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Executive Summary

This capstone project addresses the challenge of carrying a golf bag on a golf course using the disciplines of Electrical and Computer Engineering. It is a problem goaded by an elderly acquaintance of our instructor, with our instructor acting as our primary client. In the traditional sense, a golf caddy is a person who carries a golfer's bag of clubs while simultaneously giving advice on which golf clubs to use, given the current environment and the location of the next hole. With current technologies, a golf caddy can take various forms. These range from a simple push cart designed to hold a golf bag to remote-controlled carts that serve the same purpose. Additionally, there are autonomous golf caddies equipped with mapped Global Positioning System (GPS) functionality, providing an integrated advising system that follows its user without any user-directed input. We have designed the latter. Given the time, budget, and skill constraints inherent in our CME 495 capstone design project, we are designing an Autonomous Golf Caddy.

Golfers rely on caddies to reduce physical strain, conserve energy, and offer strategic advice, but hiring a personal caddy can be expensive for the average player. Therefore, the primary problem we aim to address is the accessibility of caddy benefits for the general golfing population, specifically overcoming the financial barriers associated with traditional caddy services while maintaining essential functionalities. To address this problem, in this report, we describe how we modified a golf push-cart to contain the following subsystems that perform our key features. Our subsystems are User Tracking, Obstacle Detection, Motor Control, Power and Charging, and Advising Systems.

We determined that our project is feasible and is approaching full functionality. By refining the mechanical design, especially of the motor mountings, we can create a highly affordable system capable of user tracking and obstacle avoidance, among other features. The effectiveness of our design improves as we scale up the tracking devices, due to more reliable user tracking data as the product's physical volume increases. Overall, our project has the potential to be expanded into various other autonomous human tracking applications.

In conclusion, this capstone project developed and tested an autonomous golf caddy, demonstrating the potential for cost-effective golf carts that track and follow their user with a heavy golf bag, simultaneously avoiding obstacles and giving golfing advice. While further refinement is necessary to address performance limitations in maintaining reliable obstacle detection and controlling the motion of the golf caddy by using the appropriate motors, this work can contribute to developing low-budget user tracking devices that can carry a moderate load.

Statement of Work

Background and Motivations

Golf is enjoyed globally by people of all ages, and caddies play a significant role in enhancing the game experience. A caddy, whether human or mechanical, assists in transporting a golf bag and sometimes offers advice about the course and upcoming shots. Caddies are essential for reducing the physical effort required to carry equipment and providing advice for the player, allowing golfers to focus on their game.

Many golfers who prefer walking the course but not carrying their bags seek alternatives that eliminate physical strain. Caddies, whether human or electric, allow players to conserve energy for their game. However, this convenience comes at a cost. For example, at Cabot Cape Breton Golf Course, a human caddy costs $90 per bag, with typical tips at 50% of the fee, though tips can reach as high as $500 [8]. Electric caddies, typically controlled by remote, range from $1,000 to $2,000 [10], offering a more economical solution over multiple rounds. While electric caddies save on long-term costs, they lack the personal advice human caddies provide. By combining the benefits of human expertise with electric caddy convenience, golfers can effectively address their on-course needs.

Problem Statement

Golfers rely on caddies to reduce physical strain, conserve energy, and offer strategic advice, but hiring a personal caddy can be expensive for the average player. We must develop an affordable automatic caddy for the average golfer without compromising key features, specifically user tracking, operation time, obstacle avoidance, and user advising.

Scope

Expected achievements in the Final design:

Carrying Capacity: The design of the caddy can accommodate the majority of golf bags, up to 30 lbs.

Operation Time: The caddy will last a full day of golfing, approximately 8 hours.

Simple Club Suggestion System: Based on the golf course conditions and the state of the golf match, the caddy will offer limited club recommendations.

Disclaimer: Since one of our designers, Zach Szakacs, has worked at a golf course for five years as a golf shop attendant, we have decided to rely on his experience for determining the claims made about the logistics of golf above.

Limitations of the project:

Outdoor Conditions: We do not expect our product to work on a variety of terrains. We are particularly limited by our lack of mechanical engineering skills, and will be unable to test this due to the weather conditions at this time of year.

Advanced Club Suggestion System: Only fundamental club recommendations will be given by the caddy. We will not be including more complex algorithms in the club selection process. Additionally, we will not link the caddy to golf course management systems that provide real-time information on course layout and conditions.

Weather Resistance: Weather conditions other than low-humidity sunny days will not be tolerated by the caddy.

