Autonomous People Mover: Adding Sensors

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ABSTRACT

It is no longer a question *if* self-driving cars will transform society, but when. By the mid-2020's, most agencies predict autonomous driving 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, will probably emerge in large industrial complexes before autonomous high-speed highway vehicles. A three year multidisciplinary capstone project is underway which will transform a golf cart into an autonomous people mover. In year one, the cart was converted to remote control. In years two and three, tightly integrated but independent multidisciplinary senior design teams will enable the cart to drive autonomously in controlled and natural conditions respectively. The cart will include advanced sensing and vision technologies for navigation, and use innovative 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 relative to this project. Detailed design considerations and safety issues, along with the necessary steps and parts, are covered. The paper will conclude with the year three plans to convert the golf cart into a fully autonomous people mover and beyond.

1. INTRODUCTION

Autonomous automobiles offer passengers the ability to sit back and watch a movie instead of white knuckling the steering wheel during today's hectic commutes. Can you imagine a world were texting and driving is encouraged, no drunken drivers, no worries about the elderly drivers who left their glasses at home, and friendly waves to the driver next to you that is shaving, eating breakfast, and talking with his boss on the way to work? Automobiles will be able to drive closer to one another making commutes faster, our roads less congested, our environment cleaner and lives more efficient [1-4]. Most importantly, car transportation will be safer. Honda, Nissan, Mercedes-Benz, Volkswagen, Tesla, and five other top auto manufacturers have already been given permission to test their autonomous cars in the state of California.

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. Google's autonomous cars have logged over 2 million miles, with a public offering anticipated by 2020. Self-driving 18-wheelers are already being tested by German automobile company Daimler on the roads of Nevada.

The U.S. economy could save up to $40B/year for each 10% of American cars that are converted to full autonomy [4]. Despite all the anticipation, there are some big questions that need to be resolved. Will these cars be able to speed in case of an emergency? When an object is blocking a single lane highway, will it be able to go around it? When an accident is unavoidable, will it choose to hit the car on the left or the food truck parked on the shoulder? Will lawyers sue the family in the car, the auto manufacturer, the insurance company, or perhaps the software company that programmed ill logic? Despite these questions, what started with cruise control, is now driver assist, will develop into highway autopilot, 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. In the past few years, autonomous vehicle research at both the private and university level has experienced a resurgence. As evidence, the USDOT Moving Ahead for Progress in the 21st Century Act provided $72M in each of 2013 and 2014. In 2013, the USDOT Research and Innovative Technology Administration appropriated $63M to 33 University Transportation Centers [7]. In 2015, Nokia earmarked $100M for connected vehicles, Toyota appropriated $50M for intelligent car research, and even Apple unofficially entered the autonomous car race. 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 decreased dramatically for low speed driving. The algorithms, including localization, obstacle avoidance, and navigation, are very similar for high vs. low speed driving. Today, autonomous car research is hotter than ever. The University of Michigan has created Mcity, an entire simulated city devoted to autonomous car driving under disparate driving conditions. Virginia Tech has received millions of dollars for their connected vehicle infrastructure research, and Carnegie Mellon University wants to double the size of their autonomous robotics program.

To enhance the educational experience, many universities include a capstone project to integrate engineering theory and processes in a multi-disciplinary setting. Following a sound engineering design process, project teams start with customer needs, determine specifications, evaluate solutions, select methods and components, and then design, build, and test a prototype which meets these requirements. The goals of these capstone projects 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.

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-two efforts to convert a golf cart into an autonomous vehicle under controlled conditions using state-of-the-art sensors and algorithms. Year three efforts will teach the car how to drive autonomously in natural conditions.

2. BACKGROUND

The Kate Gleason College of Engineering at Rochester Institute of Technology includes a two-semester multidisciplinary 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.

The autonomous people mover project is a three-year multidisciplinary senior design (MSD) project. 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. Each MSD team participates for two semesters with one semester of overlap. The phase I team successfully converted the vehicle to remote control. The phase II team has been making the electronics that control the vehicle more robust and has been adding sensors to the vehicle. A phase III team has just begun. As the project approaches the 1.5 year mid-point, this paper addresses several key issues in adding sensors and transition of knowledge from one team to the next.

For each team, 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, concept selection, and detailed system, subsystem, and component 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 and evaluated. During the build phase, there are regularly scheduled reviews with the customer to show the current status of the product and demonstrate functionality that has been achieved. The intent of MSD is to give graduating seniors real world design experience, using structured design process, in addition to their required internships as well as valuable insight from seasoned engineers.

The efforts of the phase I team have recently been presented [18]. The phase II senior design team for this project is comprised of three electrical engineers, two computer engineers, one mechanical engineer and one industrial engineer. This team is working with an additional group of three computer engineers. This group of seniors is responsible for the implementation of sensors to the cart and writing algorithms that enable autonomous driving of the cart under controlled conditions. This includes writing algorithms that utilize sensors mounted on the cart to navigate a pre-planned route while avoiding objects, manage electrical interfaces, user interfaces, and control systems.

Year three efforts will concentrate on improving localization, navigation, obstacle avoidance and overall functionality of the cart. 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 learning [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].

