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Slow Moving Vehicle Automation Through an Affordable Retrofit

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Design of an Autonomous Retrofit System for Electric Golf Cart

Abstract

Accessibility and mobility can be challenging for many individuals traveling across large pedestrian spaces such as airport terminals, tourist attractions, and school campuses. Automating slow moving vehicles (SMVs) can provide better accessibility, improve traffic management in crowded areas, and provide a safer mode of transportation. This project's main objective is to design a package consisting of sensors and open-source software that can be integrated with a SMV to enable autonomous driving functionality. This paper discusses the design and development of an autonomous retrofit system for a golf cart, which could potentially be used to provide rides for students needing assistance navigating the campus.

1. Introduction

Door-to-Door transportation for students with mobility issues is an issue widely ignored across campuses in the nation. Campus Disability Resource Database reveals the majority of the universities have no service for helping students with disabilities navigate from building to building [1]. Of the few that list some services, even fewer have door-to-door transportation. An interview with the Disability Resource Center at our University revealed that one of the most frequent requests students with disabilities ask for is transportation from building to building. Adjacent to this issue is the emergence of autonomous vehicles. While self-driving vehicles for general use are still outside of public access, facilities such as warehouses and university campuses provide a controlled space where the benefits of autonomous SMVs can be fully harnessed. In the current market, however, such services and products come with a steep price. Some companies, such as Perrone Robotics, offer a similar service with a monthly subscription fee of $6000 for an autonomous Transit Van [2]. Other companies, such as Carteav, do not state a price, requiring consultation before what is sure to be a high cost. While autonomous SMVs can offer a solution for students with mobility issues, the steep price available in the current market doesn't allow for these to be a reliable solution. Our goal is to create a retrofit kit using open-source and off-the-shelf components that can convert old utility vehicles like golf carts into autonomous SMVs, thereby making localized autonomous driving more accessible and offering a solution for students with mobility issues across campuses nationwide.

This project focuses on developing a computer-controlled sensor suite that retrofits an electric autonomous driving package into SMVs. The retrofit systems are primarily designed for golf carts or other small utility vehicles. The system enables semi-autonomous driving on predetermined routes. As a commercial product, it would be primarily intended for university or other campus-style facility use. Applications include aid for those with mobility impairments as well as research and development for autonomous driving courses. With a system that grants slow moving vehicles autonomous driving capabilities, freedom of mobility can be extended to users who may not be able to drive or navigate otherwise. Additionally, by using open-source software and off-the-shelf components, the autonomous vehicle retrofit system is more accessible to students and engineering professionals interested in learning about autonomous driving and improving system capabilities.

2. Methodology

The primary goal for this capstone project is to develop an electronic system that can be fitted to golf carts and other slow-moving vehicles with minimal modification, and which would enable a golf cart to navigate a given path with minimal input from the user. The system should hold safety paramount above all else for both the driver and pedestrians. Secondary to safety, the retrofit system should also provide a smooth and enjoyable experience for riders. The computer and sensor system should enable automatic/autonomous parking in designated parking locations. Finally, the retrofit system should be at a price point which is affordable to college institutions and golf courses.

Sensing and localization functions enable the autonomous driving features consist of many off-the-shelf digital hardware components. Proximity sensing is achieved with sonar sensors. Three high-resolution cameras are used to detect and classify pathways and obstacles. A kinetic sensor bumper is installed as a failsafe to the proximity sonar sensors and camera system. Braking and steering controls are handled by servo motors controlled via microcontrollers. Acceleration is controlled by a PID control system [3], via a digital to analog converter achieved by a second Arduino microcontroller. All microcontrollers handling the separate components are integrated into a personal computer running a programming script or series of programming scripts written in Python programming language. Sensors will feed data to the microcontrollers which will be passed as inputs to a computer program that will react by sending output data to the various motion control components. The control system is based upon a design found in [4], in which a central control unit handles the majority of the processing and commands.

