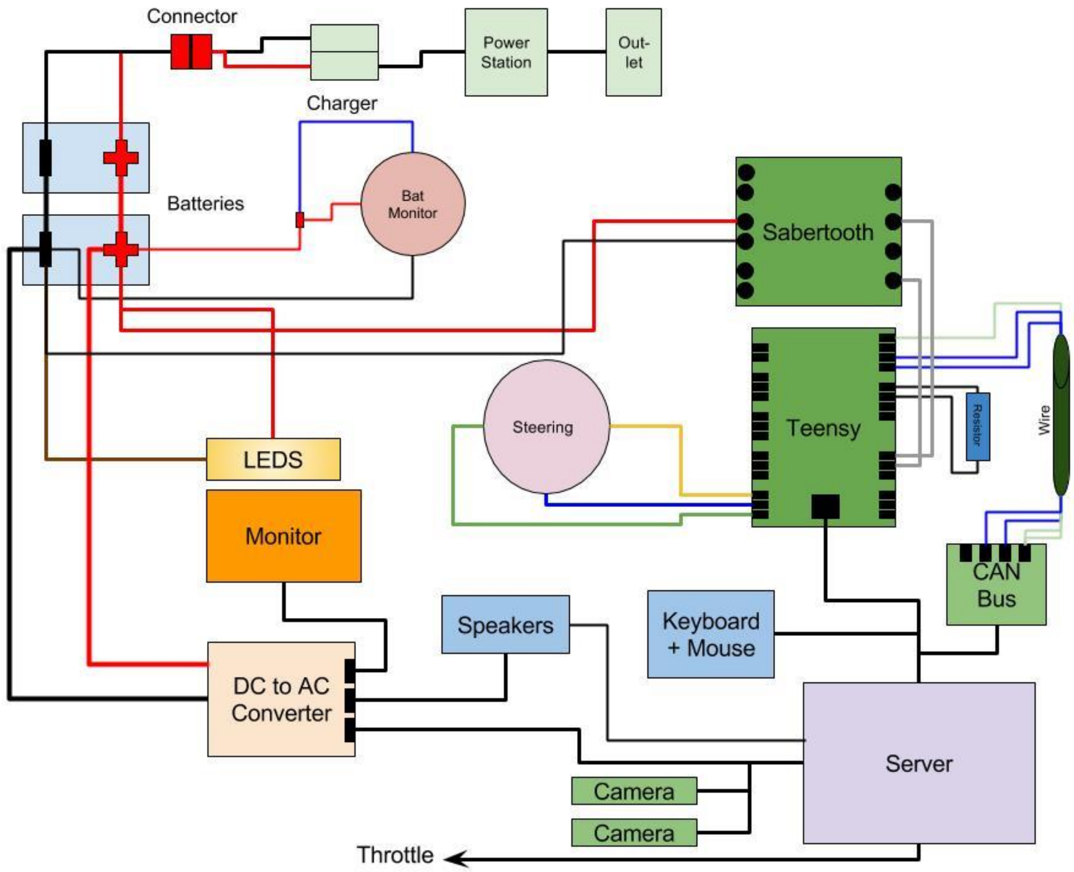


**Figure 17: Parallel Schematics as of May 2017**

## 4.4 Golf Cart Add-Ons

From the four proposed add-ons, we were able to implement all of them onto the cart. The first one that we implemented was the under glow of the cart. We were able to successfully have the lights cycle with different light patterns as well as emit different colored lights. You can see the under glow on the cart in Figure 18, and in this image you can also see Gompei, our hood ornament, in place on the cart. The sound receiver and speakers were also put in place. They were able to work as we had expected and laid out in Section 3.1.5.