3. DESIGN

Once the systems design was completed and agreed upon, a systems architecture was defined that consisted of the following subsystems; throttle, braking, steering, path and obstacle detection, and path planning.

3.1 Controls

The modification of the golf cart, to make it remote control was described by [18]. The brake, throttle, and steering are summarized here for completeness.

The cart's braking system was modified so that the brakes would work in both manual and autonomous modes. Modification was performed by utilizing a linear actuator that is attached to the brake pedal via a steel cable that can pull the brake pedal down. This solution was chosen so that in case of an emergency the brake pedal would be able to be pressed by a passenger to manually stop the vehicle. In order to control the brake actuator a Sabertooth R/C Regenerative Dual Channel Motor Controller was driven by an Arduino Due microcontroller via a 1ms to 2ms pulse width modulation signal. A 2ms signal is used to retract the actuator or brake, a 1.5ms signal is used to make the actuator not move, and a 1ms signal is used to extend the actuator.

To throttle of the cart is controlled via an analog signal being fed to the stock motor controller box. This analog signal is controlled by a 5K potentiometer connected to the gas pedal. The input to the controller of the cart was redirected from the throttle potentiometer to the analog to digital convertor (ADC) on the Arduino Due. A dummy 5K Ω resistor was added to emulate the throttle potentiometer in the situation where the power and ground to the potentiometer were disconnected. The voltage required to move the cart ranges from 0V to 3.3V, where 3.3V is the top speed of the cart of about 12mph. The voltage applied to the stock motor controller box is proportional to the speed of the cart.

The steering system was augmented with an automotive grade WickedBilt electric power steering system. This system allows passenger or motor control of the steering column. Differential signals generated by the Arduino Due microcontroller feed the

WickedBilt controller box for left and right steering. In addition to controller the steering, the controller box has torque feedback which indicates if a passenger is attempting to turn the steering wheel. A potentiometer is connected to the steering column via a drive chain to determine steering position for interactive control code. The steering control code for future teams will rely on two primary variables from the autonomous drive logic: desired steering angle and urgency of the request. The urgency of the request will be directly related to rotational velocity thresholds of the steering input and the anticipated lateral acceleration experienced as a result of the steering input.

To establish autonomy, the cart will need to be able to navigate around its surroundings. To navigate there were multiple sensors added to the cart. Each one of the sensors was picked to provide a different range, ensuring that the cart's vision is reliable as possible. All of the sensors chosen had to meet IP67 standards since the cart will be operated outside in all weather conditions. The main sensor that was chosen was the Velodyne VLP-16 PUCK. The Velodyne PUCK is a LiDAR that is used for real-time 3D distance measuring. The PUCK has the ability to support 16 channels and can measure 300,000 points per second. The VLP-16 has a range of 100m with an accuracy of 3cm, a horizontal field of view of 360 degrees, and a vertical field of view of 30 degrees. This sensor will be primarily used for two main functions: obstacle detection and path planning.

In order to perform more robust obstacle detection, two high definition Hikvision DS-2CD2032-I HD 3MP IR stereo cameras are mounted on the front of the cart. These cameras augment the LiDAR, enabling more accurate object identification, and help identify paths, roads, grass using color information. In low light or night driving, built-in IR illumination is automatically activated.

To more reliably detect objects directly in front of the cart, three MB7001 LV-MaxSonar-WR1 ultrasonic sensors were added to the front. Ultrasonic sensors use sound instead of light to measure distance. This is important because LiDAR cannot detect windows or other non-reflective surfaces. To get the data from the ultrasonic sensors code provided by Maxbotix was utilized to convert the analog input to usable measurements on the Arduino. The MB7001 ultrasonic sensors have a range of 6.45m and unlike most ultrasonic sensors the field of view is beam instead of a cone. This allows the placement of the sensors to be closer to the ground to detect objects such as curbs.

To help give the cart a sense of directionality and the ability to localize, a EM-506 GPS unit was added. The EM-506 uses the National Electrical Manufacturers Association (NEMA) protocol to communicate. NEMA sentences are translated into decimal coordinates on the Ardiuno Due microcontroller. Using these coordinates, it is possible to find distance between points, and the desired heading of the cart.

A Lilliput FA1011-NP/C 10.1 inch touch screen interface provides constant feedback to passengers. The interface will display a map of the carts surroundings and show the direction and heading of the cart as it moves about the campus. Additionally, when used in debug mode, diagnostic information of all sensors will be displayed continuously. Future teams may use this touch screen interface along with voice recognition to interact with passengers.

3.2 Software Design and ROS

The software controls for receiving and interpreting sensor data and controlling the systems on the People Mover are designed using Robot Operating System (ROS). While ROS is not an actual operating system, it is a network of programs and data registers used for the development of robotic control systems. A ROS network is built on topics and nodes. A ROS topic is a publicly accessible data register used by ROS nodes for their specific function. A ROS node contains programs that execute when the data has been updated in specific ROS topics.

