Autonomous People Mover

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Abstract

Imagine parking your car at a large industrial complex, hoping into a people mover cart, instructing the driver where to go, then sitting back while the driver shuttles you off to your destination using the fastest route. Now imagine this same scenario, but with no driver: the cart is an autonomous vehicle. You speak, it obeys your commands. Self-driving, or autonomous cars are a hot research area for car manufacturers. By the mid-2020's, most agencies predict this new phenomenon will transform the automobile market. These cars will make our roadways safer, our environment cleaner, our roads less congested, and our lifestyles more efficient. Because of safety, manufacturing costs, and limitations of current technology, autonomous off-road vehicles, such as people movers in large industrial or academic institutions, will probably emerge before autonomous high-speed highway driving. A three year multidisciplinary capstone project is underway which will transform a golf cart into an autonomous people mover. In year one, the cart will be converted to remote control. In years two and three independent multidisciplinary senior design teams will enable the cart to drive autonomously in controlled and natural conditions respectively throughout the campus. The cart will include advanced sensing and vision technologies for navigation, and use advanced audio and vision technologies to communicate with passengers. This paper will describe several factors to consider when forming capstone engineering student design teams in academia, and then discuss specific issues when designing a large autonomous vehicle. Detailed design considerations and safety issues along with the actual steps and parts necessary to convert a golf cart into a remote controlled vehicle are covered. The paper will conclude with year two and three plans to convert the golf cart into a fully autonomous people mover and beyond.

Introduction

It is only a matter of time until un-manned cars will dominate the automotive industry. Information Handling Services (IHS) Automotive, the world's top automotive industry forecaster, estimates that in the 2020's the autonomous vehicle will begin to take over the market. IHS Automotive predicts that the number of autonomous cars will grow from 230,000 in the year 2025 to 11.8 million by the year 2030 to 54 million by the year 2035, to virtually all cars and trucks by the year 2050 [1]. In 2014, Induct Technology started experimenting with the world's first commercially available driverless vehicle- an open air minibus for college and corporate campuses that can top out at 12 mph. Self-driving vehicles will make our roadways safer, our environment cleaner, our roads less congested, and our lifestyles more efficient [1-4]. Additionally the U.S. economy will save an anticipated $40B/year for each 10% of American cars that are converted to full autonomy [4]. Commuters around the world eagerly anticipate advancements in technology and changing of laws to allow these vehicles to take over our roadways. What started with cruise control, is now driver assist, will develop into highway auto-pilot, and finally into full autonomy. From the U.S. Department of Transportation (USDOT), to the National Science Foundation (NSF), to large private grants, big money is exchanging hands to bring about this transformation. Google's self-driving cars have already logged over 700,000 miles. Audi, BMW, Cadillac, Ford, GM, Mercedes-Benz, Nissan, Toyota, Volkswagen, and Volvo are all working towards driverless vehicles [4]. In the past few years, autonomous vehicle research at both the private and university level has experience a resurgence. As evidence, the USDOT Moving Ahead for Progress in the 21st Century Act provided $72M in each of 2013 and 2014. Further, in 2013, the USDOT Research and Innovative Technology Administration appropriated $63M to 33 University Transportation Centers [7].

To enhance the engineering experience, many universities include a capstone project to integrate engineering theory and processes in a multi-disciplinary setting. Following sound engineering design, project teams start with customer needs, determine specifications, evaluate solutions using proven engineering principles, select methods and components, then design and build a prototype which meets these requirements. The goals of these capstone projects may include: 1) analysis of customer requirements and engineering specifications; 2) develop creative solutions to tough problems using theory from a broad range of multidisciplinary courses; 3) obtain first-hand experience with the engineering design process; 4) documentation of the necessary engineering steps from product conception to product delivery; 5) learn how to communicate technical content in both oral and written form; 6) gain practice working in a team environment; 7) understand the rigors of developing and following a detailed budget and schedule; 8) understand how to break complex problems down into manageable components; and 9) discover how to make effective design decisions which will maximize customer satisfaction.

