Autonomous Golf Pull Cart

ECE 445 Design Document

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Introduction

1.1 Objective

When golfing, players usually decide between a golf cart, a pull cart, a caddy, or carrying their clubs around the golf course. All of these methods have downsides attributed to the cost or physical exertion required. A golf cart requires the player to drive instead of walk and it would be expensive to buy one. Then the added fee for renting a cart from the golf club every time would also be a large expense. The standard pull cart requires players to pull their bag around which may be difficult for some players to maintain around an 18 hole golf course. Hiring a caddy is the most expensive option listed since they're mainly available only on nice, expensive courses such as country clubs, and players are expected to tip the caddy. The last option of carrying one's own clubs is the lowest of options for many people. These people either physically can't or don't want to carry their golf bag that can weigh upwards of 30 pounds around an entire golf course.

Our project looks to address these problems. By utilizing GPS, Bluetooth, ultrasonic sensors, preloaded course maps, and a gyroscope/accelerometer, our Autonomous Golf Pull Cart will follow the user around a golf course within a reasonable distance. Our project will allow the player to still walk the course and exercise but without the unnecessary added weight of a bag. The user will also be able to focus on their golf game and not have the added exhaustion of carrying their bag. The cart will connect to an app on the user's phone to create an easy user experience. A manual mode will be available that allows the user to control the cart with their phone to avoid any difficult obstacles. In some difficult and unforeseen cases, the user may still need to physically pull the cart out of or around an obstacle. The cart will have automated horizontal actuators to shift weights along the axles for the cart to stay upright during elevation changes.

1.2 Background

Golf is one of the most popular leisure sports in the world with an estimated 23.8 million players in just the United States as of 2017 [1]. Outside of the US, golf is most popular throughout Europe, Canada, South Africa, and Australia [2]. Due to these numbers, there is a large market opportunity for a product such as the Autonomous Golf Pull Cart that solves the problem for people who still want the walking as exercise but can't or don't want to carry their own clubs in a more cost effective manner than hiring a caddy. There are other products on the market that attempt to tackle this problem. The Alphard eWheels Club Booster Electric Push Cart Conversion Kit [3] and the CaddyTrek Mobile Autonomous Robotic Golf Cart Caddy [4] are two products similar to our Autonomous Golf Pull Cart. Even though these products may be beneficial to some people, we noticed some key differences with our proposed project. The Alphard eWheels Club Booster Electric Push Cart Conversion Kit [3] is not a full cart but a conversion kit that can be added to a cart to create a remote-controlled push cart. This product does not introduce any autonomy and allows users to remotely move their bag with them as they walk. This product keeps the user from just focusing on their game which is why we wanted an autonomous cart. The CaddyTrek Mobile Autonomous Robotic Golf Cart Caddy [4] does have autonomy built into a complete cart setup, not just a conversion kit. This product is very expensive and has to utilize a separate piece of equipment the user must wear. Our on-person equipment will only be a cellphone. Both of these other options are also much more expensive than what we think we can design.

Our project's use of GPS will be a better solution than using sensors in the other 2 products mentioned. Preloaded maps of the course will have marked-off safe zones so the cart will not blindly follow the phone on to the green or into sandtraps. This project would be a great solution for all ages as well. The older golf demographic may struggle more with carrying and transporting their golf bag while the younger golf demographic may really enjoy the technology and automated features of this project.