In this case, the ROS network enables data to be received and processed from different types of sensors, develops an environment map of the immediate surrounding of the people mover, navigates a safe path to drive using that environment map, and finally sends the appropriate control signals to the hardware systems of the People Mover. There is an extensive ROS support community where many open source ROS packages already exist that have the functionality that the control system needs. The Velodyne ROS package contains the ROS nodes necessary to receive and format data from the Velodyne LiDAR VLP-16, which is arguably the most important and the most complex sensor to be installed on the People Mover. Using this ROS package significantly cuts down on coding and debugging time with the integration of the LiDAR. Additional existing supported ROS packages are currently being investigated for use in the People Mover ROS network, including the navigation package for its widely utilized map building and path planning nodes.

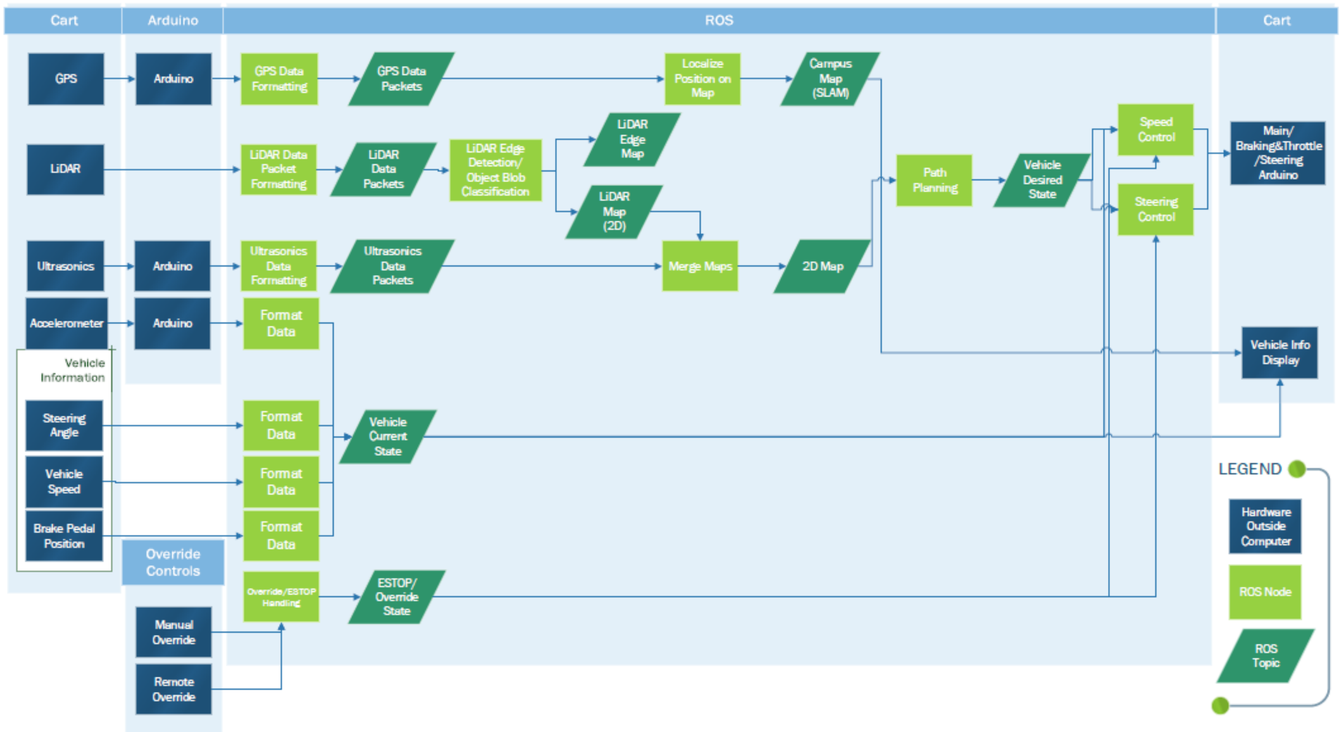

Figure 1: Complete People Mover Software System Flow Diagram

3.3 Processing

The cart required an additional processor to be added for the purpose of receiving input from all of the sensors, making control decisions, and sending control signals to the cart's other subsystems. The processor chosen needed to meet several requirements including power consumption and processing power. The processor also had to include Ethernet and TCP/IP functionality for both the LiDAR and the video cameras, USB functionality for communication with the other subsystems, as well as a video interface for future usage. These requirements restricted the choice to either high-performance microcontrollers or consumer-level desktop processors. The solution chosen was a desktop PC due to the ease of integration and wealth of existing software drivers for the chosen sensors.

The computer that was chosen was generously provided by the Department of Computer Engineering at RIT. The computer uses an AMD A10-7850K processor with a speed of 3.7 GHz and four CPU cores. Graphics processing is included in the CPU using AMD Radeon R7 Series integrated graphics. Additional hardware includes a 120GB solid state drive, 16GB of memory, and included Wi-Fi. The motherboard provides USB 3.0 functionality as well as HDMI. For an operating system, Ubuntu 14.04 LTS was installed on the computer since it was the most familiar environment for the team members as well as having great support for ROS.

The only modification that was necessary was to replace the power supply unit, as it operated off of 120/250V AC power not the 12V or 48V that was available on the cart. To solve this problem several solutions were identified, including a 12V DC ATX power supply, a 48V DC ATX power supply, and a DC-AC inverter. In the end, an additional 12V ATX power supply was chosen. This solution was chosen over several other options as it was the most cost effective and simplest.