Several universities have instituted autonomous driving projects, most inspired by the DARPA Grand Challenges from 10 years ago [5,6]. Despite an initial boom, expensive sensors and the need for large corporate sponsorship forced most universities to discontinue research. Sensor costs for high speed driving are still very high, but have since come down dramatically for low speed driving. The algorithms, including localization, obstacle avoidance, and navigation, are very similar for high vs. low speed driving. This paper describes how one university has used the multidisciplinary capstone project design process to enter the field of autonomous driving. The engineering student design team is tasked to convert a low speed golf cart into an autonomous people mover. This paper describes the year-one efforts to convert a golf cart into a remote control vehicle. Year two and three efforts will use state-of-the-art sensors and algorithms to teach the car how to drive autonomously in controlled and natural conditions respectively. As this project proceeds, the university is positioning itself to do future research on both high and low speed driving.

Background

The Kate Gleason College of Engineering at Rochester Institute of Technology includes a two-semester multi-disciplinary senior design project. This project-based course requires students from multiple engineering disciplines to work on teams, each tasked with building a project that meets customer requirements. The team must create specifications and address issues and risks to ultimately deliver a tangible product to the customer. A faculty guide assures the team practices sound engineering methodologies and one or more faculty champions who have a vested interest in the project provide technical assistance. The team must identify and recruit other technical consultants as necessary from both academia and industry. Each project has a sponsor or customer, who is the ultimate recipient of the final product. The team must extract meaningful specifications from the customer, and then ensure customer satisfaction throughout the process as unforeseen problems arise.

Large sport complexes, corporate and government campuses, and universities often have dozens of walking paths connecting parking lots and buildings. During a large event such as a festival, concert, or ceremony, dozens of club cars (people movers) shuffle humans from one location to the next. Negotiating these paths with an autonomous club car requires routine path following, potentially tricky obstacle avoidance, as well as complex tracking and interacting with dozens of dynamic objects. This paper describes a robust platform to tackle each of these problems using sound engineering principles in a senior design capstone project setting. Projects from other universities [8-11] have attempted to tackle similar problems. The project in this paper leverages learnings from others along with improvements in technology.

The autonomous people mover project is a three-year multidisciplinary senior design project (MSD). This program gives a group of student engineers from a number of disciplines a problem that must be solved using standard engineering design techniques. To do so these students are assigned a guild from industry and have regular meetings with their customers. Each MSD team participates for two semesters. The first semester is a planning and design phase and the second semester is a build and demonstration phase. The design portion of MSD is comprised of designating team roles, idea brainstorming, design selection, and detailed system design. The first semester is split into multiple three-week cycles with documentation and design checkpoints along the way. For the build phase, the detailed design created in the first half of MSD is fabricated. During the build phase, there are regularly scheduled reviews with the customer to show the current status of the product and demonstrate any functionality that has been achieved. The intent of MSD is to give graduating seniors real world design experience in addition to their required internships as well as valuable insight from seasoned engineers.

The year one senior design team is comprised of four mechanical engineers and three electrical engineers. This group of seniors is responsible for the physical modification of the golf cart to enable radio control of the golf cart, including all mechanical upgrades, electrical interfaces, user interfaces, and control systems. Sub-teams were created to tackle individual areas, but all students participated in design and brainstorming sessions for all activities. This paper will concentrate on the year one effort.

Year two and three efforts will concentrate on localization, navigation, and obstacle avoidance. Localization, or the exact determination of vehicle location and pose, will use a combination of extended Kalman filters and particle filters using measurements from GPS and sensor readings [12,13]. The year three effort will include object classification and tracking. Object classification will use advanced machine learning, borrowing concepts from the fields of manifold learning, sparse representations [14], as well as deep belief networks [15]. Tracking will use locally developed methods that borrow concepts from state-of-the-art trackers, such as Tracking-Learning-Detection [16] and Multiple Instance Learning [17].

Design

The design of the autonomous golf cart is a multi-year endeavor. In order to provide a platform for further development, a 2005 Yamaha G22E golf cart needed to be modified such that it could be driven manually (by a human driver) or driven via wireless remote control. The Yamaha model was chosen because of its simple and robust mechanical and electrical assemblies. The vehicle required heavy modification of the steering and braking systems as well as electrical integration with the onboard controller. Multiple safety mechanisms protect the passengers and those in the near vicinity. Further, to abide local laws, a trained human will ride with the cart at all times and intervene in case of an emergency.