1.3 Physical Design

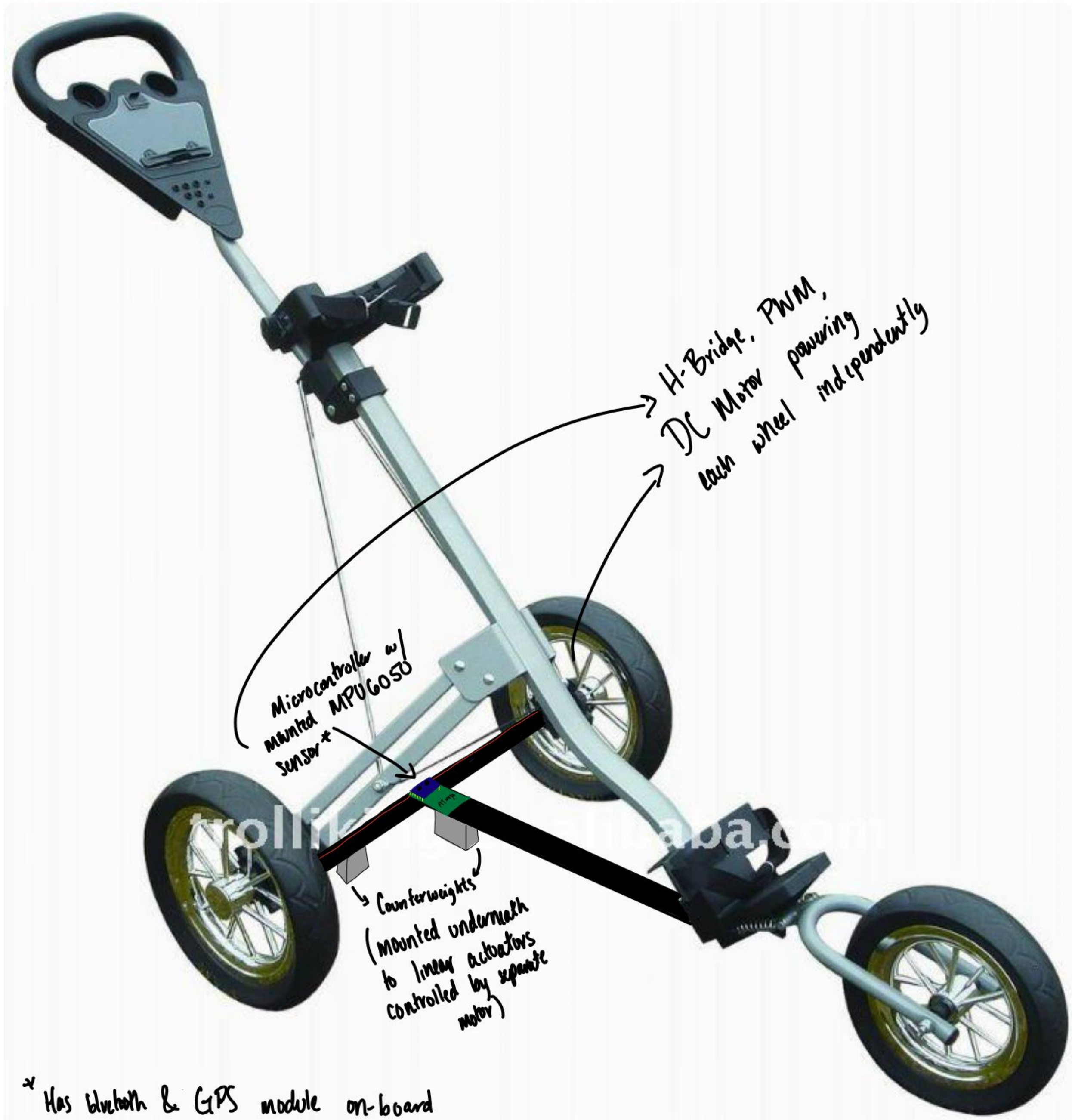

Figure 1: The physical design of the pull cart containing. Motors and counterweights will be integrated into the axle of the rear wheels and will be controlled based on input from various sensors, GPS, and Bluetooth Module

Figure 2: A rough idea of what the mobile application interface would look like for the user, in either automatic or manual mode.

1.4 High-Level Requirements

1. Autonomous pull cart follows the user using A* algorithm around the course while only moving at minimum distance of 3 meters from the user
2. The mobile application can be used to control the cart manually by using a remote control or picking a specific point on the course map to send the cart
3. Pull cart remains balanced and drives smoothly when placed on inclinations less than or equal to 15°

Design

2.1 Block Diagram

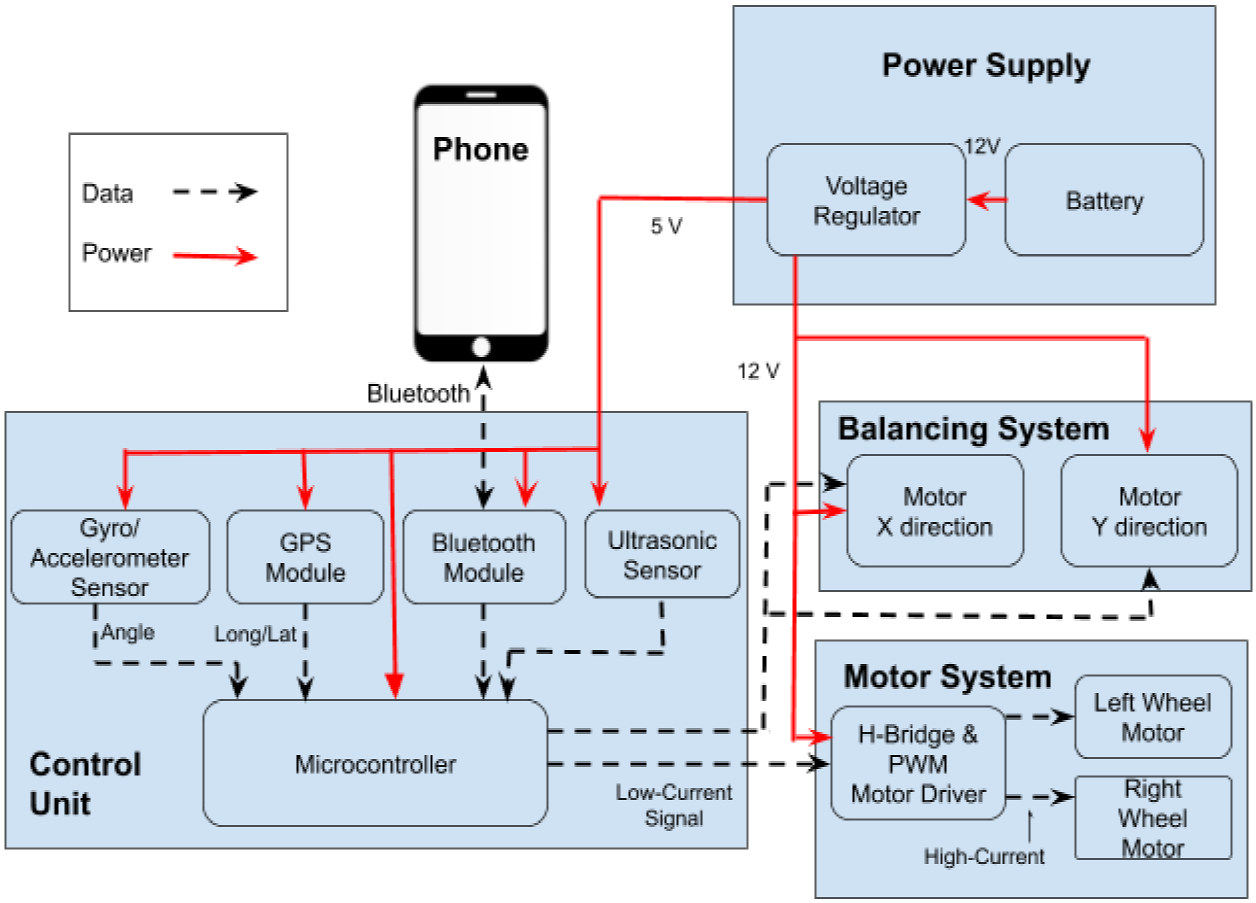

Figure 3: Block diagram for Autonomous Golf Cart. Shows how components will interact with each other and the types of connections between them.