3.4 Power

The cart is powered by a 48 volt battery bank which is reduced to 12, 5, or 3.3 volts as needed. Between the sensors and the desktop, 202 watts are required at 12 volts, with the desktop requiring 145 watts. This works out to a current draw of 17.12 amps. The CUI Inc. VFK600 Series 48V to 12V DC-DC converter provides 50 amps at 12 volts, more than enough to run the existing equipment with room to expand in the future. The cart's 48 volt battery bank is estimated to have a battery life of 1.57 hours, or 94 minutes under normal use with the current selection of sensors and compute power.

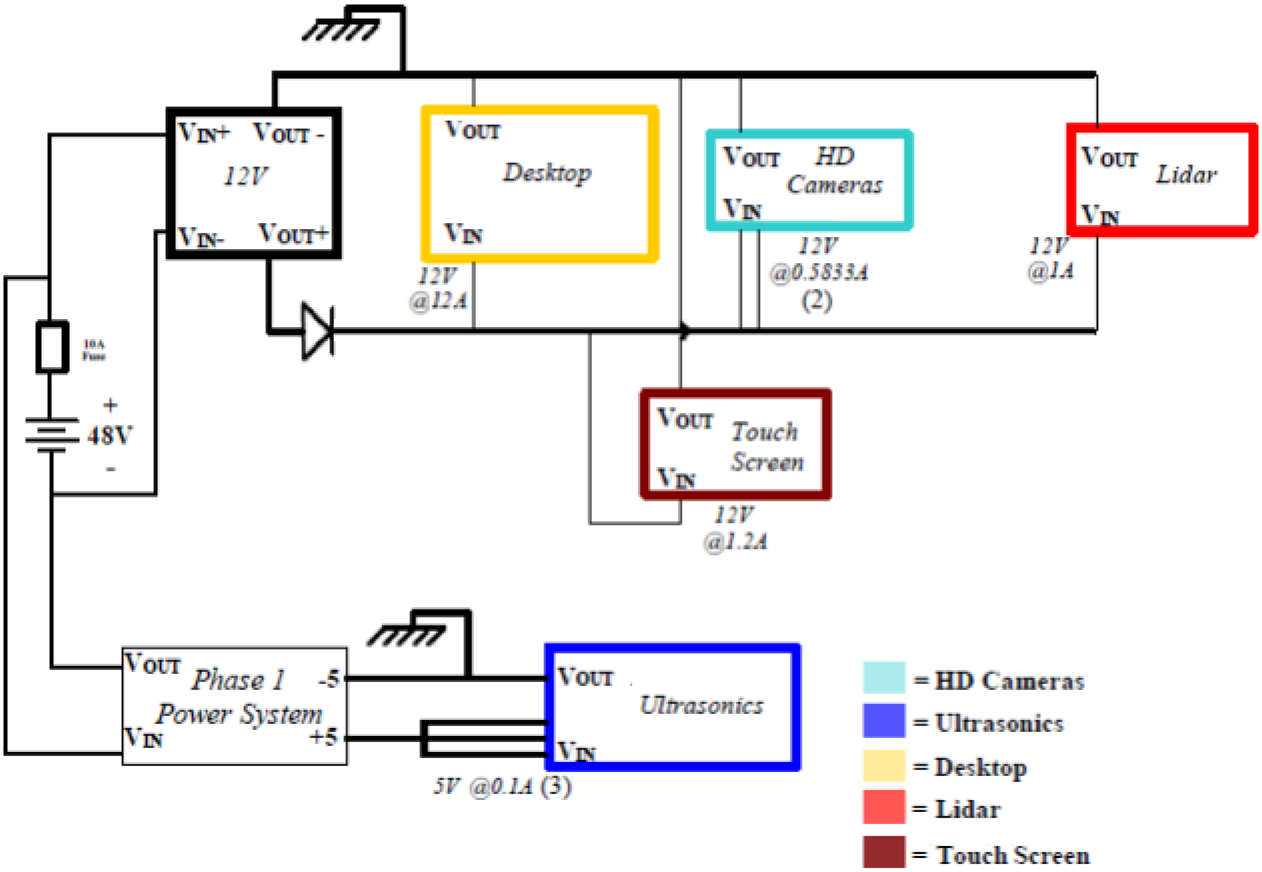

Figure 2: Phase II Overall Power Diagram

3.5 Wiring

Each of the sensors added to the cart influence the need for additional components. Figures 3-5 illustrate the connections and wiring for communication as well as the distribution of power. The 48V input for the DC-DC converter is from the existing battery bank on the cart. The 12V output of the converter is dispersed using five connection terminal blocks and powers the LiDAR interface box, the touch screen display, both HD cameras in the front of the cart, the desktop in the rear of the cart, and the Ethernet switch box. The Ethernet switch box relays the data from the LiDARs interface box, and both HD cameras to the desktop via Ethernet communication. The touch screen display has a HDMI output that splits into a HDMI and USB input to the desktop. The three high quality ultrasonic sensors, and GPS unit are powered by a remote Arduino Uno's 5V output which is distributed by a 5 connection terminal block. The analog outputs of the three ultrasonic sensors are outputted to the Arduino Uno's analog inputs, and the third ultrasonic sensor has an additional digital output that connects to the Arduino Uno's digital input. The GPS unit has a TX and RX connection to the Arduino Uno's TX and RX inputs.