Personalization: There will be no provisions that enable the user to customize the caddy’s software or hardware.

Design Objective

Autonomous Navigation: The caddy must reliably follow its assigned golfer at an appropriate distance across diverse golf course terrains while avoiding obstacles in real time.

Carrying Capacity: The design must carry the weight and volume of common golf bags while maintaining stability and performance.

Operation Time: The caddy must be capable of performing for a full day's usage on a standard 18-hole golf course, with continuous operation for the golfer's entire round.

Club Suggestion System: The design should incorporate a digital system to provide correct club suggestions to the golfer.

Design Constraints

Budget: Our team must stay with the given departmental budget of $250 plus out-of-pocket expenses that must not exceed $200 ($50 per group member)

Time: Work on the prototype must conclude by the end of March 2025.

System Block Diagram

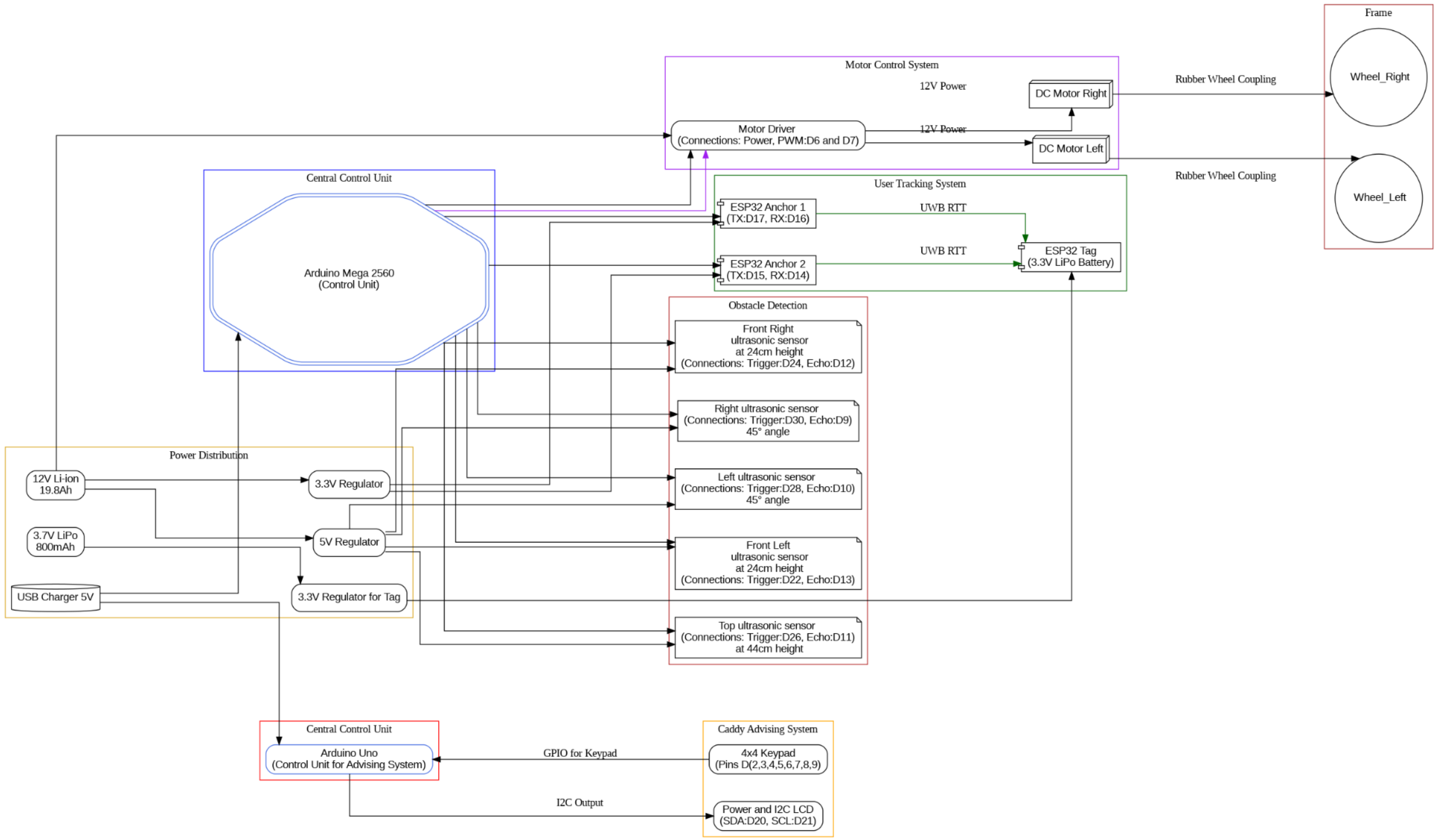

Figure 1: System Hardware Block Diagram

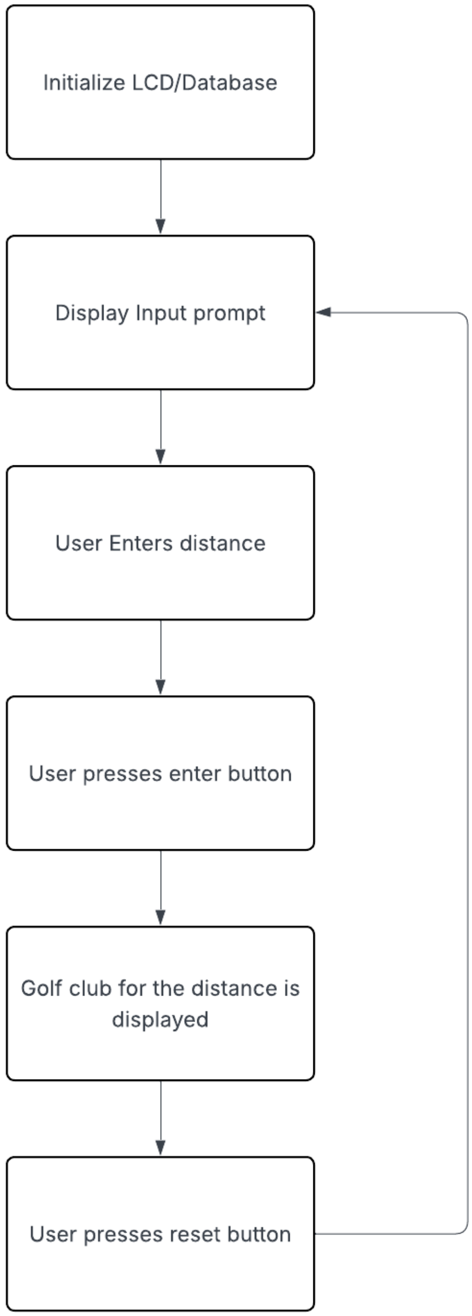

Figure 2: User Interface Software Block Diagram

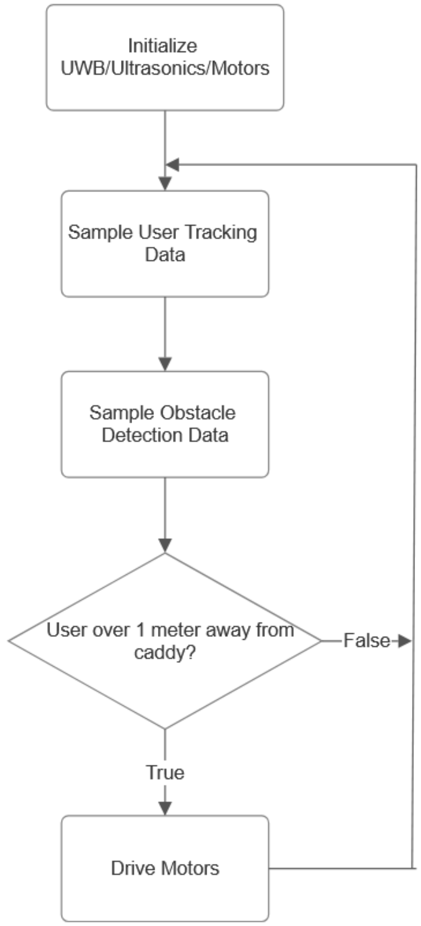

Figure 3: System Software Block Diagram

Detailed Design

User Tracking

The user tracking system comprises four main components: three REYAX UWB modules and an MCU (Arduino Mega 2560). Two UWB modules will serve as anchors, mounted on the caddy's handle with a 34 cm spacing, and powered via their 3.3V pins from the voltage regulator. The third UWB module will function as a tag attached to the user. It will be powered by a compact 3.7V 800mAh LiPo battery stepped down using an LDO (Low Dropout) 3.3V Regulator housed in a 3D-printed compartment designed for easy battery swapping. The two anchors will connect to the MCU using the following configuration:

- Anchor 1's serial transmission (TxD) connects to the MCU's serial receive port (D17), and its serial receiver (RxD) connects to the MCU's serial transmission port (D16). The power and ground pins on the UWB connect to 3.3V and ground on the voltage regulator. The NRST pin on the UWB module connects to GPIO pin 48 on the MCU.
- Anchor 2's transmission (TxD) and receiver (RxD) ports connect to the MCU's ports D15 and D14, respectively. Power and ground are connected to 3.3V and ground on the voltage regulator. The NRST pin is connected to GPIO pin 50 on the MCU.