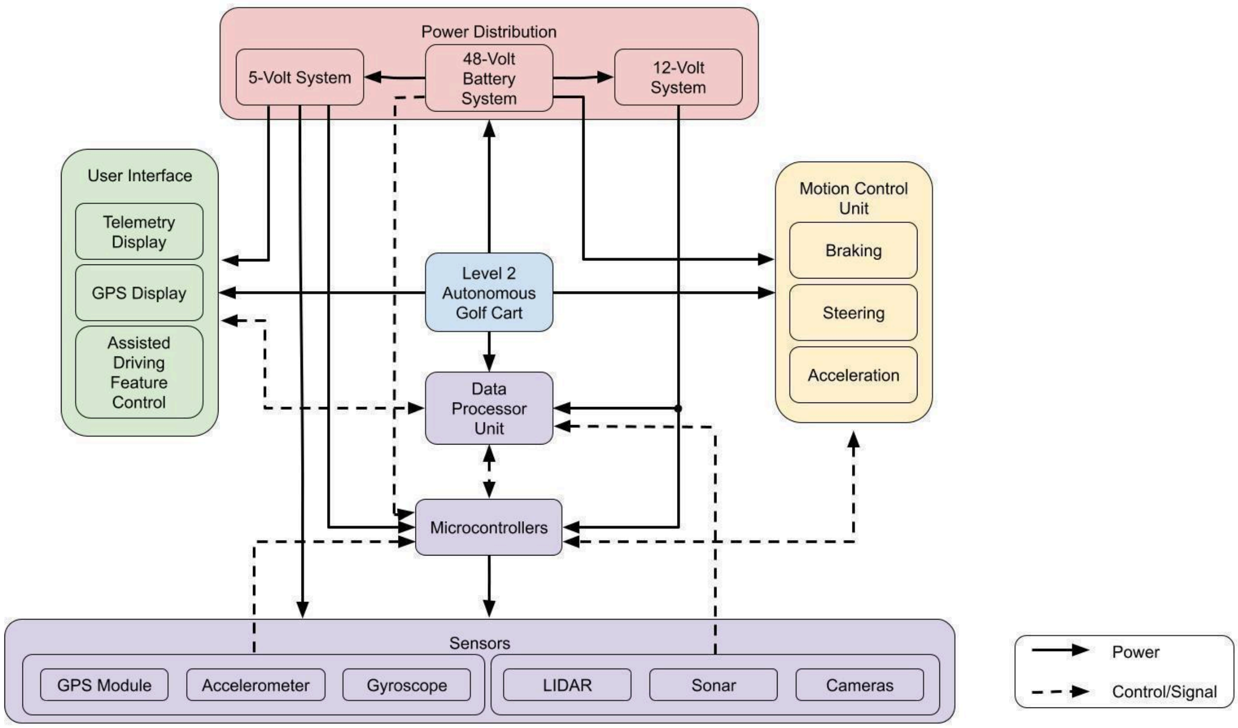


Figure 1: Block diagram of the retrofit system.

The block diagram of the retrofit system is shown in Fig. 1. The system contains four major units: power distribution, sensors, motion control and the user interface (UI). The power distribution unit contains a 5-V and 12-V system in addition to the golf cart's 48-V battery system. Power connections are indicated with solid lines connecting the power source to each component. The sensor unit has a GPS module, accelerometer, gyroscope, sonar and three cameras. The motion control unit has two servo motors controlled by Arduino microcontrollers. The UI has a Raspberry Pi with a 10-inch touchscreen for all the user interactions. Communication connections are indicated by dashed lines with arrows specifying data transfer direction.