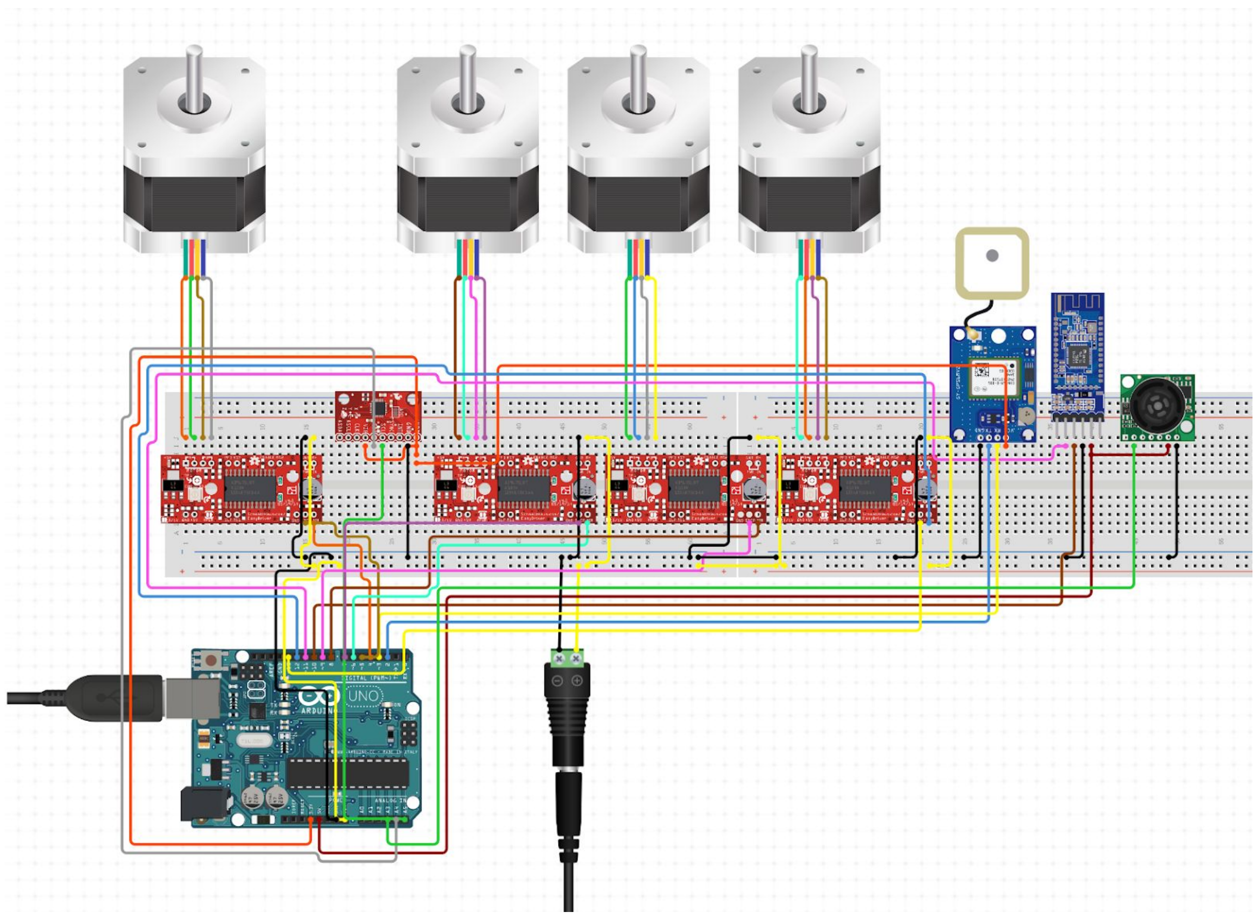

Figure 4: The proposed hardware prototype that will be used to test the control and input of each module.

2.3 Subsystem Descriptions

2.3.1: Control Unit

I. The control unit will serve as the central brain for our cart. It will combine the incoming bluetooth data from the user, GPS signals, and elevation changes to determine how to properly navigate the cart around the golf course.

II. Parts Needed:

   A. Microcontroller: The **ATMEGA microcontroller** [5] will process data from the bluetooth module to determine if the user is trying to switch its operational modes. It will also send signals to the servo motors controlling the counterweights and wheels for proper balancing and course navigation. .

   B. Gyro/Accelerometer Sensor: The **MPU6050 Gyroscope/Accelerometer** [6] will be used to determine the vertical and horizontal elevation angle that the cart is currently sitting on. If these angles are above a certain value, the microcontroller will move the counterweights to provide safer traversal around the golf course.

   C. GPS Module: The **NEO 6M GPS module** [7], in addition to the now widely available preloaded course data for most of the US on Apple Maps, will be used to allow the golf cart to operate in autonomous mode.

   D. Bluetooth Module: The **BlueSMiRF Silver Bluetooth module** [8] will allow us to connect our phone to the cart for location communication and easy user control, whether that be viewing the cart's location on the map, or switching it to manual mode so that the user can control where it goes.

   E. Ultrasonic Sensor: When in autonomous mode, the **Maxbotix LV-MaxSonar ultrasonic sensor** [9] will be necessary to ensure the cart avoids people, trees, and other large objects.