In order to properly steer the golf cart remotely, the Yamaha's rack-and-pinion system had to be modified. Multiple solutions were presented such as using a motor and belt system, drive by wire directly connected to the steering column, and a pre-built power steering system. A feasibility analysis determined a pre-built power steering system was the best option. The power steering system was donated by Wicked Bilt and consists of a torque sensor and motor. In order to install the Wicked device, a mounting bracket had to be designed and installed. The designed bracket is shown in Figure 1 below.

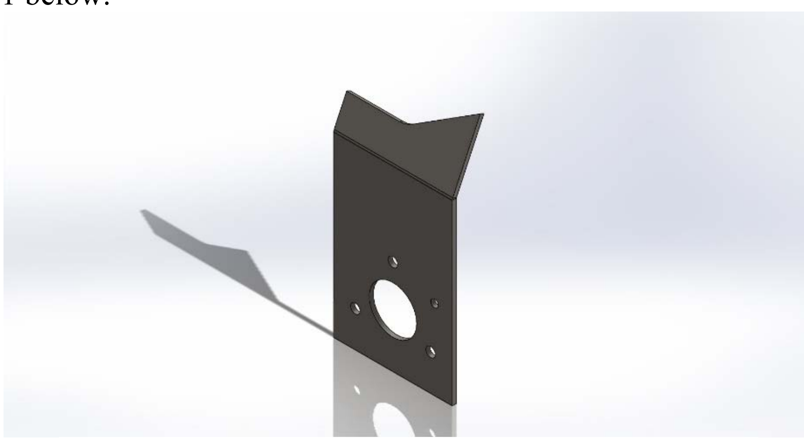

Figure 1: Designed Wicked Steering System Mounting Bracket

Additionally the steering column had to be shortened and a steering column spline provided by Wicked was used to interface with the Yamaha rack and pinion steering. To sense the position of the steering column, a multi-turn potentiometer was determined to be lower cost and simpler to implement than a multi-turn encoder. To mount the potentiometer a small L-bracket was used. The installed system is shown in Figure 2.

Figure 2: Installed Wicked Steering System

The electrical interface with the steering system consists of 12V power for the motor as well as a 5V input to the system's internal controller. Control is provided by two differential inputs coming from the torque sensor that reads the torque input from the driver. This input torque is then scaled by the Wicked system and applied to the steering column. To interface with the system, the torque sensor lines were connected to relays along with input lines from the designed control system. When power is applied to the relays, the output connected to the Wicked system switches from the torque sensor to the signal lines as shown in Figure 3 below.

Figure 3: Steering System Relay

The braking system of the golf cart also had to be modified, however not as significantly as the steering. To implement remote braking, an actuator was used to pull a steel cable that was connected to the brake petal. Due to the size of the actuator it required a pulley to make a 90° turn before connecting to the brake petal. The actuator and the pulley were mounted to the golf cart frame. The system level design with respect to the cart is shown in Figure 4 with the pink cable used for visibility.