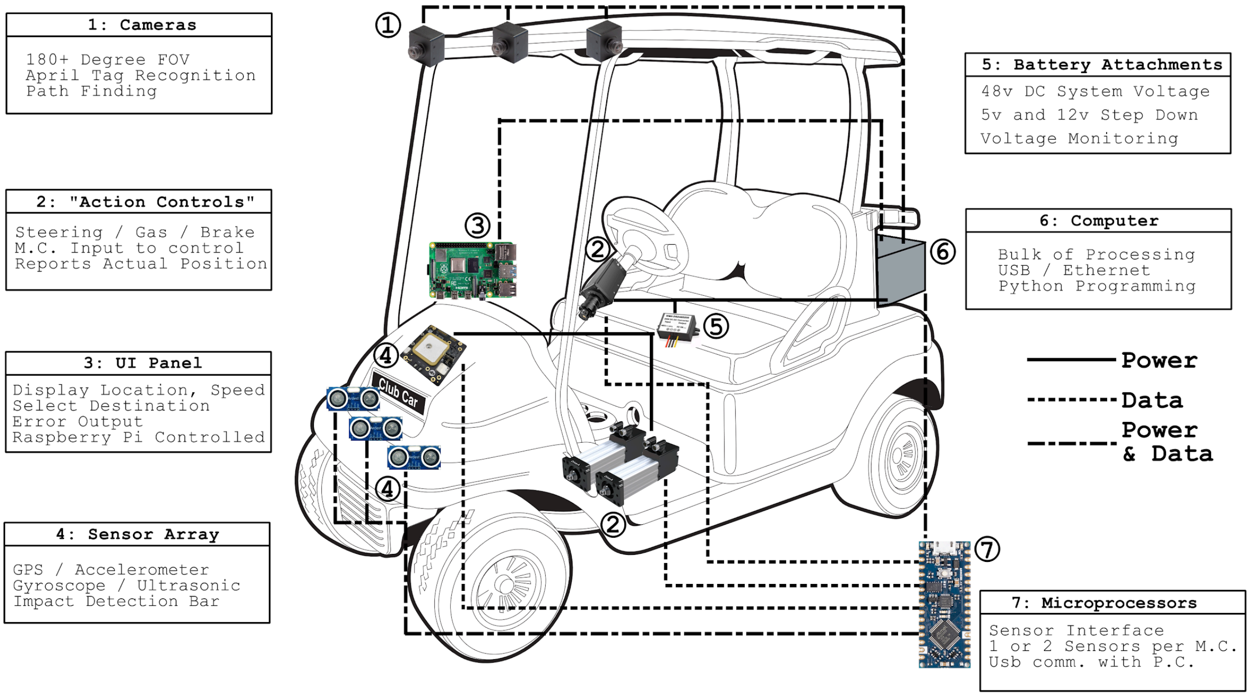


Figure 2: Club Car Golf Cart with added components.

The location, function, and connection of each component on the golf cart is shown in Fig. 2. The power line and data exchange between the components are also included. The cart's speed will be limited to 5 mph, slightly faster than walking speed, to mitigate damage in the event of a collision and allow the automatic systems adequate time to respond to sensor input. A turning angle of 90 degrees is essential for executing right-angle turns, particularly around areas such as our Engineering Building.

For safety, an emergency stop or manual override with immediate response capability (less than 0.1 seconds) ensures the cart can be controlled promptly to prevent damage or injury in the event of an impending collision. Additionally, the cart includes a vision system providing at least a 180-degree field of view to detect obstacles and AprilTags in the path while driving forward.

The GPS system incorporated into the cart can provide high-precision location accuracy, typically around one inch, to maintain the cart's course en route to its destination. To further enhance safety, the collision avoidance system will be capable of detecting obstacles at least 15 feet away, allowing sufficient time for the automatic systems to respond effectively.

Finally, the power system will utilize a 48-volt LiFePO4 battery system, chosen for its high capacity and low maintenance requirements, aligning with the original design specifications of 48 volts.

3. Design Details

The retrofit design includes many components that work together to create a system enabling our golf cart to operate autonomously. Each component plays a crucial role within a larger system that enhances the cart's autonomous capabilities.