III. Proposed Schematic

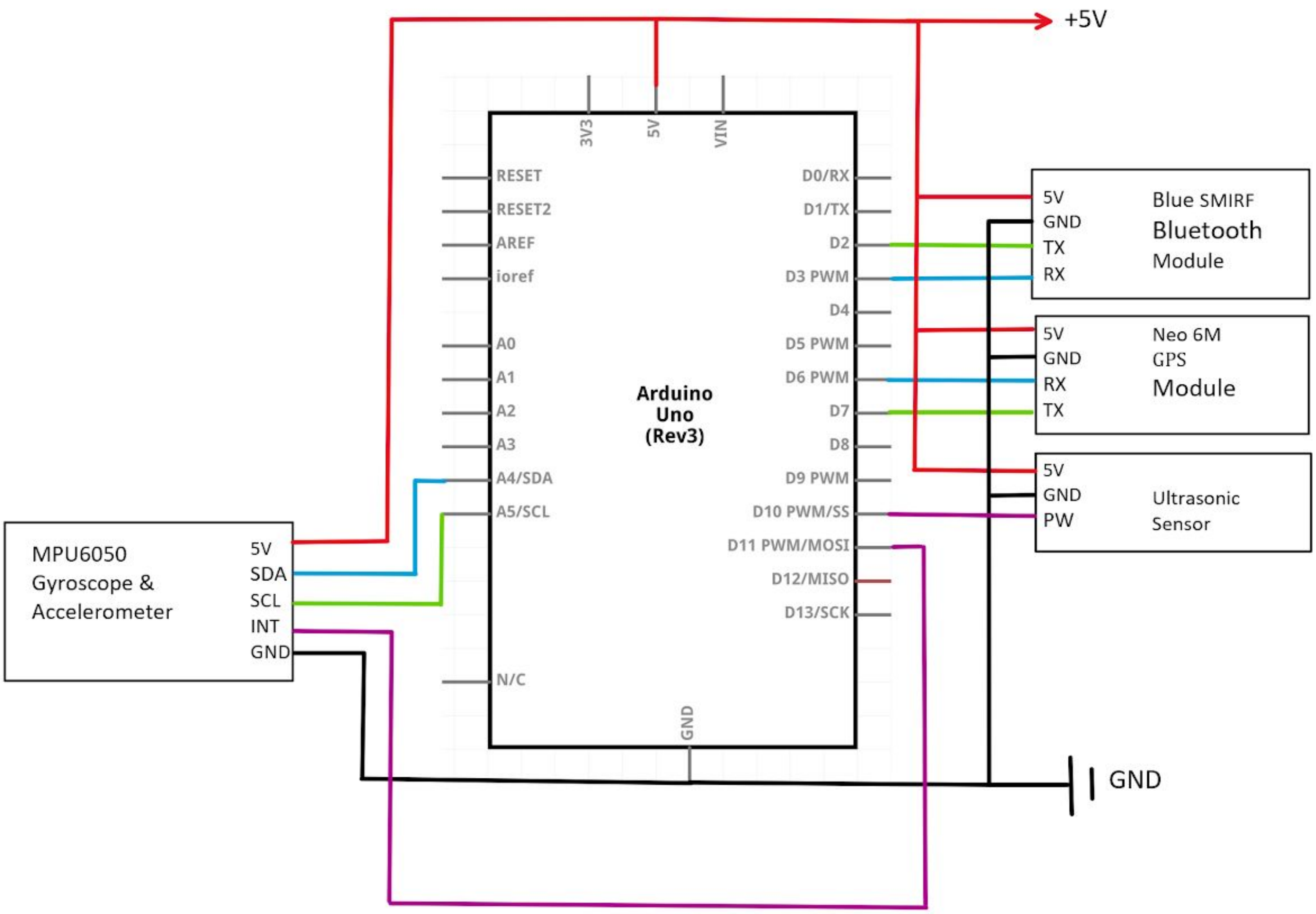

Figure 5: Proposed hardware schematic for the control unit components

IV. Algorithm

A. Graph Construction: Data from a map API will be used to construct a graph data structure. When constructing the graph, we will use a 100 x 100 meter area of the golf course at a time, where the user's position is at the center. Each vertex in the graph will represent a 1 m^2 section of the area yielding 10,000 vertices. Each vertex will have up to 8 edges representing the 8 directions that the cart can move. Each vertex will also be labeled as a restricted or unrestricted area depending on the data provided by the map API

B. A* Search: Given the constructed graph, the cart's location (start), and the user's location (goal), we will use the A* Search Algorithm [10] to find the shortest path from start to goal while avoiding the restricted areas. The heuristic used to find the optimal path will be based on Euclidean Distance from a position on the graph to the goal. A* Search will be done each time the cart is more than 10 m away from the user and will return a list of compass directions to be sent to the microcontroller.
C. Graph Reconstruction: If the user or the cart is outside the 100 x 100 meter area used to construct the graph initially, we must reconstruct the graph using a new area of the golf course that would place the user back to the center.
D. Recomputing A*: The user will be constantly moving. Therefore, instead of recomputing the optimal path each time the user moves, we will instead compare the user's previous location (the location used to run A* previously) and the user's current location. If the distance between them is more than 10 meters, then we recompute A* using the user's current location. Else, we continue using the originally computed path.
E. Object Detection: If the cart detects an object while traversing the path, it should mark that vertex as a restricted area and recompute A*