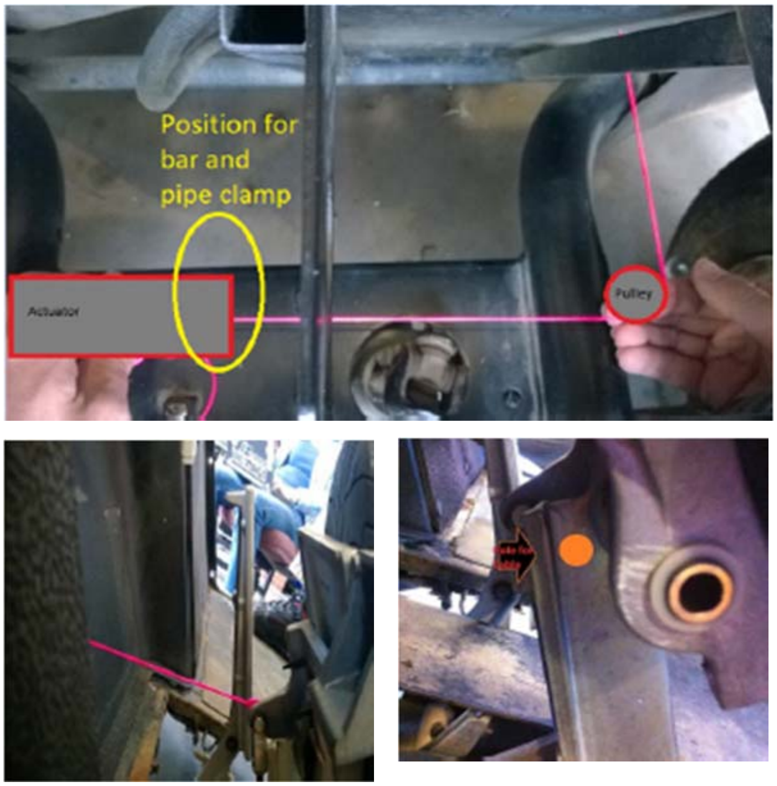

Figure 4: Braking System Design with Respect to Cart Placement

This method allows for the passenger in the driver's seat to still be able to hit the brake in an emergency situation. To sense the position of the brake pedal, internal potentiometers inside the actuator along with a magnetic field sensor on the brake pedal are used. The fully installed system is shown in Figure 5.

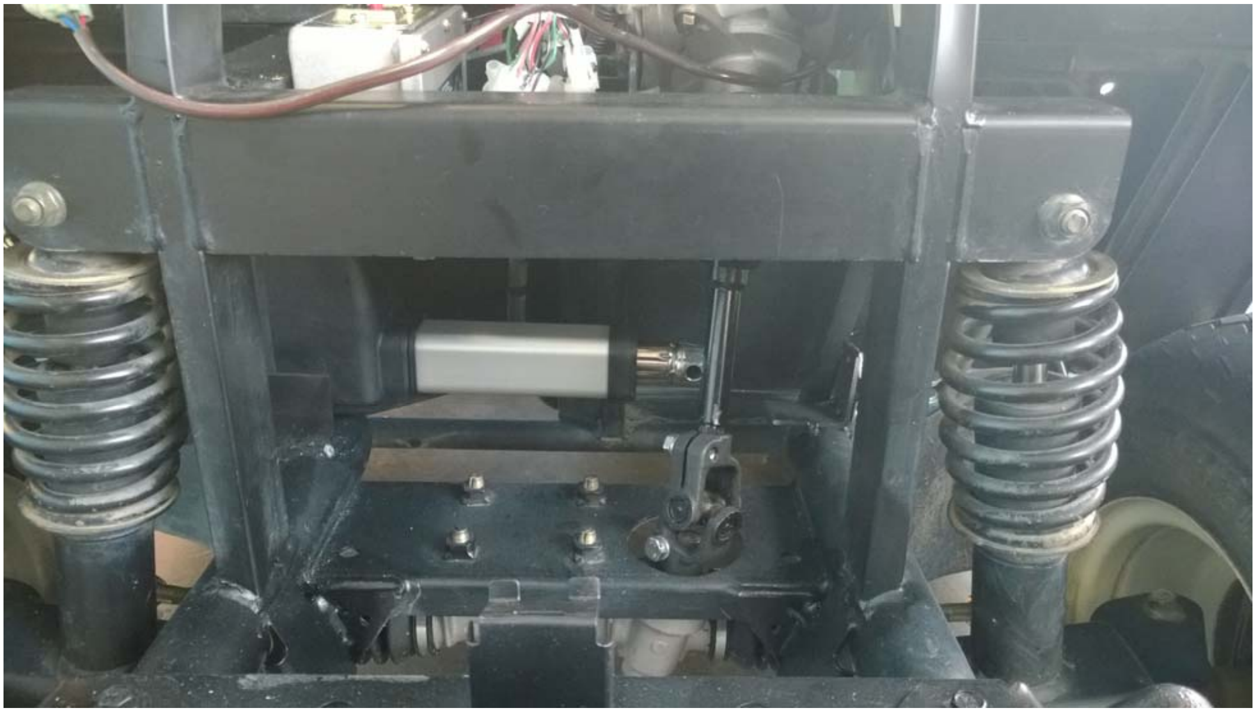

Figure 5: Fully Installed Braking System

The braking system is controlled using a Sabertooth R/C Regenerative Dual Channel Motor Controller. This system requires a 12V input as well as a 1ms to 2ms-pulse width input signal provided by the designed control system. The internal actuator potentiometer is used to control the position of the actuator and the magnetic sensor is used to sense if a human passenger applies the brake. If a human passenger applies the brake, the golf cart will be stopped.

To control the acceleration, the input to the controller of the golf cart is switched from the existing throttle potentiometer to an analog to digital converter (ADC) from the controller. A relay system was used similar to that of the Wicked steering system as shown below in Figure 6.