3.1 Hardware

3.1.1 Ultrasonic JSN-SR04T sensor

To measure the distance between the golf cart and any object in front of it, we use the ultrasonic JSN-SR04T sensor, ensuring that an appropriate distance of 15 feet is maintained from pedestrians and obstacles.

3.1.2 Arducam AR0234 camera and AprilTag

Another essential part of our autonomous driving system are the cameras used: Arducam 2.3MP AR0234 cameras. The system incorporates three cameras; two of these cameras are dedicated to edge detection, enabling the golf cart to maintain its course by identifying and avoiding boundaries. The central camera is equipped with AprilTag detection, allowing the golf cart to find specific locations and execute tight turns with precision. AprilTag detection software offers a fast and cost-effective means of using computer-aided vision to provide location, position, and pose information for automated vehicles and robots [5]. This allows for navigation without use of expensive equipment such as LIDAR and can work in tandem with edge and lane detection software to guide the SMV on its path autonomously. All the data from these cameras is processed by the retrofit system, ensuring seamless and reliable autonomous operation of the golf cart.

3.1.3 Teknic SDSK servos

Two Teknic ClearPath SDSK servo motors are used for the golf cart. These servos have built-in encoders, servo drives and controllers, with maximum speed up to 5000 RPM, continuous torque from 0.1 Nm to 5 Nm, and high positioning accuracy.

3.1.4 Main computer

The autonomous driving system incorporates a main computer as shown in Fig. 3, enabling communication and control to each subsystem from a central processor. This PC is mounted to the rear of the cart using vibration damping mounts to ensure its safety and longevity. Hardware specifications were chosen for reliable computing bandwidth and speed to accommodate the various sensor inputs. The PC has a 9th Gen i7 processor which will offer sufficient data processing power. Another core component is the 32G DDR4 sodimm form factor. This RAM storage along with 3TB of SSD storage will allow for handling large datasets. The PC's motherboard has two PCIe x16 slots and two PCIe x8 slots. One PCIe x16 slot will be populated by a NVIDIA 3070-Ti accelerated graphics processing card. Two of the PCIe x8 slots will be populated with USB expansion boards to accommodate the connections needed to the various subsystems including microcontrollers and cameras.

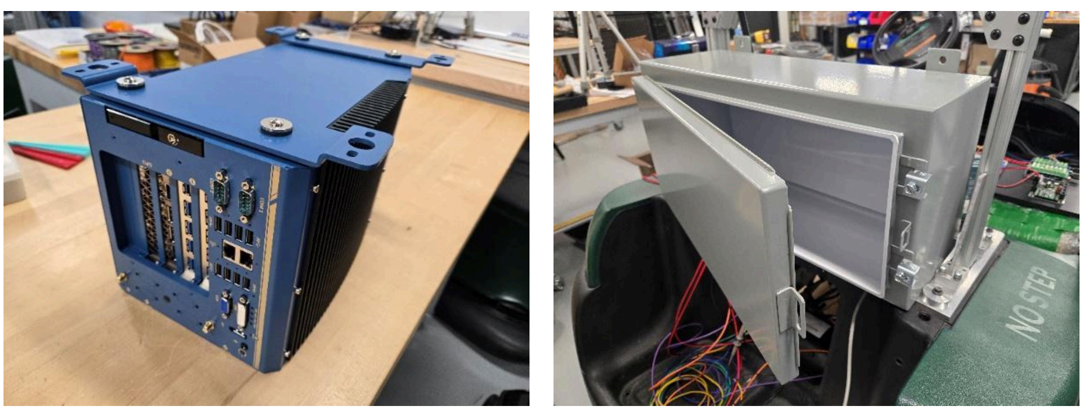


Figure 3: Main computer with GeForce 3070 GPU (left) and the component housing/PC mount (right).