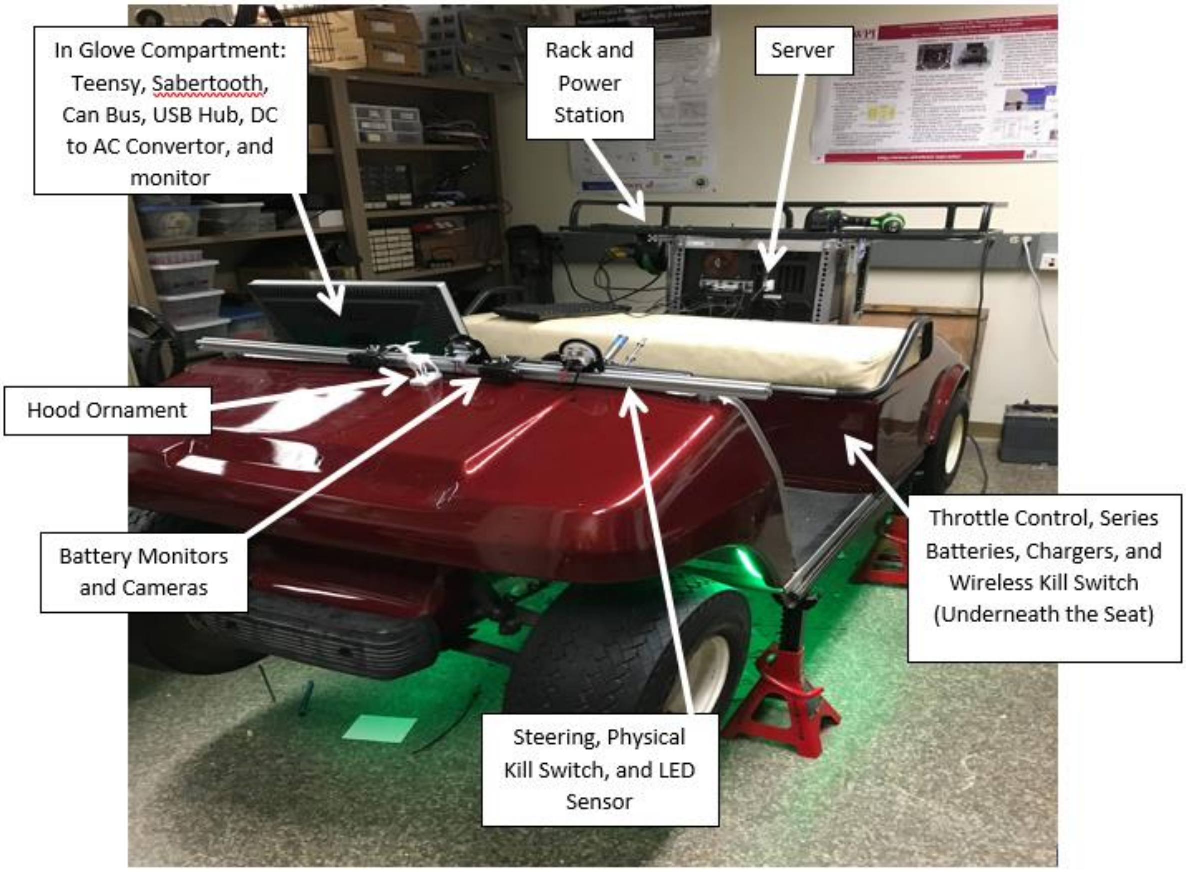


**Figure 18: Under Glow of the Cart in Use and Hood Ornament in Place**

## 4.5 Mounting Components

### 4.5.1 Batteries

To implement mounting the batteries we started by drilling one inch holes through the wood floor boards for the Velcro straps to snake through. We put one battery on the left and right, when facing the golf cart, wood panels and then two batteries in the middle. For the two middle batteries, we did not drill holes into the wood since the width of the two batteries was the same as the piece of wood it was on. We used ¾ inch Velcro to make sure we had a strong strap to hold the batteries in place. You can see the four series batteries in Figure 19.

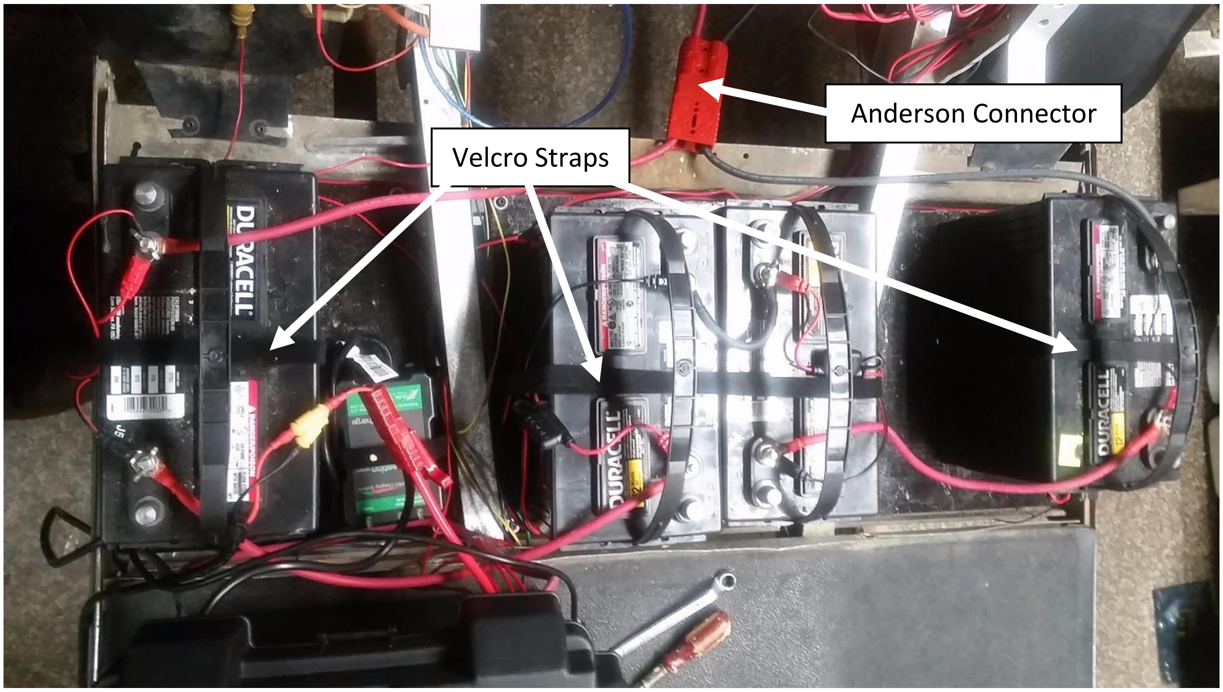


**Figure 19: Series Batteries Mounted**

Figure 20 shows a close up of one of the batteries in series to show how the strap keeps the batteries in place.

**Figure 20: Close Up of Mounted Series Battery**

To implement mounting the batteries in parallel we placed the batteries in boxes in the legroom of the passenger seat. These do not require straps because of the weight of the batteries. The battery boxes cover any exposed terminals and protect the batteries from the elements. We drilled holes through the boxes in order to have safe and discreet places for the wires to snake through. You can see how they are mounted in Figure 21.

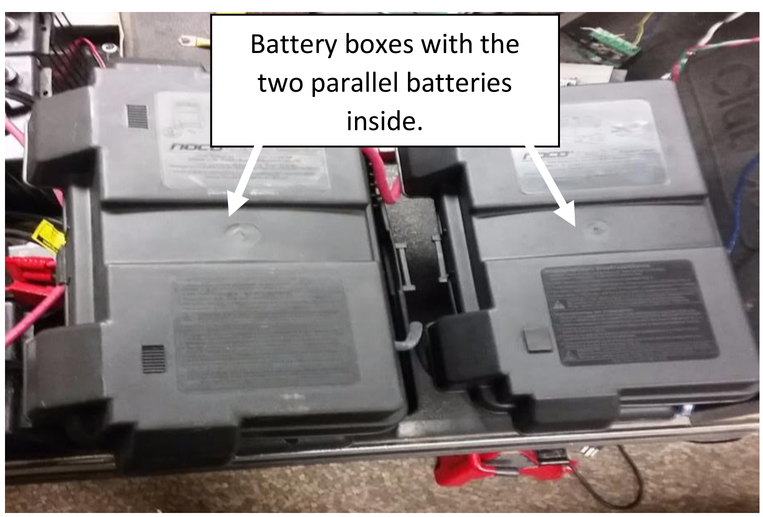


**Figure 21: Parallel Batteries Mounted**

### 4.5.2 Chargers

To mount the series battery charger, we first drilled holes through the frame of the seat. In order to make room for the charger we moved the on-board computer to a different location on the seat frame. We used two x-bar frame pieces in order to hold up the charger and connect it to the seat frame of the cart. We drilled holes through the x-bars that lined up with the holes in the charger. We then used bolts, washers, and nuts to secure the charger tightly in place. You can see the charger in Figure 22.