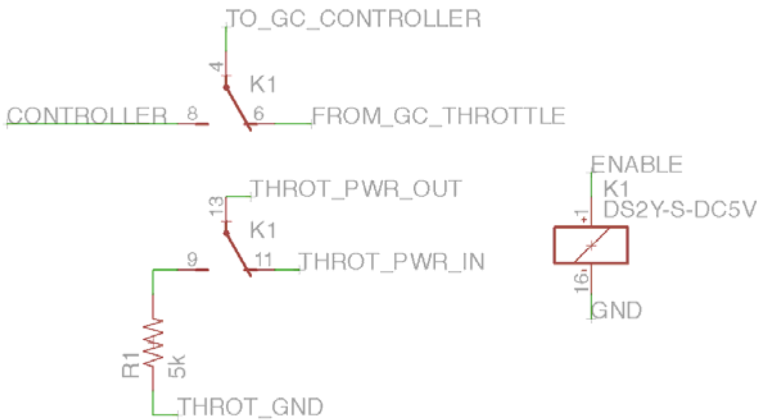

Figure 6: Throttle Relay Circuit

In order to prevent a condition where the power and the ground to the potentiometer are disconnected, a dummy 5kΩ resistor is used to emulate the throttle potentiometer. Without this the golf cart controller experiences a fault and will not operate.

To provide feedback to the passengers in the vehicle, the dashboard was modified as shown in Figure 7.

Figure 7: Modified Dashboard

The modified dashboard includes five LED status lights, three green for the accelerator, steering, and braking systems, one green for the readiness of the overall system, and one red for check engine. The large red button show in Figure 7 is an emergency stop button. A LCD is used to show the current speed, position, and time. The large red LED is a status light provided by the wicked system. A rocker switch (above the keyhole) allows passengers to switch between remote and manual operation of the vehicle. A second rocker switch (next to the keyhole) is the FWD and REV switch.

To control all of the golf cart systems, three Arduino Dues are being used; one for the braking/acceleration, one for the steering, and the third for the dashboard and overall control. A custom printed circuit board (PCB) was created using Eagle PCB design software for general connections and support circuitry. The throttle and braking Arduino uses both available ADCs to output the accelerator control signal. The output of the Arduino ADCs are bound between .55V and 2.75V. In order to convert this range to the required 0-3.3V the golf cart controller requires the level shifting circuit shown in Figure 8.

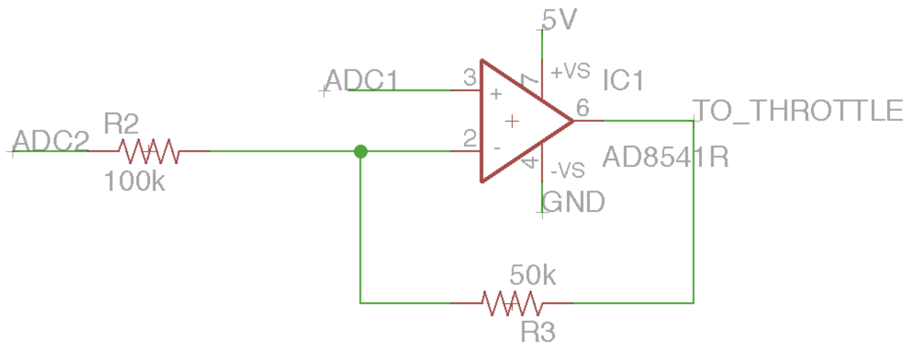

Figure 8: Level Shifting Circuit for Accelerator

The Wicked system requires a input voltage of 0-5V from each of the differential input signals therefore the same topology as Figure 8 was used but with different resistor values to adjust the range. Arduino pulse-width modulation pins were used to control the actuator controller.

The remote and receiver kit is a Spektrum DX6i with a receiver that is attached to the electronics box on the rear of the golf cart. The receiver outputs a 1ms-2ms pulse that is read in by the Arduinos. The remote channels used are forward, left-right, and a toggle switch. The toggle switch is an emergency stop that, when activated, will bring the cart to an immediate stop. Additionally, a global positioning system has been included in the cart to read position and speed from an external source. The designed PCB is captured in Figure 9 and is used to make connections for the power system, Arduinos, Yamaha controller, and Dashboard.