3.1.5 GPS U-Blox C099-F9P

The U-Blox C099-F9P with Real-Time Kinematics (RTK) capabilities was chosen for the GNSS module to provide precise and accurate position and timing information. A typical GPS module can provide accuracy within about 3 to 10 meters. The on-board zed-F9P allows for RTK capabilities that can provide accuracy in the range of 1-3 cm [6]. In order to achieve RTK capabilities, the SMV will use the Michigan Department of Transportation (MDOT) base stations to determine the error in the received satellite signals. This will require the SMV to have wi-fi on board. The board utilizes an ODIN-W2 module for wireless connectivity. The GPS will work alongside other sensors like cameras and IMUs to provide robust positioning and situational awareness.

3.1.6 Microcontrollers

In addition to the Arduino Mega 2560 microcontrollers connected to the motion control servos, the Arduino Nano Every microcontroller was chosen to control power distribution and control the ultrasonic JSN-SR04T sensors. This microcontroller was chosen for its small form factor (4.5cm x 1.8cm) and versatility for sensor integration. There will be one microcontroller for the sonar modules and one microcontroller for the power distribution module. Each microcontroller has a clock speed of 20 MHz, which is sufficient speed for sending and receiving data to the PC.

3.1.7 Raspberry Pi and Touchscreen

A Raspberry Pi 3B Touchscreen Kit will provide a user-friendly and cost-effective display that provides pertinent information to the passengers. The product allows for a highly customizable interface. Easy integration with vehicle systems provides a platform to display navigation and real-time vehicle diagnostics. The built-in Wi-Fi and Bluetooth capabilities supply a seamless connection to the SMV's sensors.

4. Result

4.1 Safety Design

Three ultrasonic sonar sensors will be installed on the front bumper of the cart, providing a wide field of view for detecting obstacles. Fig. 4 shows the sonar power and control wiring. 5VDC will be used to power the sensors, and the Arduino Nano Every will be used to handle the signal.

This microcontroller will also be used to monitor the safety bumper which is mounted on the front of the cart as shown in Fig. 5. A voltage divider is used to convert the 20V signal from the bumper to a 5V signal which the Arduino can read.

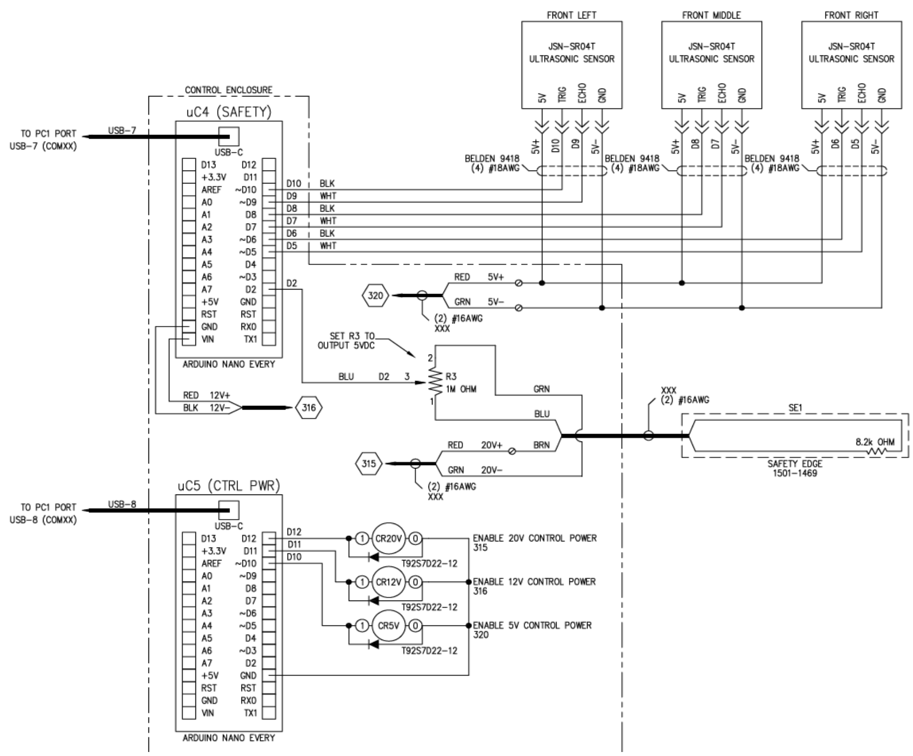
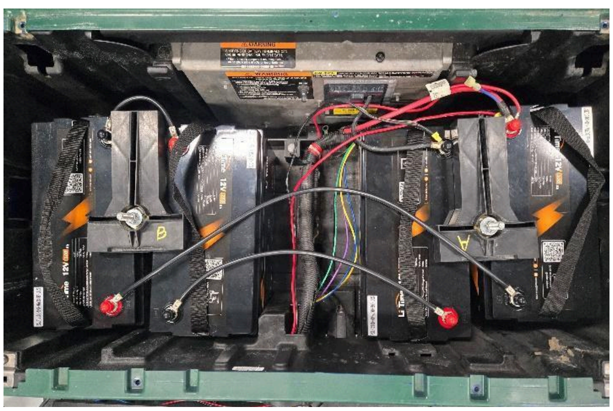