V. Flow Chart

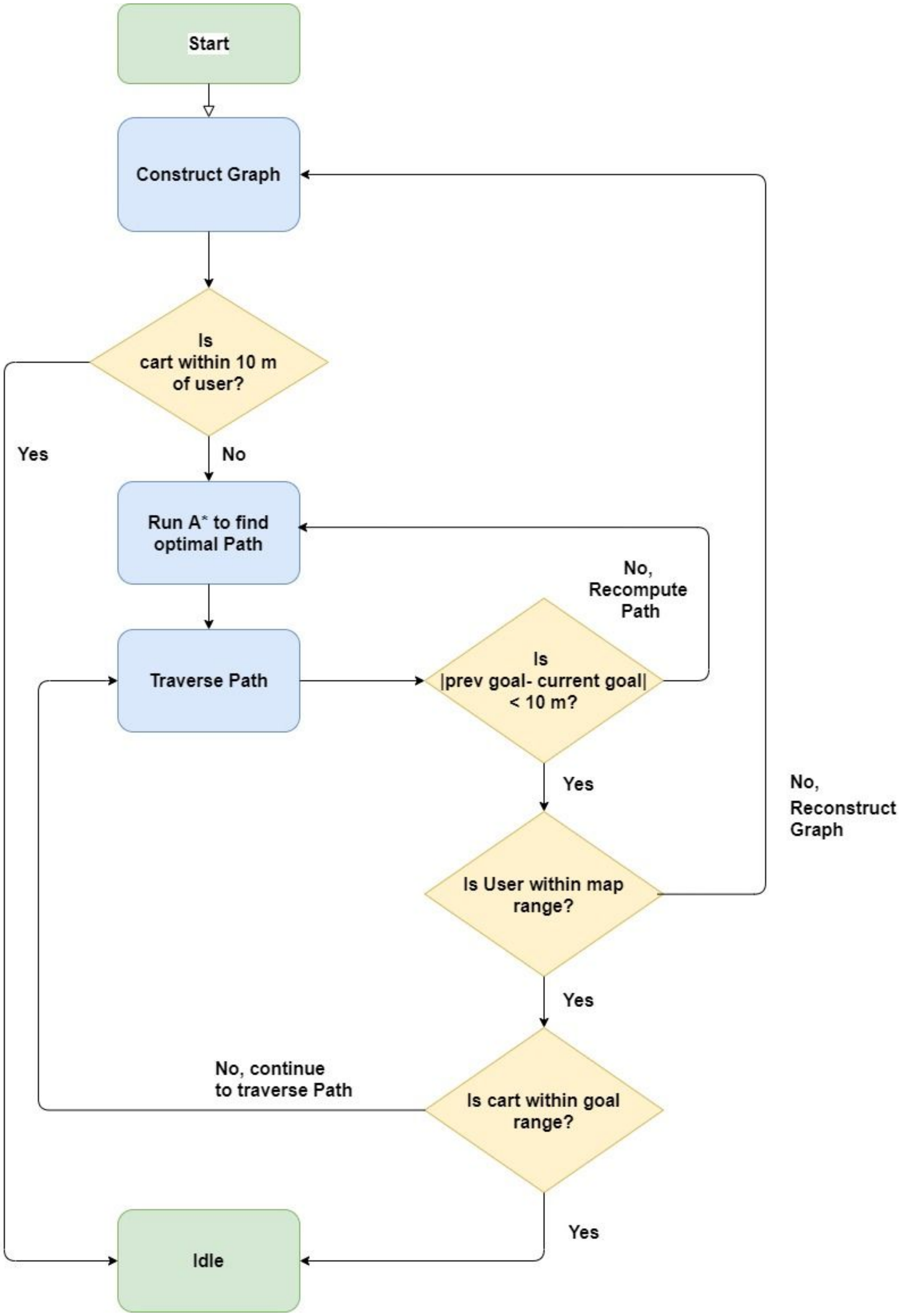

Figure 6: Proposed hardware schematic for the control unit components

2.3.2: Motor System

I. The cart will be designed similar to a traditional golf pull cart with two rear wheels and one front wheel. However, it will also include motors on the rear wheels to allow the cart to move autonomously.

II. Parts Needed:

   A. DC Motors: Two **12 V DC motors** [11] will be used to control the movement of each of the rear wheels. The DC motors will be controlled and powered by the motor driver.

   B. Motor Driver: We will use the **L298N motor driver** [12] to control the speed and direction of the two DC motors simultaneously. This motor driver consists of two components:

      1. H-Bridge circuit for changing the rotation direction of the motor allowing for forward and backward movement of the cart.
      2. Pulse Width Modulation (PWM) to control the rotation speed of the motors independently. This will be useful for moving left and right and adjusting to varying walking speeds and angles.