This setup allows the MCU to communicate independently with each anchor. See design/system_connection_diagrams/user_tracking_connection_diagram.png for the User Tracking connection diagram.

The communication protocol between the MCUs and Anchors involves the MCU requesting distance measurements from both anchors. Each anchor calculates its distance from the tag on the user and sends the measurement in centimetres back to the MCU. The MCU then uses bilateration to compute the user's position relative to the front of the caddy.

Round-trip time (RTT) is used to calculate the distance between the anchors and the tag by measuring the time it takes for a signal to travel from the anchor to the tag and back. The anchor sends a message to the tag, which immediately responds with a reply message. The elapsed time between sending and receiving the signal is recorded as the RTT. Since the signal travels at the speed of light, the distance is calculated by dividing the RTT by two (to account for the round trip) and multiplying by the signal's speed. The distance is computed within the tags and sent to the MCU, which simply performs the bilateration calculation. See design/calculations/bilateration.png for a mathematical breakdown of bilateration.

Obstacle Detection

Initial Plan:

A single 45-degree conical ultrasonic sensor mounted on a servo motor was used in the initial design of the obstacle detection system. It was connected to the Arduino Mega 2560 via the GND, 5V, TX2, and RX2 pins to calculate distance. To enable the caddy to halt and search for a clear path when it detected impediments within 50 cm, the servo, which was powered by PWM on pin D10, was designed to sweep left and right. This method was unsuccessful, though, since high-frequency servo vibrations created noise and inaccurate sensor readings, making it hard to detect obstacles accurately.

Current Implementation:

To address these issues, the system now employs five fixed ultrasonic sensors: three facing forward (two at 24 cm height, spaced 40 cm apart to cover the caddy's 80 cm width, and one at 44 cm height for upper obstacle detection) and two side sensors angled at 45 degrees relative to the front. The 45-degree side placement compensates for the caddy's inability to make sharp 90-degree turns due to the half H-bridge motor drive, ensuring smoother navigation while maintaining reasonable side coverage. Ultrasonic sensors are connected to Arduino Mega with ground and 5V power linked to the power regulator system. Echo pins of the sensors are connected to digital pins D13-D9, while Trigger pins (for transmitting waves) are connected to D22, D24, D26, D28, and D30 (with Echo pins receiving the return signal). See design/system_connection_diagrams/obstacle_detection_connections.png for the Obstacle Detection connection diagram.

This fixed-sensor configuration eliminates servo-induced noise, though detection reliability remains angle-dependent, particularly for objects at oblique angles.