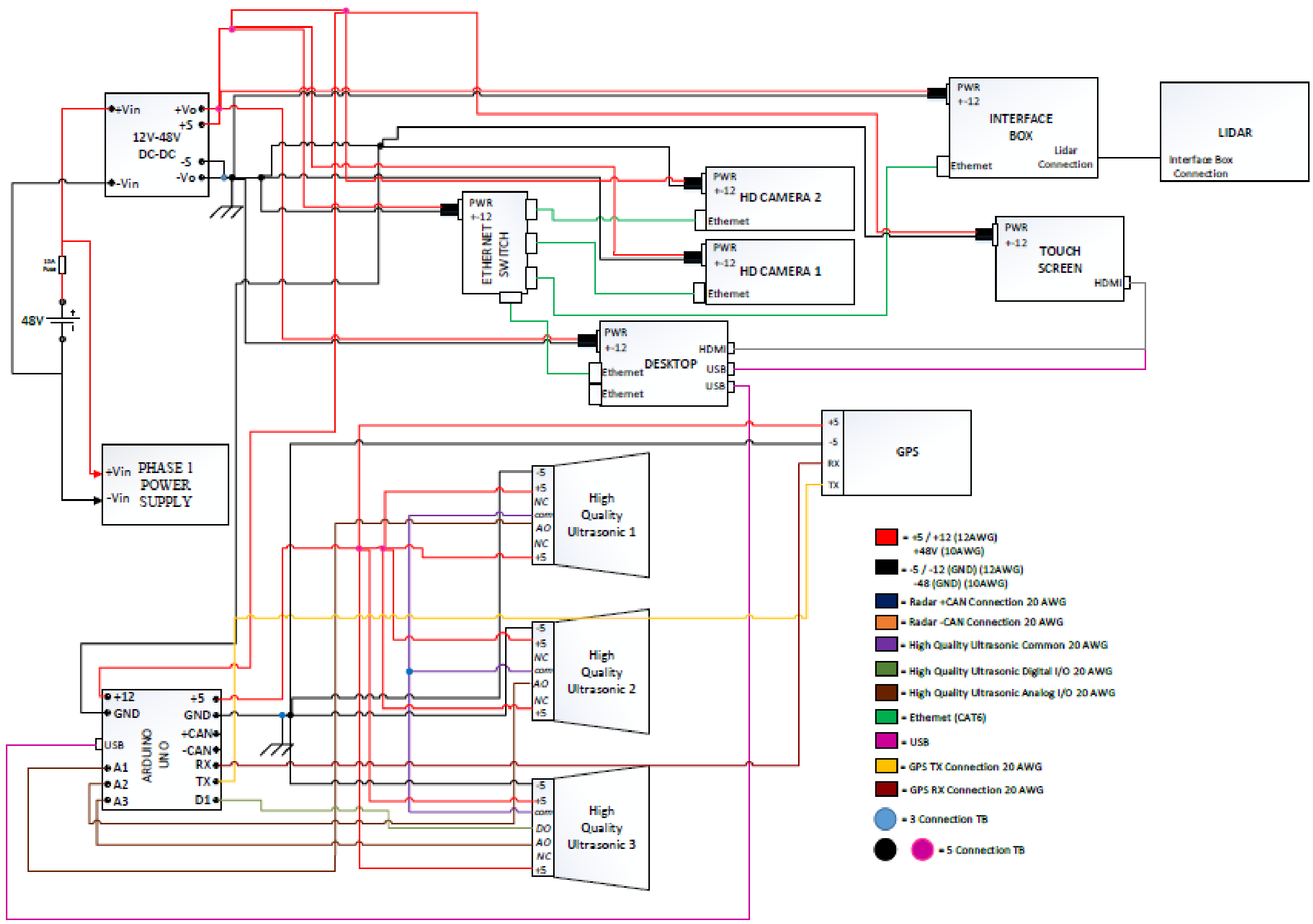

Figure 3: Phase II Overall Wiring Diagram

The placement of each sensor on the cart is shown in Figure 4. The three ultrasonics are at the front of the cart and are powered by, and communicate with the Arduino Uno in the front of the cart. The Arduino Uno also communicates with the GPS units TX and RX. The ultrasonic signals are collected by the Arduino Uno at the front of the cart as to not make the analog signals travel the length of the cart to the back control box, and possibly become distorted during transmission.

Figure 4: Sensor Placement on Cart

The Arduino Uno then relays digital signals directly to the desktop via USB. The 12V output from the 48V to 12V DC-DC converter is run to the 5 connection terminal blocks in the front of the cart to be distributed to save wire and lower costs. The terminal block powers the HD cameras, LiDAR, touch screen display, and Ethernet switch in the front of the cart and the desktop in the rear of the cart. The touch screen display has a HDMI output that splits into a HDMI and USB input to the desktop. The power wiring will be distributed along the right side of the cart and the left side of the cart houses the connections for communication between the sensors and components with the desktop.