III. Proposed Schematic:

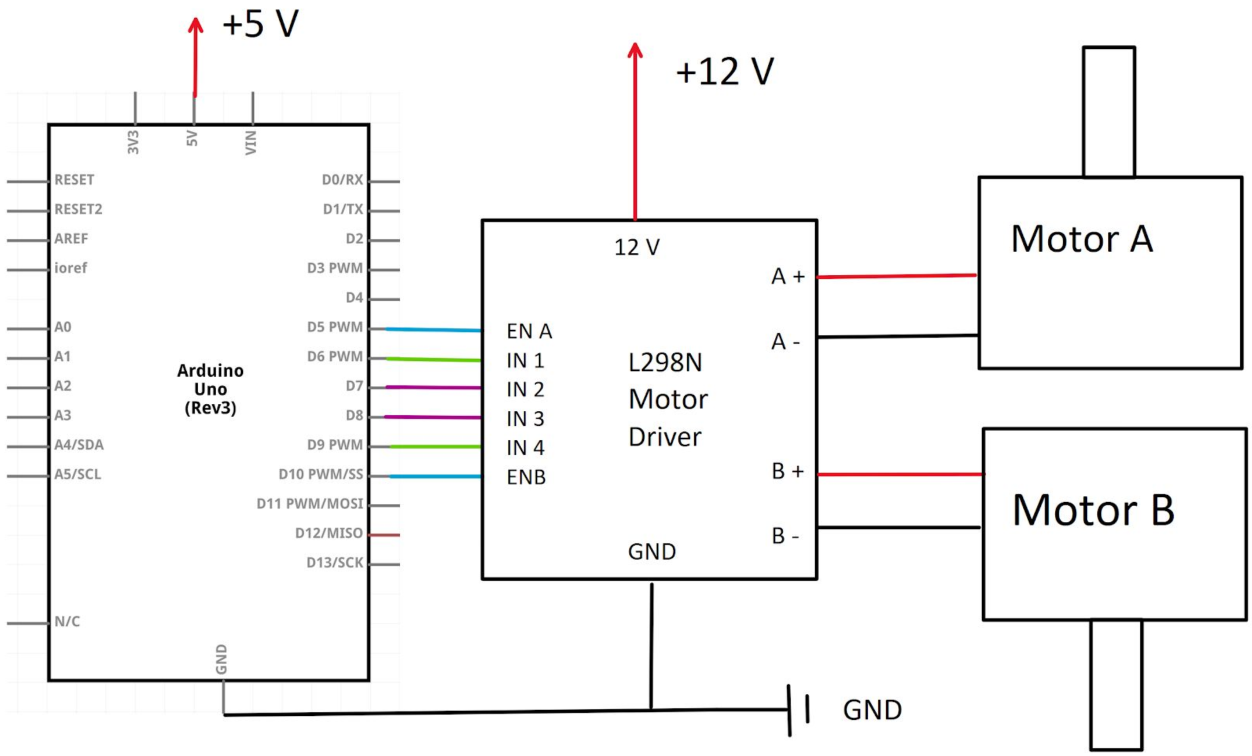

Figure 7: Proposed hardware schematic for the Motor system components

2.3.3: Balancing System

I. The balancing system for the cart will be controlled by two linear actuators with counterweights mounted onto them, following a design found in a YouTube Tutorial [13] so that each counterweights' axis can be independently controlled from the arduino. The arduino will take in readings from the gyroscope and accelerometer, and process that data to determine where to position each counterweight. For example, if the cart is on a 10 degree horizontal incline with respect to the ground, it will want to move the horizontal counterweight towards the right wheel to maintain a consistent center of mass.

II. Parts Needed:
   - A. 2020 Aluminum Extrusion [14]: This is what both actuators will be mounted onto with 3D-printed bearings for the lead screws.
   - B. 12V DC Motor with Encoder [15]: The encoder is necessary so that either actuator can be moved in either direction along the bolt.
   - C. 8mm Lead Bolt, .8m [16]: This is what the bearings and counterweight will be attached to and controlled with the motors.
   - D. 8mm Set Screws [17]: These will be used to fix the position of the mounted bearings on either side of the lead screw.
   - E. 3D Printed 2020 Brackets: Brackets for the bearings and lead screws will need to be 3D printed according to the CAD documents provided from the instructional video that was used to design this actuator. The bracket for the lead screw will need to be modified so that the counterweight can be easily mounted to it.

III. Proposed Schematic

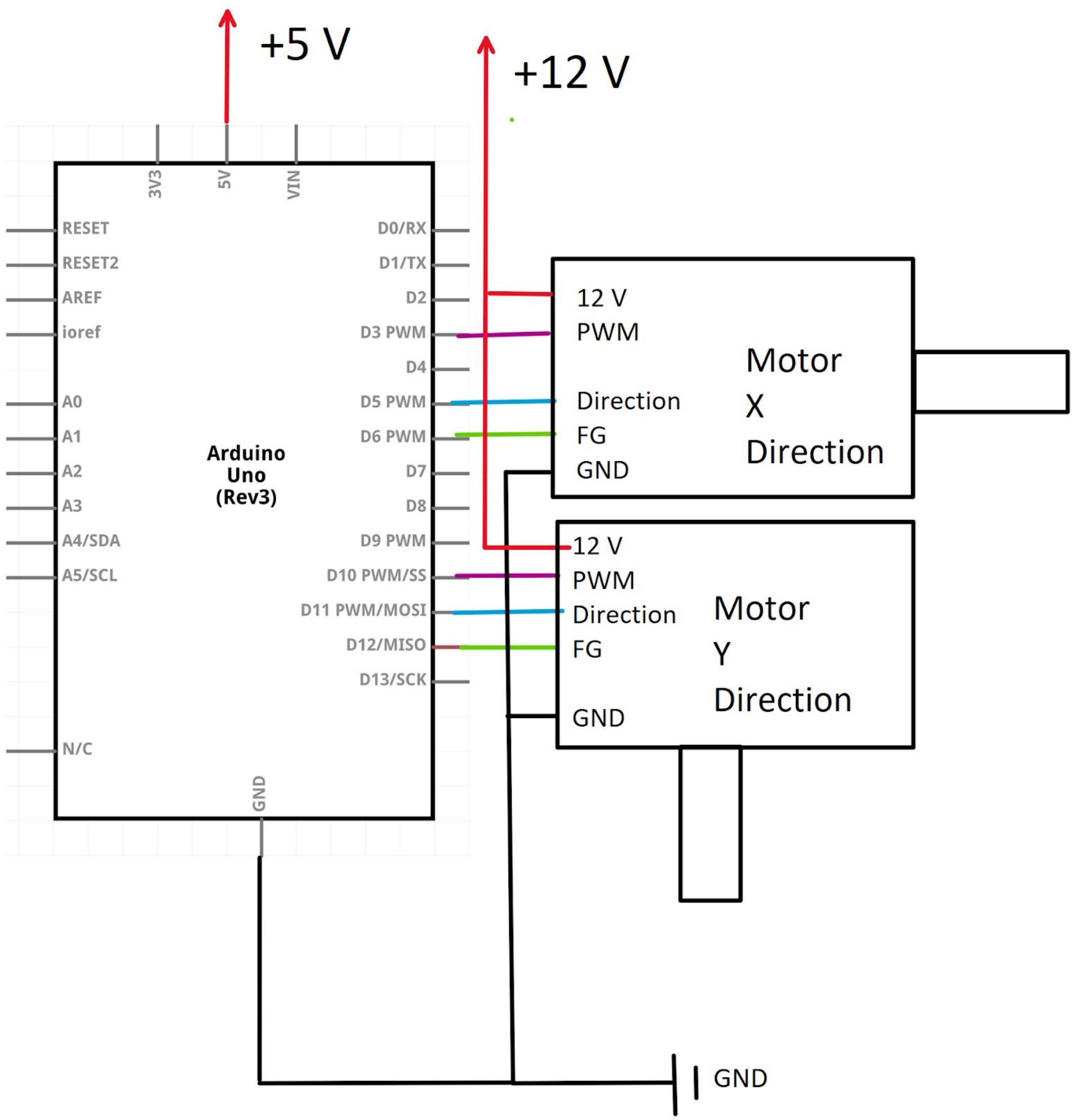

Figure 8: Proposed hardware schematic for the Balancing system components, which includes two motors moving counter weights in the x and y direction