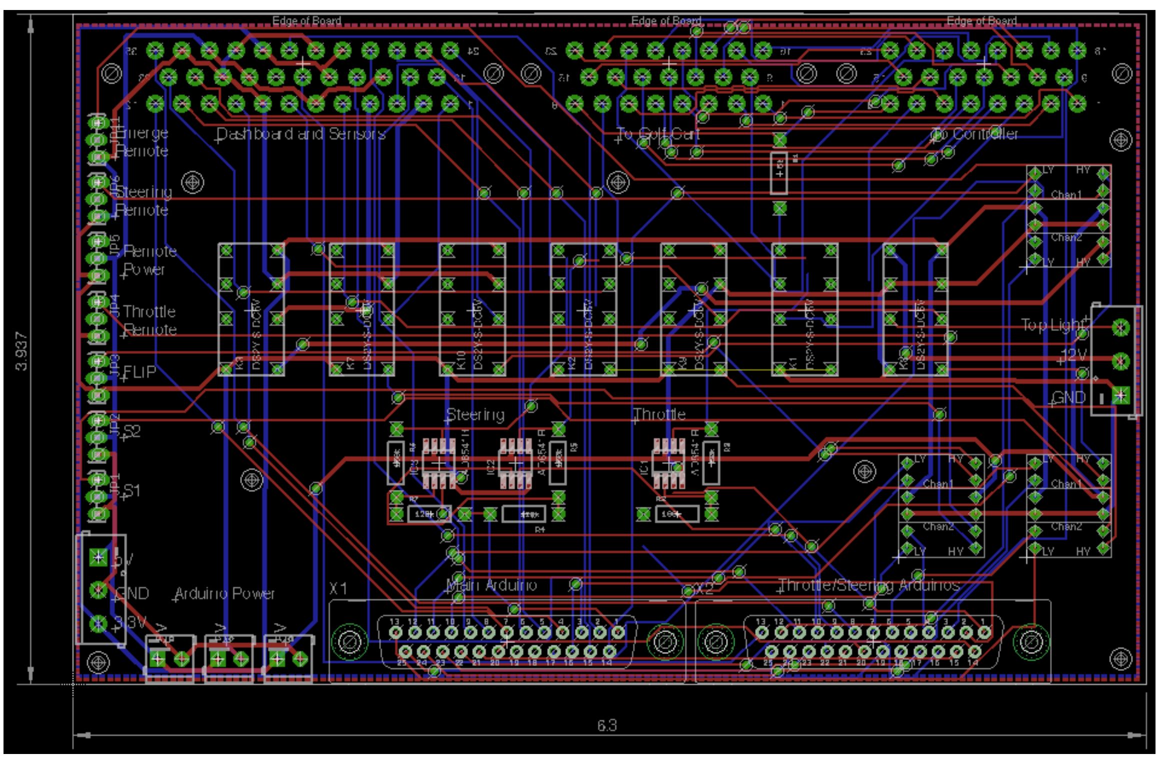

Figure 9: Designed PCB

The golf cart is powered using the onboard 48V battery bank and supplemented with a 12V battery to help mitigate large instantaneous current draws by the braking and steering systems. The power system diagram is shown in Figure 10.