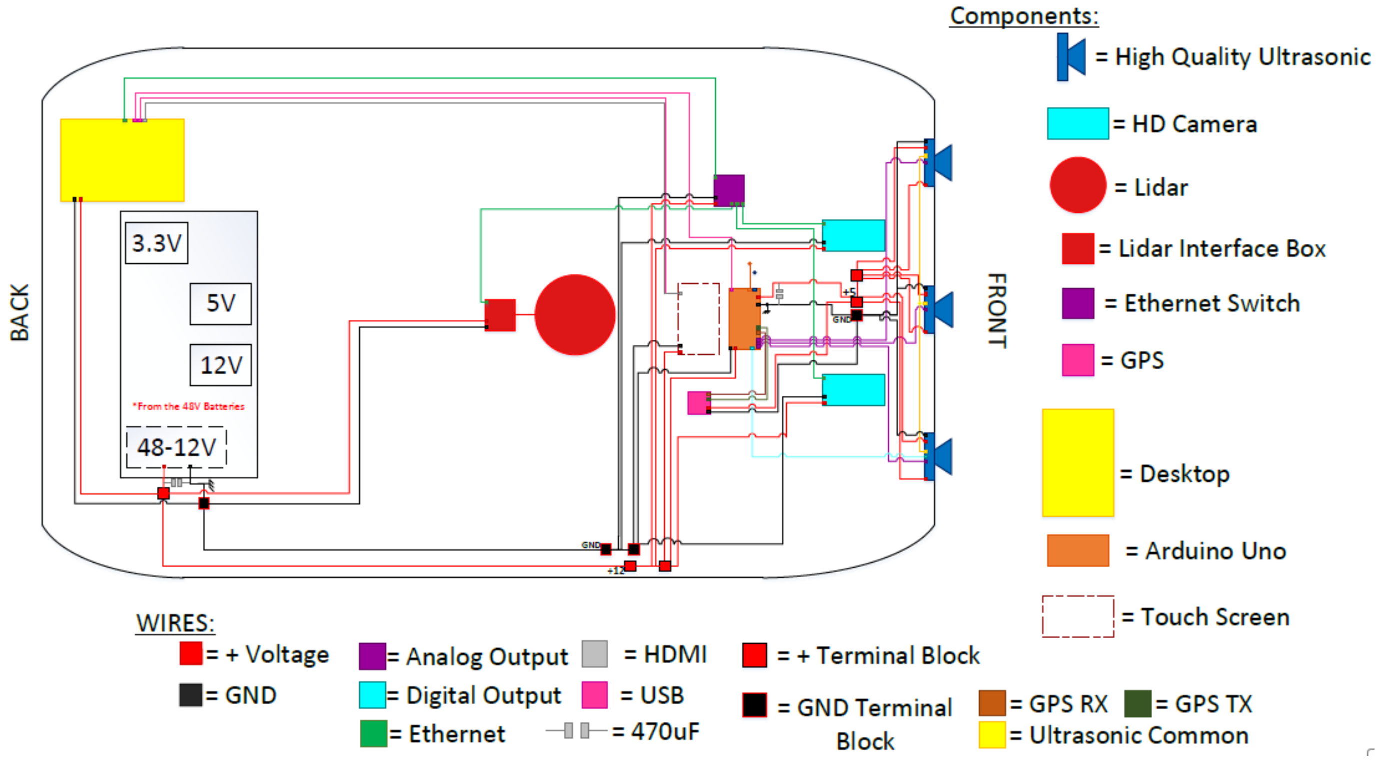

Figure 5: Phase II Overall Wiring Layout

The people mover utilizes three Arduino Due microcontrollers at the back of the cart. The three Arduinos are the main Arduino Due, the throttle Arduino Due, and the steering Arduino Due, each of which are connected to one another via digital IO lines. All Arduinos communicate with the desktop via USB connections.