2.3.4: Power Supply

I. The power supply will ensure that all hardware components that exist on the cart are properly receiving the correct amount of power for a sufficient amount of time. It provides power to the ATmega chip and all motors.

II. Parts Needed:

A. Battery Pack: A rechargeable lithium ion battery pack [18] will be responsible for powering the ATmega and motors. This pack will be placed underneath the cart next to the microcontroller. This pack comes with a wall plug-in charger and is rated at 12V/5Ah.
B. Voltage Regulator: The LM2575 [19] will regulate the battery pack output to the 5V needed for the ATmega. This will be placed on the PCB.

2.4 Requirements & Verifications

2.4.1 High-Level Requirements

Table 1: Verification process needed to ensure proper function of whole project

Requirement	**Verification**
1. Autonomous pull cart uses A* algorithm around the course and follows the user walking less than 4 mph within 10 meters .	User walks around the course with the cart in autonomous mode and another person measures how far the cart follows behind to ensure a maximum separation of 10 meters.
2. The mobile application can be used to control the cart manually by using a remote control	User switches mode to manual on the phone. User verifies the cart moves according to the remote inputs on the phone by the user.
3. The cart does not tip over while traveling along inclines less than or equal to 15 degrees.	Move the cart through various inclines within the required range and verify that the balancing system keeps the cart upright and keeps it from tipping over

2.4.2 Control System Verification

Table 2: Verification process to ensure the control system block is functioning as intended

Requirement	Verification
1. The cart can maintain communication with the phone for ranges up to 90m.	The user can walk 90m away from the cart and still accurately locate its position on the map.
2. Cart safely avoids obstacles such as water, sand traps, etc.	The user will drive the cart near or into a restricted area during use in manual mode, the app will notify the user and the cart will stop moving and reroute its course back to the user. The user will verify that this process happens.

2.4.3 Motor System Verification

Table 3: Verification process to ensure the power supply block is functioning as intended

Requirement	Verification
1. Motors are able to move the cart at speeds up to 4mph and support weight up to 40 lbs +/- 10%.	Use manual mode to and push the forward button to ensure the cart can move at a comfortable walking pace when loaded with 40 lbs of weight.
2. Motors must be able to be independently controlled to steer the cart either left or right.	Each motor operates independently of the other motor. User will determine if motors are working together to make turns.

2.4.4 Power Supply Verification

Table 4: Verification process to ensure the power supply block is functioning as intended

Requirement	Verification
1. The battery must be able to power the cart for at least 5 hours	Utilize the full system at expected capacity for a timed minimum of 5 hours with batteries at full charge.
2. The voltage regulator must provide 12V +/- 5% to the motors and 5V +/- 10% to the Arduino module	Measure output voltage from regulator with oscilloscope.

2.4.4 Balancing System Verification

Table 5: Verification process to ensure the control system block is functioning as intended.

Requirement	Verification
1. Must be able to efficiently move each counterweight along the linear actuator.	By slightly tipping the cart back and forth with nothing on it, the incline change should be sensed by the gyroscope and the counterweights should adjust opposite of the direction the cart is tipped.
2. The counterweights do not move for incline changes < 1 degree to conserve power for the system.	We will slightly tip the cart in all directions and verify that the weights do not immediately move so that power is not being

	wasted by moving the counterweight for a temporary, miniscule change in incline.

2.4.5 Phone Application System

Table 6. Verification process and requirements for phone application subsystem

Requirement	Verification
1. Must accurately display the location of the cart and the user on the map	When the app is open, the user will determine if they can accurately identify where they and their cart are on a real world map.
2. Must allow for transition between automatic and manual modes, the latter enabling full control of the the cart for the user	User will verify they can switch between modes. While in manual mode, user will see if they can control the cart and send it to desired maximum of 90m to see if functionality remain.

2.5 Tolerance Analysis

Given two GPS coordinates, the distance between the two coordinates can be found using various trigonometric functions. For better performance and adequate accuracy at small distances, we can use the following equirectangular approximation to calculate the distance between two GPS coordinates:

$$X = \Delta\, Longitude * cos(\,(Latitude1 + Latitude2) / 2\,)$$

$$Y = \Delta Latitude$$

$$Distance = Radius\ of\ Earth * \sqrt{X^2 + Y^2}$$

Using such formula, we can determine that changing latitude by .00001 degrees (Hundred Thousandth of a degree) results in a 1.1 meter change in the latitude. Similarly, changing longitude by the same amount, .00001 degrees, results in a .83 meter change in Longitude. Both values are close to 1 meter. When constructing the graph, we plan to divide the golf course map into 1 meter intervals as well. To be able to do so, we must ensure that our GPS for the phone and the cart is able to accurately determine Longitude and Latitude to at least a hundred thousandth of a degree.