Figure 4: Wiring diagram for the sonar sensor, the safety edge, and the two microcontrollers. The diagram is made by AutoCAD R14.

Figure 5: A safety edge (bumper) for the golf cart.

4.2 Power distribution system

The original lead-acid batteries which were originally used to power the cart have been replaced with four LiFePO4 batteries connected in series resulting in a roughly 48VDC supply. LiFePO4 was chosen due to its balance between safety and power density. The new batteries have a total capacity of 100Ah, resulting in an estimated run-time of 4-12 hours, depending on conditions. A prototype of the power distribution board can be seen on the left, and consists of the servo power and control components listed under the ‘Motion Control System”, power enable SSRs, lighting relays, and power distribution terminals. A control enclosure houses all of these components, providing full system protection and enabling easy diagnostics.



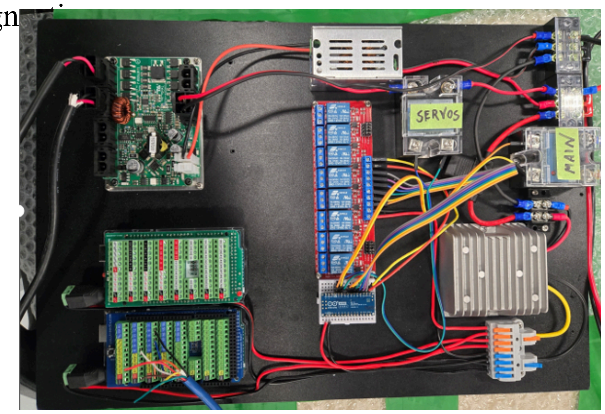


Figure 6: The 48-volt LiFePO4 battery system (left) and the power distribution circuit (right).

4.3 Motion Control System

The motion control system is realized by two Tecnic SDSK servos that actuate the braking and steering system. The steering servo is linked to the steering column with a reduction gear. The braking servo is linked indirectly to the braking linkage through a cable connected to the brake pedal. Fig. 7 shows the power and control wiring schematics for the braking servo. The software used to generate the diagram is AutoCAD R14. The POWER4-HUB will be used to distribute 48VDC from the batteries to each servo. For maximum responsiveness, each servo will be controlled by its own microcontroller, an Arduino Mega 2560. Additionally, 24VDC logic backup power is provided by a small buck converter. The steering servo and braking servo with linkage are shown in Fig. 8.