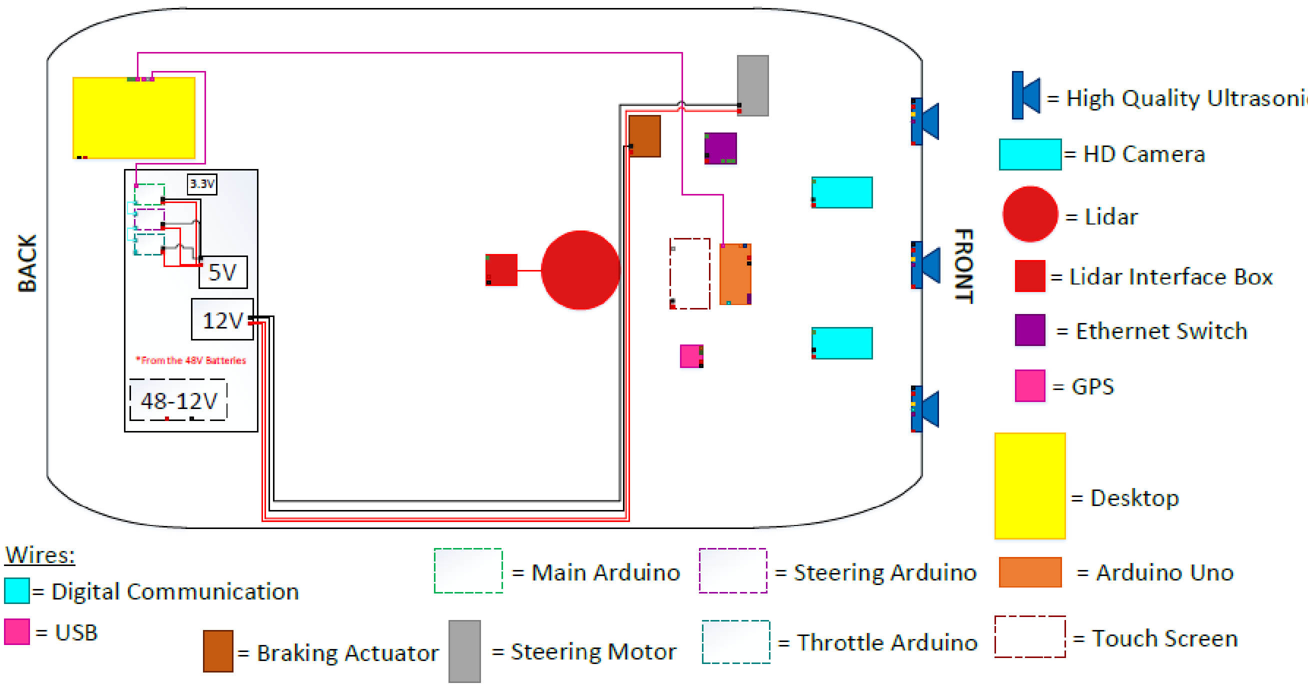

Figure 6: Phase I & II Overlay Wiring Layout

The prototype printed circuit board from the Phase I team was redesigned by D3 Engineering, an engineering company based in Rochester, NY. In addition to updating the electronic controls, D3 designed a custom shield board that allowed each of the three Arduino Due's to be plugged directly into the circuit board.

3.6 Mounting

The three primary mounting challenges present for the autonomous people mover are the Velodyne LiDAR, the PC, and the Stereo Cameras. The Velodyne LiDAR is mounted to the roof of the cart. This mount as shown in Figure 7 is elevated 4 and ½ inches above the roof such that the LiDARs lowest of its 16 beams (pointed 15° below horizontal) clear the edges of the roof.

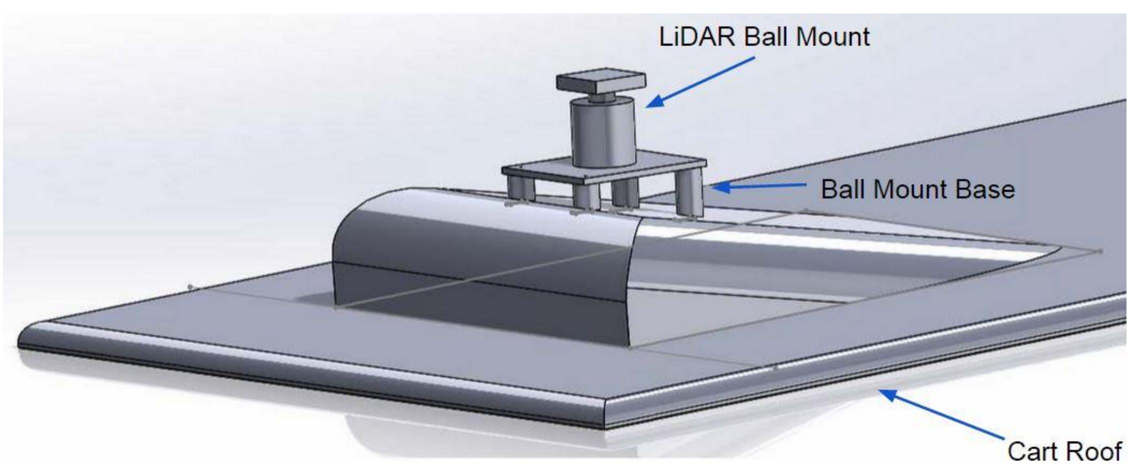

Figure 7: Preliminary LiDAR Mount

The PC is mounted in a hanging rectangular frame that lies just below the primary control box of the cart as shown in Figure 8 . It is mounted to the bottom of the same crossbars that the control box sits on top of.