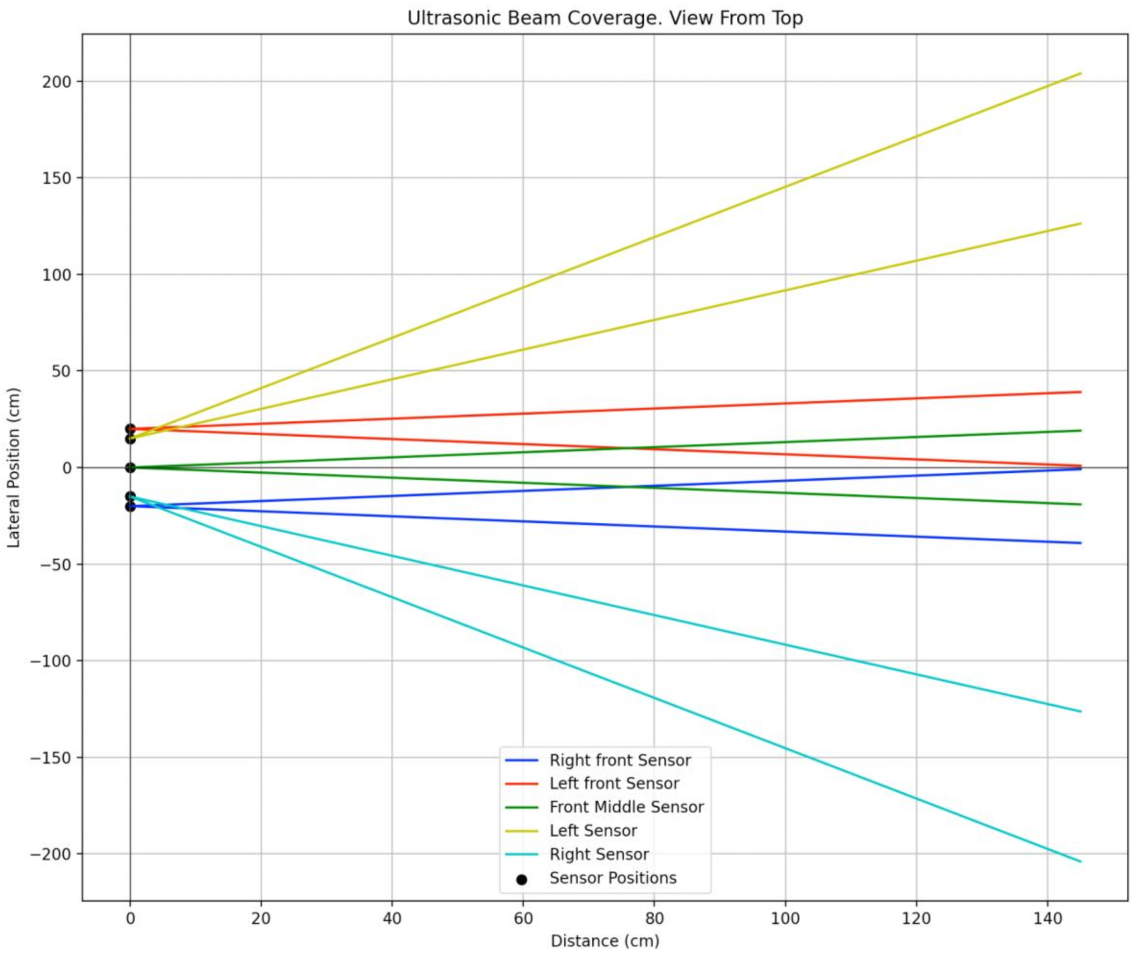

Figure 4: Obstacle Detection System Visualisation. View From Top

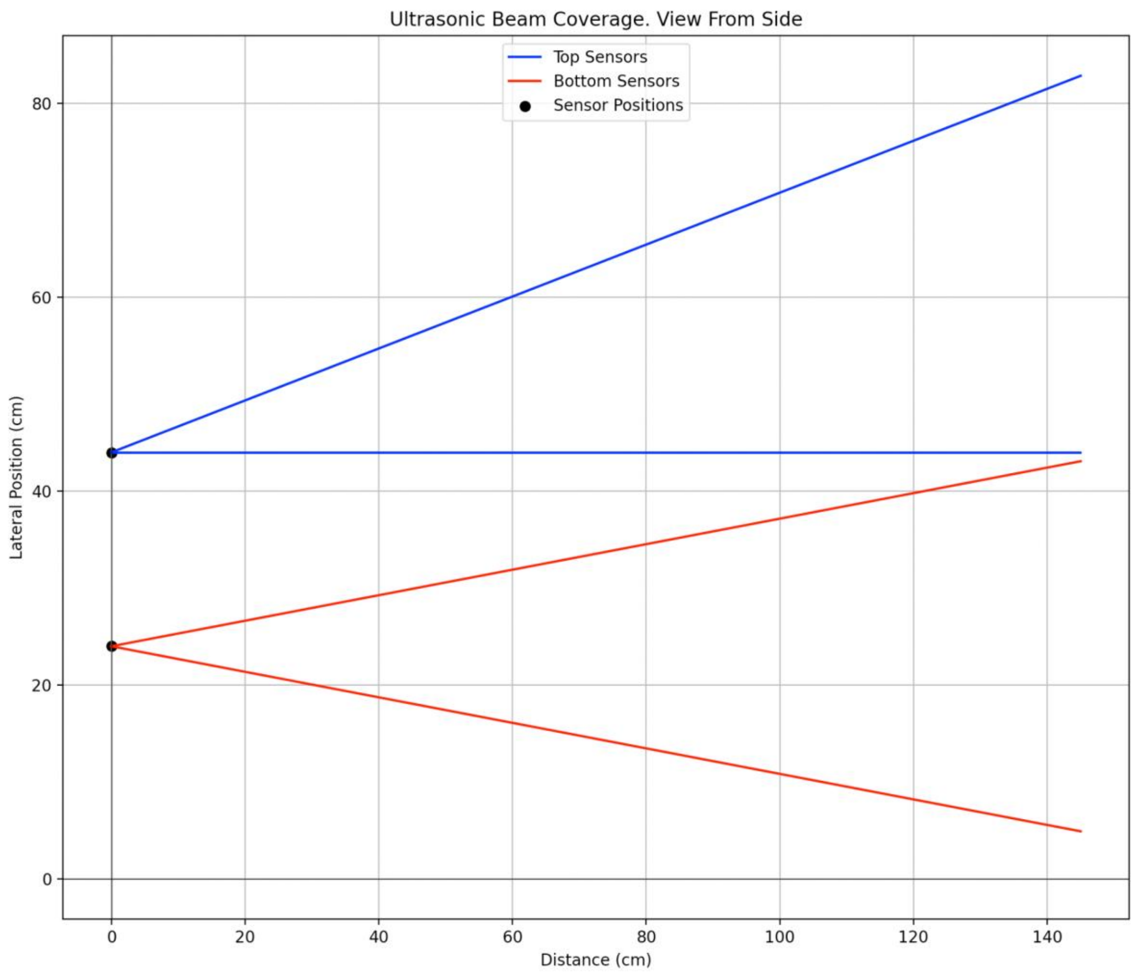

Figure 5: Obstacle Detection System Visualisation. View From Side

Motor Control System

The Motor Control System consists of two brushed DC motors connected to a motor driver created by our design team. The motor driver consists of a simple MOSFET circuit with flyback diodes to prevent reverse polarity current from damaging the power source. The motor driver has eight connections: positive and negative terminals for both motor 1 and motor 2, power and ground connections from the power source, and two GPIO connections from the Arduino to control the voltage applied to the motors. The maximum voltage a GPIO pin can provide is 5V, meaning the motor speeds were controlled by applying a voltage between 0V and 5V. Since we have constrained the project to only have the user standing in front of the caddy, a simple MOSFET circuit is sufficient for movement.

Data from a specialized tracking system that tracks the user's position and movement is used to dynamically modify the motors' speed. The tracking mechanism along with the obstacle detection system makes sure the caddy keeps a constant following distance by allowing the Arduino to modify the motor speed by altering the pulse width modulation (PWM) output when the user distance changes, or when an obstacle is preventing the caddy from moving in the direction of the user. On the other hand, the technology reduces the motor speed as the user approaches to avoid abrupt stops or crashes, guaranteeing fluid and flexible mobility. See design/hardware_diagrams/motor_driver.png for the motor driver circuit schematic.

Caddy Advising System

The caddy advising system will utilize the number pad, LCD, and the programming language of C to advise the user while they are playing a round of golf. The number pad and LCD will be wired to the Arduino Uno and will be used to display yardages and allow the user to enter both their club distances and distance to the hole on each shot. The user will first be prompted to enter the distance they hit each club in their bag