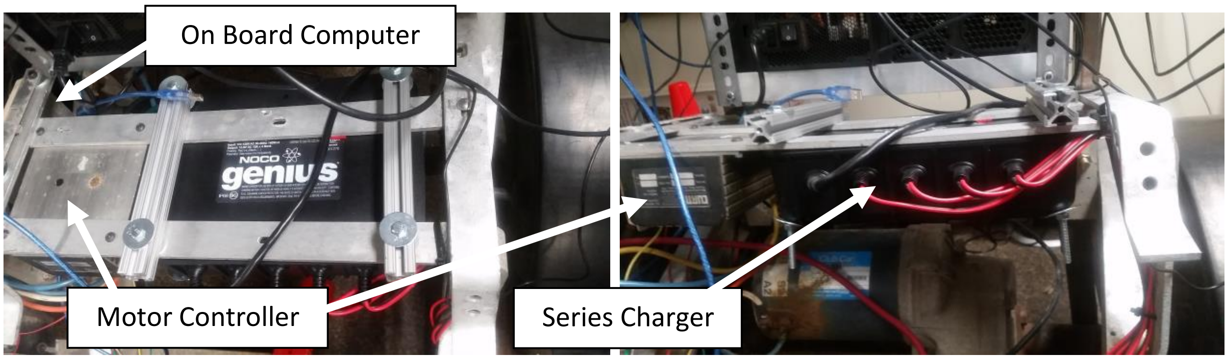


**Figure 22: Series Battery Charger Mounted**

This particular charger was chosen for its ability to charge all four batteries at once, as opposed to the prior charger. It also has a waterproofed exterior, charge control, various safety mechanisms, and functions under 48V operation. When mounting the parallel battery charger, we used the same Velcro straps we used for the series batteries to keep it in place. We drilled a one-inch hole in order to snake the Velcro tightly around the charger. You can see it mounted in Figure 23.


**Figure 23: Parallel Battery Charger Mounted**

### 4.5.3 Battery Monitors and Cameras

To mount the batteries and cameras we used the x-bars attached to the front of the cart to secure all the components. Using nuts and bolts we were able to keep all the components in place. This location also provides the perfect viewing angle to check the battery charge state and for the camera vision. You can see how they were mounted in Figure 24

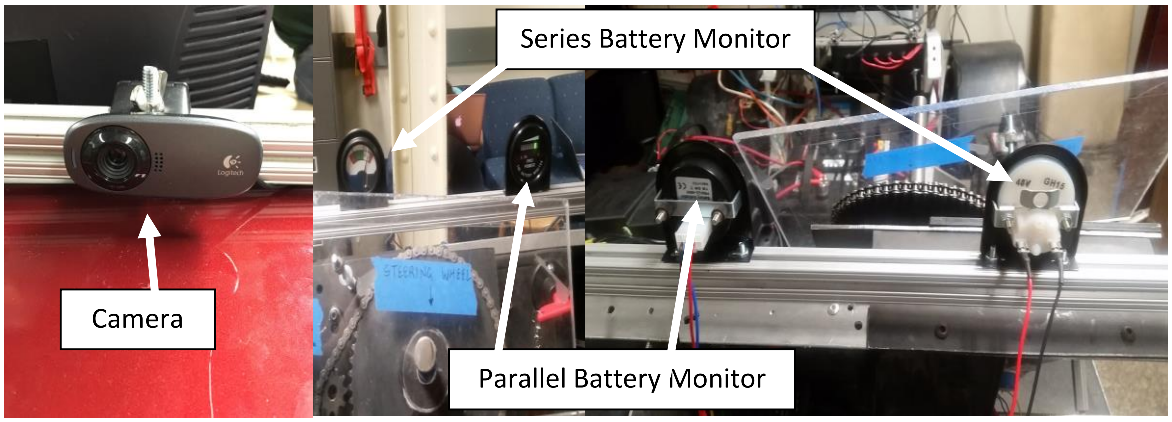


**Figure 24: Battery Monitors and Cameras Mounted**

### 4.5.4 Throttle Control

We mounted the throttle control on one of the wooden floor panels next to where the series batteries are located. The Arduino had holes already made for it so we screwed the board directly into the wood. This will prevent it from moving while the cart is on the move. We used doubled sided tape in order to secure the circuit in place. You can see how we mounted it in Figure 25.

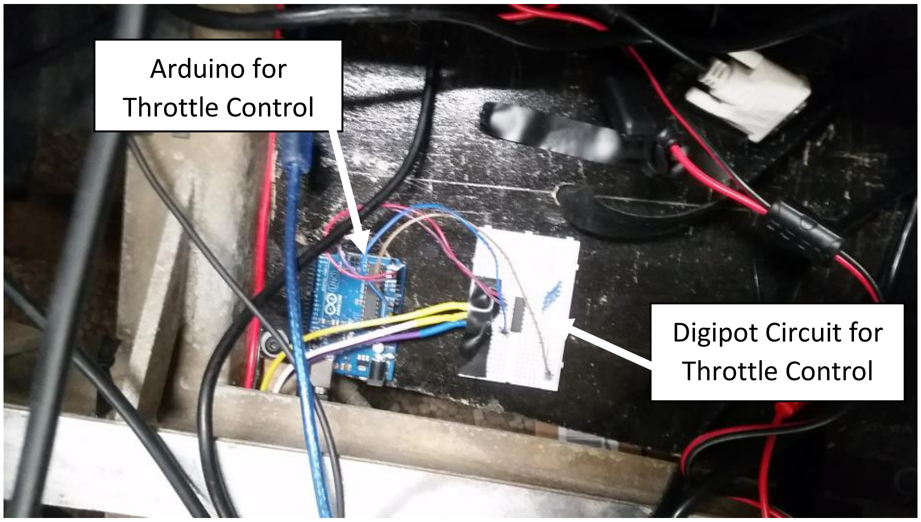


**Figure 25: Throttle Control Mounted**

### 4.5.5 Glove Compartment

When mounting the components in the glove compartment we used double sided tape to secure the different components in place. This will help prevent the part from moving when the cart is under way. The glove compartment also allows for easy access for future teams to work on the components. We did not use the double-sided tape for some of the components in order for it to be easier to make modifications to the parts in the future. You can see them mounted in Figure 26.