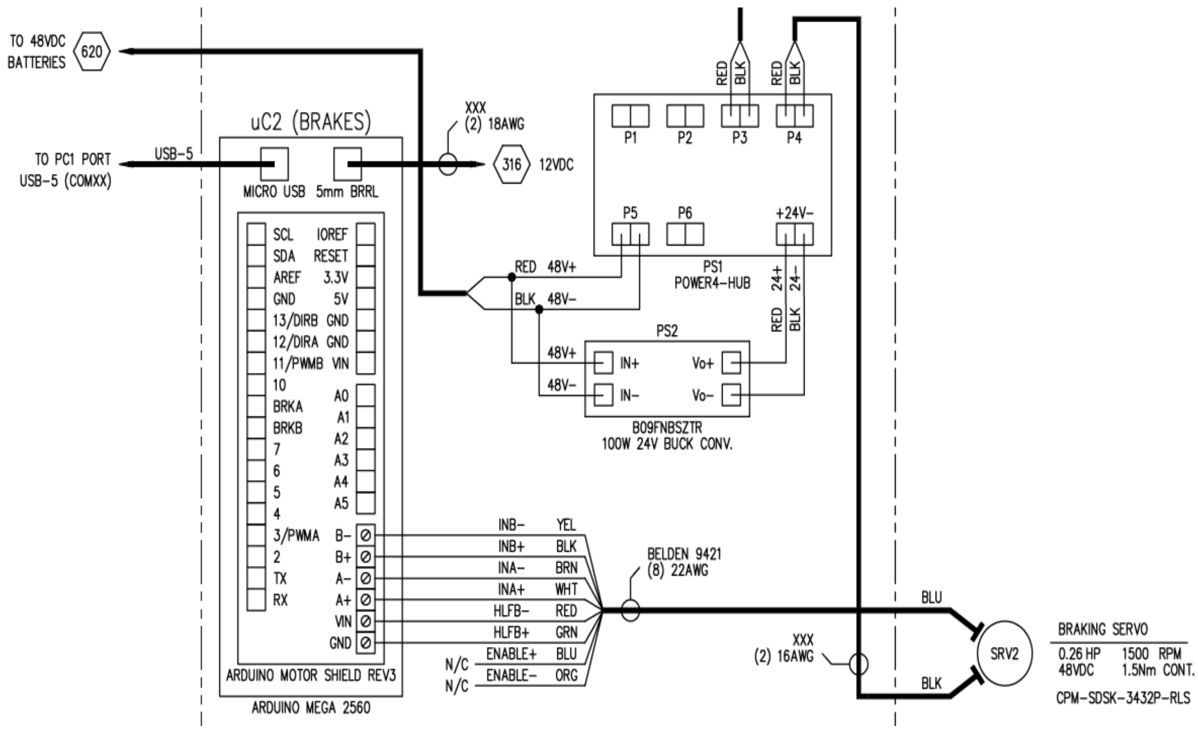


Figure 7: Schematic for braking servo power and control.