2.6 Design Improvements

As this is the second iteration of a solution to this problem statement, we are required to discuss how our implementation is superior to the one that was proposed previously. First, the autonomous mode from the prior design was going to use a combination of IR and Ultrasonic sensors to track the user and stay close to them. However, due to the various obstacles that can be on a golf course like trees, bushes, and other things, this could easily disturb the reception and cause the golf cart to lose its user's position and move erratically. Secondly, the user would have to keep their IR sensor pointed at the cart to make sure that it is receiving a strong enough signal (unless their belt had IR blasters pointed in every direction, which would require a separate system and battery).

By integrating our control system with a bluetooth app instead of remote, we save money by not needing to purchase more hardware. We also can process data about both the user and restricted areas like sand traps, water hazards, and greens to determine the best and safest path to the user without relying on the user to be facing the right direction.

In addition, the previous design had no plans for a manual mode or balancing system. We believe that this feature would be very beneficial, as it allows the user to send the cart somewhere else to deliver something to a fellow player or go to the next hole and wait for them while they are on the green. Having this as a secondary option to an autonomous mode can also prevent any accidents from happening in the unfortunate scenario that the automated control unit began to malfunction. The balancing system we also believe to be necessary because of the amount of hills and inclinations that can exist on a golf course. As golf bags can be top heavy from the weight of the heads of the clubs, the linear actuator counterweight system will provide reliable, stable movement so the user doesn't have to worry about their clubs tipping over while they aren't paying attention.

These improvements and design differences create a much more dynamic and reliable user experience by using stronger sensors and algorithms to determine automated movement.

Cost and Schedule

3.1 Cost Analysis

Our costs of labor are estimated to be $40/hour, 15 hours/week for three people, over the next nine weeks. This would make our total costs of labor to be:

$$\frac{\$40}{1\ hour} * \frac{15\ hours}{1\ week} * \frac{9\ weeks}{1\ person} * \frac{3\ people}{1\ prototype} = \$16{,}200 \text{ in labor}$$

Table 7: Individual parts and their costs for the prototype of the design.

Part	Cost (prototype)
A. ATMEGA microcontroller	$20.50
B. MPU6050 Gyroscope/Accelerometer	$4.99
C. NEO 6M GPS module	$16.99
D. BlueSMiRF Silver Bluetooth module	$29.58
E. Maxbotix LV-MaxSonar ultrasonic sensor	$29.95
C. 2020 Aluminum Extrusion	$23.18
D. 12V DC Motor with Encoder (2x)	$29.76
E. 8mm Lead Bolt with Lead Screw (2x)	$35.98
F. 8mm Set Screws (4x)	$13.84
G. 8mm Bearings (8x)	$5.98
H. TalentCell Rechargeable 12V DC Output Lithium ion Battery Pack	$24.99
I. LM2575 - switching buck converter	$2.22
J. L298N - motor driver	$1.69
K. Greartisan DC 12V 1000RPM Motor (x2)	$31.98

Total	$271.63

Combining the product and labor costs, the total cost for one prototype of our design is estimated to be $16,471.63.

3.2 Schedule

Table 8: Proposed week-by-week schedule and designated tasks for the rest of the semester.

Week	Oumar	Dillon	Kyle
1	Begin developing skeleton for mobile app	Gather Arduino libraries for controlling the different modules (GPS, Gyroscope, etc)	Order all parts. Begin designing schematics for PCB.
2	Add map to automated half of app, controls to manual half	Begin writing Arduino code to process data and control various motors	Finish schematics and test on a breadboard with parts
3	Research bluetooth control from phones to Arduinos and how to process different control signals from the phone	Finish Arduino code for basic movement and balancing with hypothetical values for motors	Create PCB design off update schematics and order PCB
4	Finish mobile app completely and prepare to interface with hardware	Test Arduino code with hardware prototype to determine appropriate control system speeds,	Solder and Test PCB. Build prototype for testing with Arduino code with Dillon
5	Help Dillon integrate the app and bluetooth signals into the Arduino control unit	Expand Arduino code for bluetooth control and work with Oumar to build manual control system	Debug any issues with PCB and design a second PCB. Order 2nd PCB
6	Develop code for avoiding objects based on values from ultrasonic sensor	Integrate Apple Maps API with control system to begin automated movement function	Solder 2nd PCB and begin testing and integrating with whole system
7	Work with Dillon to build	Work with Oumar to build	Help debug entire

	A* search and movement algorithm for automated control, integrating with object avoidance	A* search and movement algorithm for automated control	system and assist teammates with remaining work
8	Finish automated movement and polish manual movement for easy control	Finish automated movement and polish manual movement for easy control	Continue finishing all aspects of the project and polish for completion

Ethics and Safety

One of the biggest safety concerns that we see in creating this project is making sure that the cart is always operating in a safe manner. Golf clubs and the things that people put in their bag can be very expensive (phones, wallets, etc) and we would not want the autonomous cart to cause damage to the user's belongings in some way. More importantly we do not want to risk injuring the user or others. Any occurrence of the above would be a violation of IEEE Code of Ethics, #9: "to avoid injuring others, and their property" [20]. Therefore, we must ensure that the cart is operating at a safe speed and can accurately detect objects with the ultrasonic sensor to avoid damage to the user, property or the cart itself. We believe that maximizing the speed of the cart to 4 mph, the speed of a brisk walk, will ensure overall safe operation.

A worst case scenario would be the cart not detecting a lake, and driving into it with all of the user's possessions while they weren't paying attention. Due to these considerations, we will need to make sure that the GPS data being received and processed by the microcontroller is done very accurately, and draw 'safe zones' around these potential hazards to ensure that the cart never comes close to interacting with them.

In addition, we must make sure that we deliver on our promises. We would not want the user to purchase this autonomous cart and have to pull it around as if it were a regular cart due to it not working as intended. Therefore, we must ensure that the cart operates with the levels of accuracy mentioned in the requirements. Providing inaccurate data to the user would be a violation of IEEE Code of Ethics, #3: "to be honest and realistic in stating claims or estimates based on available data" [20].

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