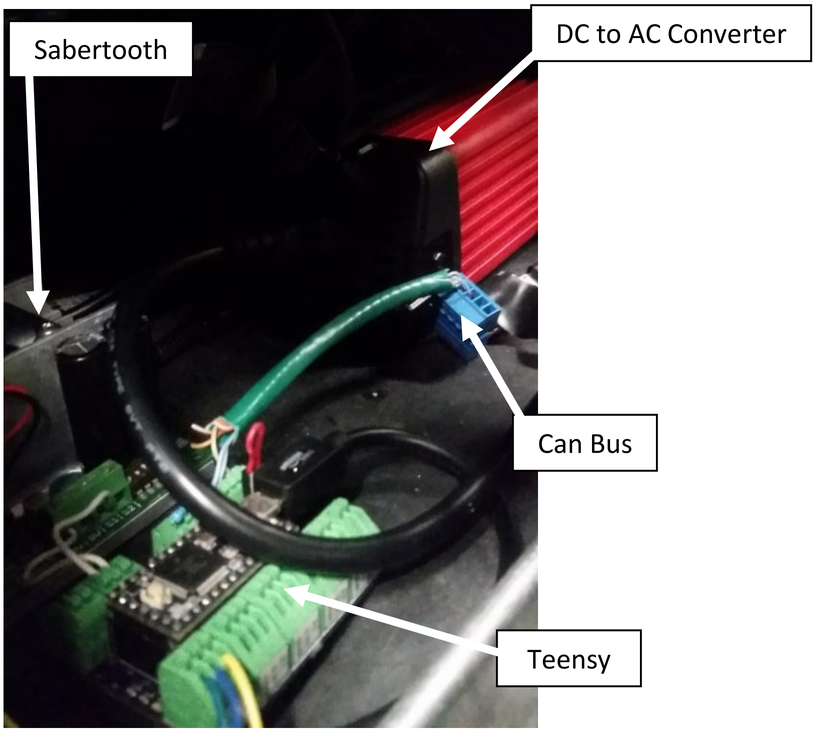


**Figure 26: Glove Compartments Mounted**

### 4.5.6 Kill Switches

To mount the physical kill switch, the team drilled holes through the dashboard that lined up with the holes on the physical kill switch. We then used nuts and bolts to secure the device in place. We placed the kill switch next to where the passenger sits for easy access for the user just in case a problem occurs. If the key is turned counter-clockwise, the key will be disconnected from the system, which turns off the motor.

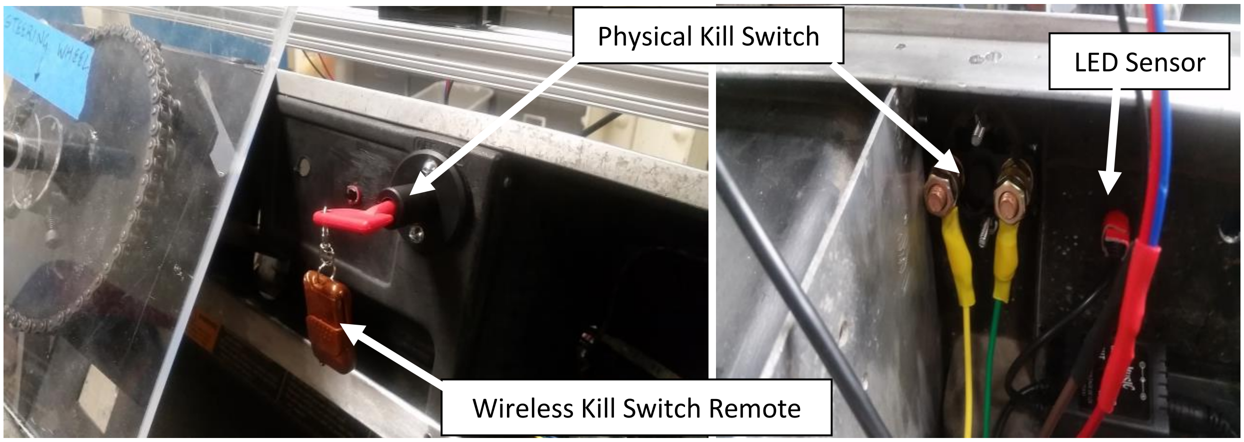


**Figure 27: Physical Kill Switch Mounted**

The wireless kill switch is mounted next to the series batteries and the parallel charger. We used the double-sided tape in order to secure the component in place. As long as the user holds down the button on the remote, the motor circuitry is disconnected and the cart is unable to accelerate. Figure 27 shows the physical kill switch mounted in place, as well as the remote kill switch hanging off of it.

### 4.5.7 Wires

In order to keep the wires secure and out of the way of all move components we used zip ties. We zip tied the wires together and to the frame to make sure they were secured to the cart. The advantage of zip ties at the moment is being able to quickly cut and replace zip ties when wires are added or moved. We also needed to drill holes into the frame in order to have areas to snake the zip ties through to secure the wires. You can see how we mounted the wires in Figure 28.

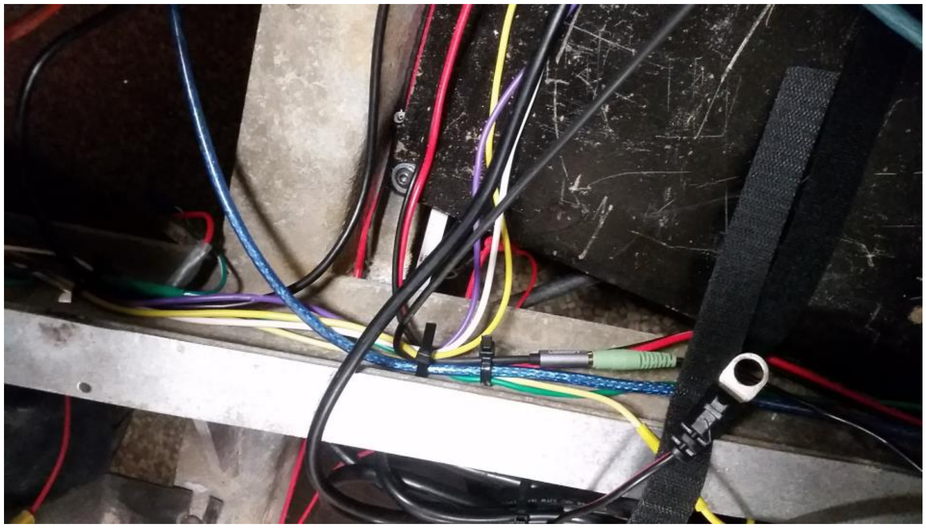

**Figure 28: Wires Mounted**

### 4.5.8 LEDs

The LEDs were securely mounted to the underside of the cart by using double sided tape. Unfortunately, the LEDs started to fall off after about a week. In order to fix this problem, we used a hot glue gun to secure all the LEDs in place. Once the hot glue was added the LEDs were safely secured around the entire golf cart. We made sure the LEDs would not become tangled in any of the golf cart mechanics in order to protect the equipment. You can see the mounting process in Figure 29.