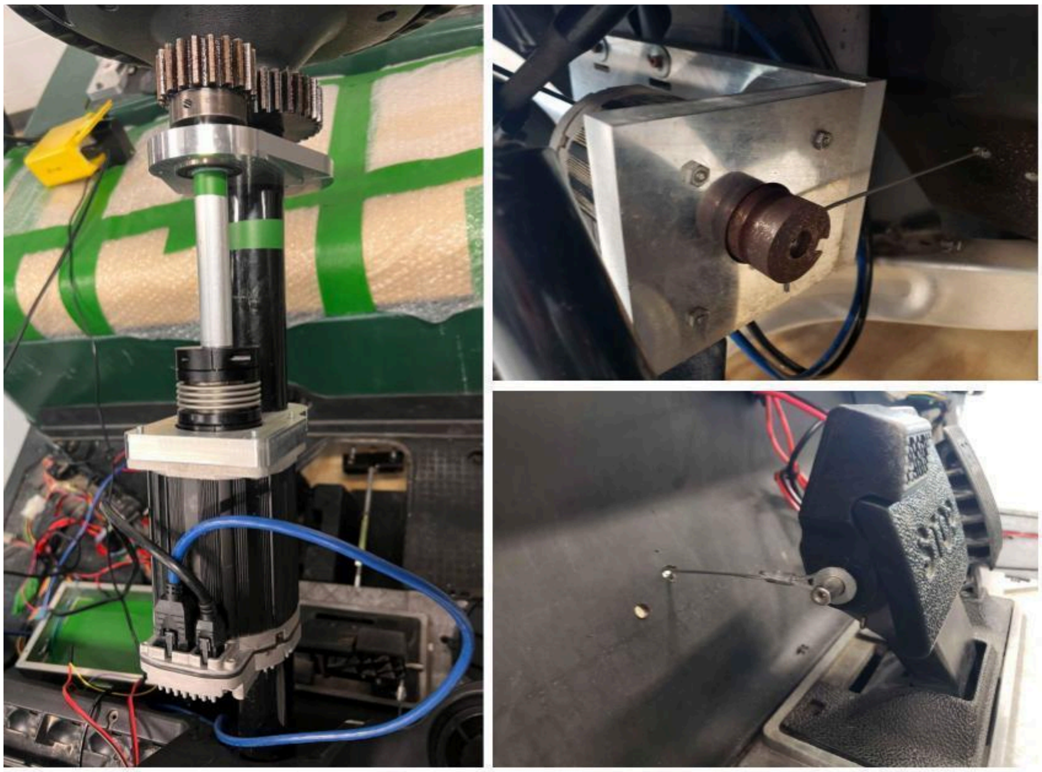


Figure 8: Steering servo and linkage (left) and braking servo with linkage (right).

4. Discussion

The goal for this project is to develop a level-2 autonomous golf cart (as defined by SAE standard J3016_202104 [7] retrofit system. The golf cart with the retrofit system can travel from point “A” to point “B”, making one entire lap around the building with minimal human intervention. This will be accomplished in a cost effective and sustainable way, subject to environmental constraints and the longevity of the materials. Additionally, ethical constraints along with state and local laws and regulations will be adhered.

The long-term production goal for this project is to create a full package autonomous kit that can retrofit any SMV. With a robust control framework and a focus on safety, the autonomous driving retrofit system could be extended in terms of application to other types of vehicles, such as tractors, mowers, mobility scooters and more. This entails stricter adherence to accessibility with the intent goal of reducing mobility issues on campuses and facilities by providing a cost-effective mode of autonomous transportation. Not only can the system developed by this project be sold as a kit or service, but the system can also be developed as a learning tool for future students to learn about the various components and algorithms which enable autonomous driving features on a vehicle. The capstone project team hopes to pursue both avenues in commercial and educational development in the long term. IEEE standards applicable to this project in its production goal will be reviewed to ensure compatibility with industry standards.

In achieving these goals, the hope is to have a kit that can be installed and maintained by the university's engineering department. In this manner, it will serve as educational material for engineering students who wish to pursue autonomous driving related fields of study.

Simultaneously, this project will also present a solution to a critical problem across a majority of university campuses: building-to-building transportation for students with mobility impairments. This is a multi-phase project. The first phase of this project is to simply produce a functioning self-driving golf-cart that will successfully complete a circuit around one designated building. The next phase includes upgrading the route to encompass more of the campus. The final phase will involve a close relationship between the campus disability center and the engineering department to adhere to direct needs as presented by the students who will benefit from this project the most.

5. Conclusion

Results from initial testing show a realistic potential for the realization of this project. The separate technologies used in this project are not new, but the integration of these technologies for the purpose of creating a kit that can upgrade existing SMVs to provide both an educational and public service to students is a novel implementation. Further testing and continued work are required, but initial tests are promising and the designs are grounded in well-documented and reliable technologies.

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