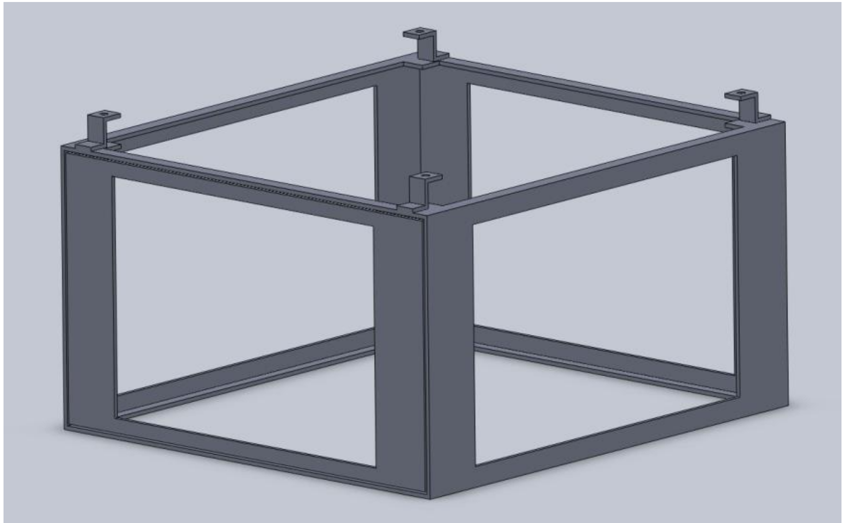

Figure 8: PC Mount

The stereo camera mount as shown in Figure 9 is an angular base that sits on the bottom section of the roof frame just in front of the driver and passenger seat. The angular base compensates for the rake of the roof frame itself and insures that the stereo cameras are pointed perfectly forward. The centers of each camera base are 100mm apart, ideal for stereo camera calibration.

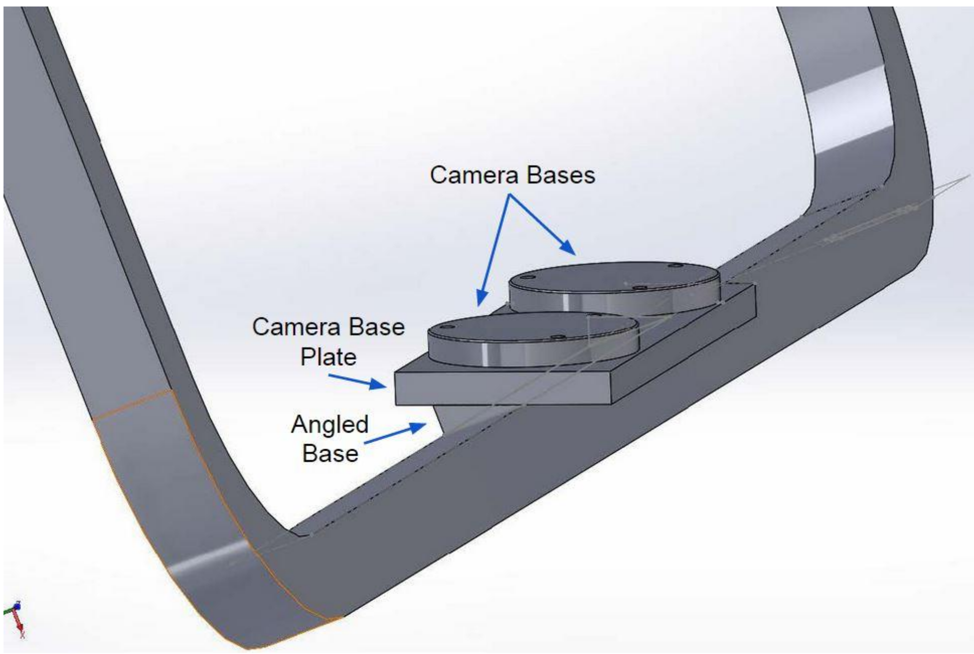

Figure 9: Stereo Camera Mount

4. DISCUSSION AND FUTURE WORK

This paper summarized key findings from a two-semester multidisciplinary capstone project, where the particular capstone project was the second of three consecutive one year long projects. Each capstone project will build upon the learnings, successes, and failures of the previous project(s). This second phase will result in an autonomous driving platform by making the necessary mechanical and electrical modifications to the cart.

Although sound engineering principles were followed, the execution of the project to date has 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 understand and in turn, integrate with the Phase I systems, which delayed the implementation of the sensors. The team learned the value of methodical troubleshooting, noting that even the simplest tasks can be difficult. In addition, the team learned how to split up the work amongst one another and work together to get as much done as possible in the short time frame. Because the team was building upon the Phase I system while developing a foundation for autonomy from which future teams will expand upon, there was additional pressure to ensure perfection and thorough documentation throughout each step in the process.

During the next phase of this multi-year project, the cart will be able to drive autonomously under natural conditions. This Phase III team is currently researching optimal algorithms to perform navigation and obstacle avoidance. This phase will later 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.

5. 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 important to the automotive industry due to the increased safety benefits of removing the human factor from driving. This technology will help to make commute times shorter and decrease the likelihood of accidents. The second step in designing an unmanned vehicle was to take an electric golf-cart, add sensors and program it to navigate a preplanned route. The team added a state-of-the-art LiDAR, three high quality ultrasonic sensors, two infrared (IR) cameras, a touch screen, and a desktop processing computer to the cart. The processing computer will take in data from all the sensors, cameras, and the touch screen to analyze the data and send signals to the Arduinos, which will then control the brake, throttle and steering and allow the cart to drive on its own. The power system required the generation of 12V, 5V, and 3.3V to power the electronics, sensors and other systems. The team gained real-world experience on how to satisfy customer needs while staying within budget and on schedule. This project laid the foundation of autonomy for the next senior design team to expand upon and make a truly 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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