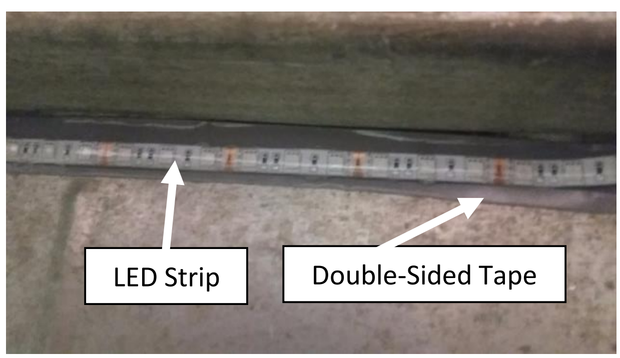


**Figure 29: LEDs Mounted**

### 4.5.9 Speakers

The speakers were mounted using double-sided tape in order to keep them safely in place when cart is underway. We attached the speaker with the volume control on the right side of the cart in order to make it easy to use for the passenger and the other speaker was placed in the glove box on the left side of the cart. We used multiple pieces of double-sided tape on the speaker on the right in order to get it high enough where the volume/power control we above a part of the frame. You can see how the speakers were mounted in Figure 30.

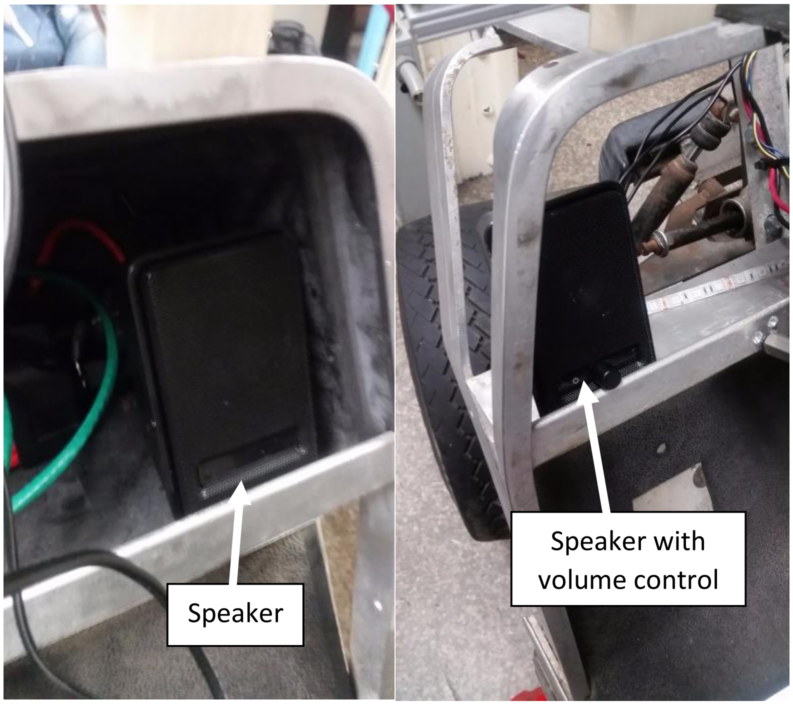


**Figure 30: Speakers Mounted**

### 4.5.10 Hood Ornament

The team mounted the hood ornament by drilling a hole through the base of the hood ornament and using a nut and bolt to secure it to the hood of the cart. The hood already had a hole drilled into so we utilized that. You can see how we mounted it in Figure 31.

**Figure 31: Hood Ornament Mounted**

### 4.5.11 Summary

The team was successful in mounting all of our components we added to the golf cart. The components are protected from weather and the user, secured in place for when under way, are space efficient, and are position in smart location to best utilize the components purpose. With the items mounted correctly this will help protect the lifetime of the components.

# 5 Results

The purpose of this chapter is to break down the results from all of the components we added during this year's MQP. Figure 32 shows the cart's state on our last day. To setup every test, we left the golf cart in the lab, on jacks, which ensured it would not move during any tests we performed.

**Figure 32: Final State of the Cart 2017**

## 5.1 Throttle

To obtain results for the throttle subsystem, the digital potentiometer was set to varying resistances using the Arduino Uno. The corresponding speeds for each resistance were empirically determined by testing Arduino operation at different impedances on the motor controller path. On the Arduino Uno and digital potentiometer, there are 256 different levels of resistance that can be set, which correspond to the 256 wipers internal to the potentiometer. The boundary on throttle acceleration was rather low, as the cart began to move forward at around 5 wipes up from the lowest resistance available. The wiper value is inverted, from 255 down to 0, since the impedance at the motor controller is between the high pin of the DS1803 and the wiper pin of the DS1803. Replacing the high pin with the low pin would convert the relation from 0 increasing to 255. Below is a table of data that could be used to program speeds for the golf cart in the future. Linear extrapolation between the two points allows other speeds to potentially be set.

**Table 1: Throttle Resistance Data Points for Linear Extrapolation**

| Wiper variable | Resistance equivalent | Speed equivalent |
|---|---|---|
| 0xFF | ~200 ohm | 0 mph, stand still |
| 0x94 | ~5500 ohm | 15 mph, top speed |

## 5.2 Vision

Over the course of the year, we managed to implement stereo vision and occupancy grid generation. While testing, we were able to successfully run all the individual components. Using test calibration images, we could successfully obtain the camera calibration. When we ran these images through the stereo matcher, it produced an undistorted disparity map, seen in Figure 33.

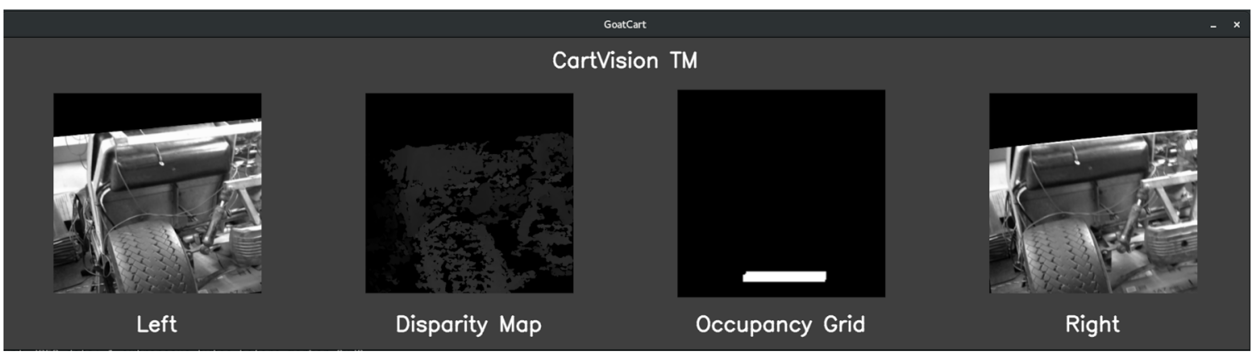


**Figure 33: Stereo Matcher Disparity Map**

Using a set of undistorted test images and pre-generated calibration data, we were able successfully generate a disparity map and then convert that disparity map into an occupancy grid, also seen in Figure 34.