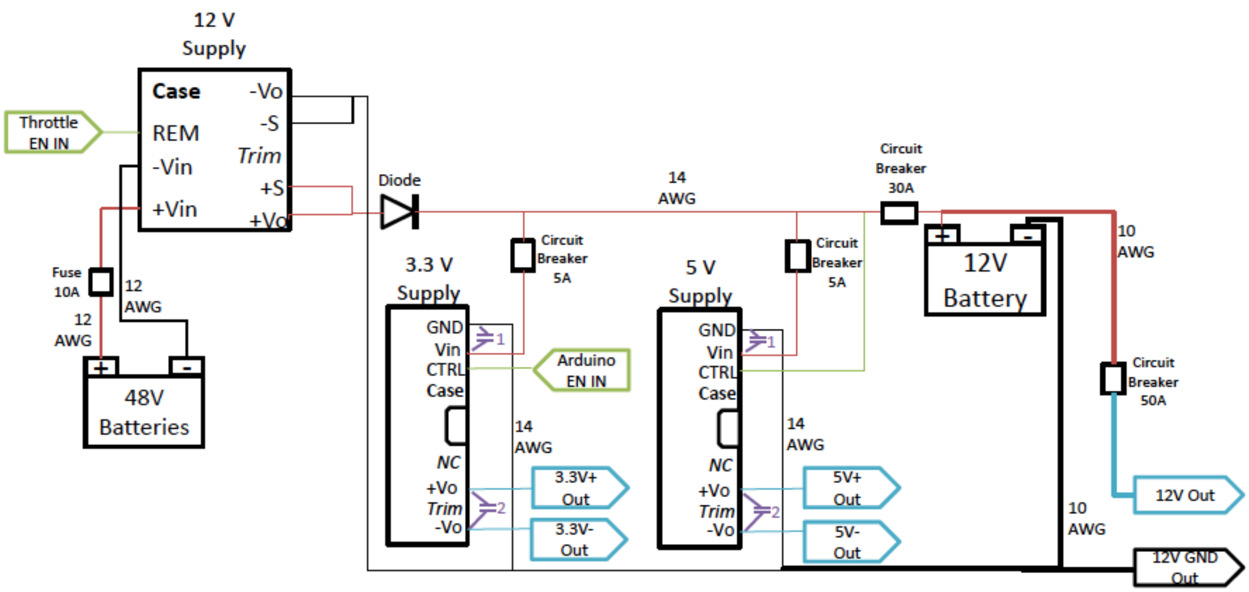

Figure 10: Designed Power System

Safety was the driving factor in the design of all systems. In order to ensure passenger safety, multiple mechanisms have been built in. There are three ways to instantly stop the cart: the emergency stop button on the dashboard, the brake pedal, and the emergency stop button on the remote. If any of these buttons are pressed, the golf cart will instantly stop. Additionally, the unpowered position of all relays is in the manual-driving mode, therefore even if power is lost the passengers will be able to safely take control of the vehicle. Within the control system, all systems must run through a test sequence each time the cart is switched into autonomous mode. This is to prevent unknown faults in the system from going unnoticed.

Discussion and Future Work

This paper summarized key findings from a two-semester multidisciplinary capstone project-where the particular capstone project was the first of three consecutive one year long projects. Each capstone project will build upon the learnings, successes, and failures of the previous. This first phase successfully created an autonomous driving platform by making the necessary mechanical and electrical modifications to a golf cart. Although sound engineering principles were followed, the execution of the project had its fair share of problems. For example, most tasks took longer than expected and many small time slippages often turned into larger schedule problems. Further, it proved difficult to forecast the difficulty of a diverse set of tasks, and therefore the required effort and time commitment was not always shared evenly across all team members. The team learned the value of methodical trouble shooting, noting that even the simplest tasks can be difficult. Because the team was developing a foundation from which future teams could build upon, there was additional pressure to ensure perfection throughout each step in the process.

During the next phase of this multi-year project, the golf cart will have sensors installed and be able to run a pre-determined course without the assistance of an operator. This second phase team is currently researching optimal sensors and developing algorithms to perform navigation with obstacle avoidance. The final year will develop more complicated control systems to allow the cart to navigate anywhere on campus, track surrounding objects, and make decisions as to the quickest route through pedestrian filled walkways.

Conclusion

Multidisciplinary senior design capstone projects provide students with a unique opportunity to experience all aspects of the product life cycle including customer interaction, customer requirements, industry research, product cost, product risk, schedule management, and product deployment. To provide sound experiential learning for senior engineering students and to facilitate future autonomous driving research, an autonomous senior design project has been created. Self-controlled vehicles are a popular item in the automotive industry due to the increased safety benefits of removing the human factor from driving. The hope is this technology will help to make commute times shorter and decrease the likelihood of accidents. The first step in designing an un-manned vehicle was to take an electric golf-cart and convert it to be controlled remotely. The steering system was replaced by an in-line, power steering system provided by Wicked Bilt. The brakes use an actuator and pulley system to move the brake petal. To modify the accelerator, the control signals from the throttle petal were intercepted and replaced with microcontroller generated control signals. The power system required the generation of 12V, 5V, and 3.3V to power the electronics and electromechanical systems. The team gained real-world experience on how to satisfy customer needs while staying on budget and on schedule. This project laid the foundation for future senior design teams to design an autonomous people mover. The final autonomous cart will also serve as a multidisciplinary platform for further research into all areas of autonomous vehicles.

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