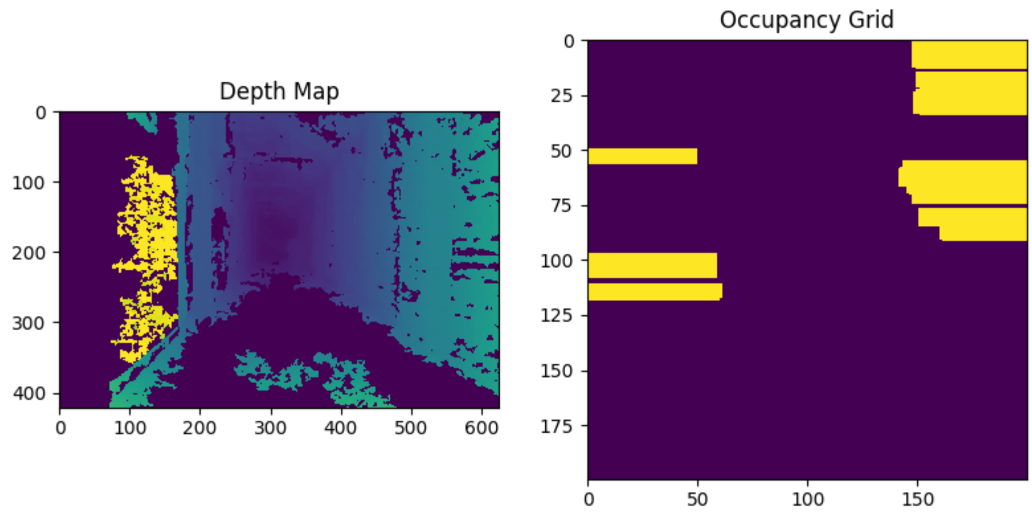


**Figure 34: Depth Map to Occupancy Grid Conversion**

While testing the code proved its functionality, we ran into a problem with the cameras we selected. At the beginning of the year, we did not know about all the potential requirements for the cameras, so we chose to buy two Logitech webcams to provide vision for the cart. While it is possible to extract a disparity map from the webcams, running calibration using the webcams was not successful. Whenever we tried running the whole program with webcams, the “undistorted” image was monstrously distorted. We are not certain as to the cause, but we believe that it may be from a problem with the lens of the webcams.

As a stopgap solution, we implemented an algorithm that guesses when the traffic cones are too close by using the perspective effect. Since the shade of orange on the cones is not usually seen, we convert the image to HSV (Hue Saturation Value), then detect regions of the image containing that shade. Since cones further away are smaller, we detect when a certain portion of the frame is filled with the right shade. While this is a simplistic solution and prone to false positives, it works. Another issue with the vision system is that the hood of the cart cuts off the lower half of the webcam view.

## 5.3 Series Battery Life

In order to get the results for the series power system, we decided to find the result mathematically. We knew from the golf cart manual that the motor of the cart is 3.1 horsepower. We also knew that the watt-hours on our series system was 3680Wh. From this, we calculated in ideal conditions how long the cart could run for if the cart was running at full speed. The results can be found below in Equation 1.

**Equation 1: Max Run Time for Series Batteries**

$$1hp = 745.7W$$
$$3.1hp * 745.7W = 2311.67W$$
$$3680Wh/2311.67W = 1.59hrs$$
$$\text{Total Run Time} \approx 1hour35minutes$$

From the knowns we had, we were able to find that under ideal conditions and running the golf cart at max speed, the cart would be able to run for around 1.5 hours. For future teams, they should take this information and use it for when they are trying to apply the Goat Cart to real world situations. With only 1.5 hours of run time, and needing to provide time for charging batteries as well, it will need to be taken into consideration for what the intended use of this cart is meant to be.

## 5.4 Parallel Battery Life

For the parallel power system, we did the same calculations as we did for the series system in order to find out the longest possible time the parallel system can be run for. From our parallel system, we had multiple items needing power which include: the server, the monitor, LEDs, speakers, and the Sabertooth. For these calculations, we assumed ideal conditions and the worse-case scenario, meaning the highest power draw from our components. We knew that if the server was running at max full load operation, it would pull 360W. As well as if the Sabertooth is running at max full load operation, it would pull 720W. Our monitor, LEDs, and speakers pull 55W, 36W, and 3W respectively. Our parallel power system was 2070Wh, from this we were able to calculate the longest running time for the system and that can be seen below in Equation 2.

**Equation 2: Max Run Time for Parallel System**

$$720W + 360W + 55W + 36W + 3W = 1174W$$
$$2070Wh/1174W = 1.76hrs$$
$$\text{Total Run Time} \approx 1hour45minutes$$

From what we had known, we were able to calculate under highest power draw with ideal conditions, how long the parallel system on the Goat Cart would be able to run. It was found that it would be able to run for around 1 hour and 45 minutes. This is closely related to that of our series power system, which could run for 1.5 hours.

# 6 Conclusion and Future Work

At the conclusion of this year's project, the team has successfully outfitted our 1995 Club Car Golf Cart to be in a roadworthy condition for future years. The team improved upon the three previous iterations of past work to be able to get the cart into a condition that makes it safe and functional for testing. The team successfully got a basic vision system working on the cart, that detected obstacles in our path, along with a throttle system in place, that allowed our cart to accelerate to a set speed. Safety features as shown in Chapter 4 were also added onto the cart that had never been there before to ensure that if something were to go wrong with the cart, it would be able to be stopped. We also were able to get everything that was located within the cart to be able to be powered off of the two power systems, as shown by tests where every cart component was active off battery power. Although we were able to accomplish all of these tasks in the past year, the Goat Cart still has a lot of work to be done on it. The team came up with tasks we believe would be the future steps for this project and these are outlined following.

A number of opportunities exist that would provide increased functionality for the golf cart's operation. These improvements have been cataloged and separated into smaller, achievable tasks in order to best provide goals for future MQP students' work. Completion of some or all tasks would bring the golf cart closer to a functional, autonomous state that could potentially be roadworthy.

The first opportunity would be improved cameras for the computer vision system. While webcams are a functional alternative to many of the camera systems commercially available on autonomous vehicles, there exist features that the golf cart could use. The mounting solution for the webcams works as intended, but movement of the cart or crossbar could dislodge or reorient the camera lenses. Fixing this whenever it occurred would mean recalibration of the vision system, which could be a lengthy and difficult process. Additionally, more software-programmable settings such as white balance and other post processing would be useful. Currently, if one camera autocorrects its white balance and the other does not, this interferes with the server-side image processing. Being able to set that behavior from the server would eliminate this issue and improve vision sensing.

Another opportunity exists where future teams could install better sensors for the purpose of polling subsystem state. Even if the golf cart reaches a point in development where the throttle, steering, and braking can be set to specific user values, there needs to be a way where the server can determine what the current state of each subsystem is. On power on, the wheels may be turned in some direction other than straight, and the steering subsystem must be able to compensate for that fact to function properly. This applies to the braking system as well, and less so to the throttle, where the server already knows the exact speed that has been set.

Unifying the interface to the three subsystems would also improve ease of development on the golf cart. Currently, the throttle system is controlled by an Arduino Uno using one codebase, and the braking and steering systems were intended to be operated using a Teensy with another codebase. Developing two separate codebases is difficult and impedes or complicates future software development. Any safety component implemented in software would have to be implemented twice for both codebases. Additionally, unifying the interface into one microcontroller would reduce power consumption, and allow subsystems to poll each other's state and interact with one another. This could give the throttle an opportunity to disengage if it sees that the brake system has recently engaged.

Additionally, the interface to the cart can still be improved. The monitor installed now has high power consumption and a low-resolution screen. Also, the interface to the monitor is a keyboard and mouse, which could be difficult to use in motion, and especially without a flat surface to rest on. Replacing the computer monitor with a power-efficient, high-resolution touchscreen monitor would eliminate both these concerns at once. A custom graphical interface could also be developed with buttons that could be tapped to issue different commands to the golf cart.

Finally, the Gompei hood ornament was recently damaged in transit, as this year's MQP attempted to transport the golf cart to the second floor of the Atwater Kent building. It is recommended that a new print be made, where data files can be found in the appendix, and that a coat of paint be added for visual appeal.

These future improvements together would do a great deal in bringing the golf cart closer to roadworthiness and completion. Each task can be broken down into reasonable subtasks that could be achieved within the course of one MQP, if done appropriately and carefully. The team hopes that these changes will be implemented, and will the further the success of the golf cart for future years.

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# Appendix A: Server Components Information

| Central Computing Platform | Quantity | Price | Total | | |
|---|---|---|---|---|---|
| Motherboard: LGA1150 (CPU-compatible socket) | 1 | $199.99 | $199.99 | | ASUS Z87-PRO Intel motherboard |
| CPU: Intel i7-4770K, 3.5 GHz quad-core | 1 | $339.99 | $339.99 | | Intel Core i7-4770K Haswell 3.5GHz LGA 1150 84W Quad-Core (BX80646I74770K) |
| GPU: NVIDIA GeForce GTX 770 | 1 | $380.00 | $380.00 | | GIGABYTE GeForce GTX 770 2GB 256-bit GDDR5 450W (GV-N770OC-2GD) |
| RAM: 4x8GB, DDR3-2133 (240-pin) | 1 | $314.99 | $314.99 | | G.SKILL Ripjaws Z Series 4x8GB, DDR3-2133 (F3-17000CL11Q-32GBZLD) |
| SSD 240GB | 1 | $170.00 | $170.00 | | Intel 335 Series Jay Crest SSDSC2CT240A4K5 2.5" 240GB SATA III |
| PSU (1050W) | 1 | $200.00 | $200.00 | | SeaSonic X-SERIES X-1050 1050W |
| Case | 1 | $52.00 | $52.00 | | 120 qt coleman xtreme cooler |
| Case fans | 6 | $15.00 | $90.00 | | COUGAR CF-V12H Vortex Hydro-Dynamic-Bearing |
| CPU Cooler | 1 | $50.00 | $50.00 | | XIGMATEK Dark Knight II SD1283 Night Hawk Edition |

# Appendix B: Car Battery Datasheet

## Duracell Marine & RV Batteries

| GROUP NO. | PART NO. | PERFORMANCE LEVEL | | FREE REPLACEMENT WARRANTY | MAXIMUM OVERALL DIMENSIONS | | | | | | FOOTNOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCA @ 0°F | REF. MCA. | | Length | | Width | | Height | | |
| | | | | | inch | mm | inch | mm | inch | mm | |
| **12 VOLT DURACELL® MARINE / RV STARTING** | | | | | | | | | | | |
| 24 | HP24M | 800 | 1000 | 12 MONTHS | 10 ¾ | 273 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,17,22,U |
| 24 | D24M | 550 | 650 | 12 MONTHS | 10 ¾ | 273 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,17,22,U |
| 27 | HP27M | 840 | 1050 | 12 MONTHS | 12 ½ | 318 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,17,U |
| **12-VOLT DURACELL® MARINE / RV DUAL PURPOSE STARTING / CYCLE SERVICE** | | | | | | | | | | | |
| 24 | HP24DP | 550 | 685 | 12 MONTHS | 10 ¾ | 273 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,12,17,44,U |
| 27 | HP27DP | 650 | 810 | 12 MONTHS | 12 ½ | 318 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,12,17,44,U |
| 31 | HP31DP | 700 | 875 | 12 MONTHS | 13 | 330 | 6 ¾ | 171 | 9 ½ | 241 | 6,17,21,22,44,U |
| **12 VOLT DURACELL® MARINE / RV DEEP CYCLE SERVICE** | | | | | | | | | | | |
| 24 | HP24DC | 500 | 625 | 12 MONTHS | 10 ¾ | 273 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,11,17,35,44,U |
| 27 | HP27DC | 575 | 715 | 12 MONTHS | 12 ½ | 318 | 6 ¾ | 171 | 9 ⅜ | 238 | 6,11,17,35,44,U |
| 31 | HP31DC | 650 | 810 | 12 MONTHS | 13 | 330 | 6 ¾ | 171 | 9 ½ | 241 | 6,11,17,21,22,35,44,U |

FOOTNOTES:
6. Black cover / Black case
11. Low maintenance-low antimony grids
12. Hybric construction
17. Includes handle
21. Anchor lock elements
22. Flush manifold vented cover
35. Deduct 15% from CCA and CA rating shown to allow for double insulation (glass mat)
44. Free replacement warranty is 3 months in full electric vehicle use

U. Molded-in offset SAE post and vertical 5/16" NEG., 5/16" POS. stainless steel studs & hex nuts

### STARTING

***Quicker Turnover with Less Cranking***

- High cranking power for quick engine starts
- Flush cover, easy-to-install design
- Extra reserve capacity for emergencies
- Maintenance-free design

### DUAL PURPOSE

***Starting and Cycling Power Solutions***

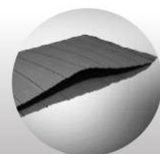
- High starting and deep cycle capability
- Longer cycling than starting battery
- Extra reserve power for accessory loads
- Rugged vibration resistant construction

### DEEP CYCLE

***More Fish-Finding, Trolling and Accessory Power***

- More power for trolling and electronic accessories
- Built-in protection against deep discharge damage
- Rugged vibration resistant construction
- Reliable power for modest starting

*Deep cycle batteries also have special fiberglass mats to improve deep cycling and long-life performance.*



**Extended Life Systems**

- *Special separators prevent life-robbing electrical shorts*
- *Protects power producing components*


**Optimized Full-Frame Plates**

- *Better withstands severe service demands*
- *Optimizes current transfer*

**Enhanced Durability Designs**

- *Fortified current carrying components resist vibration*
- *Maximizes performance throughout battery life*

**EAST PENN manufacturing co., inc.**

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# Appendix C: Parts List for 2016 – 2017

| Part | Description | Link | Price |
|---|---|---|---|
| Velcro Straps | Keep batteries + wiring in place | https://www.amazon.com/dp/B0069FJR2M/ | $14.00 |
| USB hub | Expands on the amount of USBs available from the server | https://www.amazon.com/dp/B00BWF5U0M/ | $7.00 |
| USB/aux cord speakers | USB powered speakers for music | https://www.amazon.com/dp/B00GHY5F3K/ | $14.00 |
| Physical kill switch | Cut power | https://www.amazon.com/dp/B015GYB7FQ/ | $8.00 |
| 14 Gauge Wires | For components on cart | https://www.amazon.com/gp/product/B0196ZHPIE/ref=oh_aui_detailpage_o03_s01?ie=UTF8&psc=1 | $30.00 |
| Underglow Led Light Strips | For style | https://www.amazon.com/dp/B00ASHQQKI/ | $23.00 |
| 4 Gauge Wire | For between batteries, main connection to engine + server | https://www.amazon.com/dp/B016HGOH3G/ | $52.80 |
| 4 Gauge Wire Copper Rings | | https://www.amazon.com/dp/B005V9UVXG/ | $10.00 |
| Electrical Strink Wrap | To cover wire conections | https://www.amazon.com/dp/B00LVFDLUO/ | $8.00 |
| Remote security system | Used for wireless kill switch | https://www.amazon.com/dp/B002FYK586/ | $30.00 |
| 48 volt carger | For motor batteries charging | https://www.amazon.com/dp/B003JSLWWA | 300 |
| 4th battery for motor | Exra battery | http://www.samsclub.com/sams/duracell-marine-battery-group-size-27dc/prod3590231.ip | 80 |
| 2xWebcam | To replace Raspberry Pis | https://www.amazon.com/dp/B003LVZO8S/ | 64 |
| 2xElectrical Gloves | | https://www.amazon.com/dp/B003U2P00U/ | 36 |
| Anderson Connector 4 Gauge | Physical Kill Siwtch | https://www.amazon.com/gp/product/B0129E1KF8/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1 | 15 |
| Wire Terminals | Terminals to connect wires to different terminals | https://www.amazon.com/gp/product/B00H1O0WOM/ref=oh_aui_detailpage_o03_s00?ie=UTF8&psc=1 | 16 |
| 48V Battery Monitor | Measures Battery Power | https://www.amazon.com/gp/product/B01EOWAEXW/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1 | 30 |
| 12V Battery Monitor | Measures Battery Power | https://www.amazon.com/gp/product/B01IBYO4MQ/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1 | 30 |
| Power Strip (Power Station) | Plug in for both chargers | https://www.amazon.com/gp/product/B00BH2RU9O/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1 | 20 |
| Fuses | To protect devices | https://www.amazon.com/gp/product/B01CEB6B1Y/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1 | 7 |
| Fuse Holders | To hold the fuses | https://www.amazon.com/gp/product/B00VLBAF84/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1 | 7 |
| Solder | to solder wires together | https://www.amazon.com/gp/product/B000G31NWK/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1 | 7 |
| Solder Wiring Holder | To help solder wires | https://www.amazon.com/gp/product/B000RB38X8/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1 | 6 |
| Bolts, Nuts, Washer kit | Kit with an assortment of sizes of nut,s bolts, and washers | https://www.amazon.com/gp/product/B019PXB6Z0/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1 | 9 |
| Double Sided Tape | Double sided tape | https://www.amazon.com/gp/product/B00D38MFXQ/ref=oh_aui_detailpage_o08_s00?ie=UTF8&psc=1 | 10 |
| Battery box | Box to hold on of the parallel batteries | https://www.amazon.com/gp/product/B004W5SGBO/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1 | 16 |
| 4 Gauge battery cable plugs | Connectors for 4 Gauge wires | https://www.amazon.com/gp/product/B00030CXWU/ref=oh_aui_detailpage_o05_s00?ie=UTF8&psc=1 | 7 |
| Battery monitor holder | Holds battery monitor in place | https://www.amazon.com/gp/product/B019DXZRBQ/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1 | 7 |
| Music LED controller | Sensor to have LEDs react to music | https://www.amazon.com/gp/product/B00L7ORS76/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1 | 7 |
| Electrical tape 10 Pack | Electrical Tape | https://www.amazon.com/gp/product/B01H0S9BSG/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1 | 15 |
| Wireless kill switch | wireless kill switch | https://www.amazon.com/gp/product/B012ZR49LQ/ref=oh_aui_detailpage_o03_s00?ie=UTF8&psc=1 | 10 |
| Wireless kill switch batteries | Batteries for remote for kill switch | https://www.amazon.com/gp/product/B005HX2YT0/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1 | 6 |
| Raspberry Pi 3 Kit | Raspberry Pi 3 Kit | https://www.amazon.com/gp/product/B01C6Q2GSY/ref=oh_aui_detailpage_o05_s02?ie=UTF8&psc=1 | 70 |
| Aux extension cord | Extension cord for aux | https://www.amazon.com/gp/product/B00LM4ON2E/ref=oh_aui_detailpage_o03_s00?ie=UTF8&psc=1 | 7 |
| DVI to DVI cable | Display cable fore monitor to server | https://www.amazon.com/gp/product/B0131RQX6I/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1 | 12 |
| Resistor 20W 500Ohm | Replace solenoid resistor | https://www.amazon.com/gp/product/B008G4PZ48/ref=oh_aui_detailpage_o00_s01?ie=UTF8&psc=1 | 7 |
| Computer extension cord | Cord to reach from server to DC to AC convertor | https://www.amazon.com/gp/product/B01IWB65AW/ref=oh_aui_detailpage_o00_s01?ie=UTF8&psc=1 | 9 |
| Monitor Mount | Mount monitor for future years | https://www.amazon.com/gp/product/B000ID7QNI/ref=oh_aui_detailpage_o05_s00?ie=UTF8&psc=1 | 15 |