using the number pad. The program will store these distances in a local database and will constantly prompt the user for the distance they have to the hole on their next shot. Once a distance is entered by the user, the program will display a club suggestion on the LCD until the user presses the reset button and then will be asked to provide another distance. This gives the user the freedom to enter what distance they want and how long they want to keep it displayed.

Frame and Assembly

The assembly of the frame will consist of mounting all our parts on an existing push cart. The parts will be mounted on the caddy strategically for efficiency and ease of access to allow both the caddy and the user to operate efficiently. The Arduino Uno, LCD, and Keypad will be mounted on the front handle of the caddy to ensure easy access for the user to enter club distances and receive club suggestions for their next shot. Since the caddy is only going to track the user and detect objects in front of the caddy, the UWB sensors will be mounted on the front handle of the caddy to ensure the anchors are on a similar level to the tag, which will likely be carried in the user's pocket. Ensuring the UWB sensors are at the same height will yield more accurate positioning in bilateration. The voltage regulator and Arduino Mega will be mounted centrally to ensure that they can be accessed from all parts and all positions on the caddy. The brushed DC motors will be installed using a rubber wheel mounted on top of the existing wheel on the caddy. For accurate speed and direction control, the Arduino Mega 2560 will be attached to the digital control ports of the motor driver, which will be mounted underneath the MCU and voltage regulator. With the help of our supervisor, the back wheel will be swapped to a swivel wheel using metal clamps to fix the wheel in the proper position.

Control Unit (MCU)

The control unit for the Caddy Advising System is an Arduino Uno microcontroller. The purpose of the two Arduino modules as the Control Unit is to address the Arduino Mega's known issues with the SDA and SCL communication ports being faulty. This issue is well documented on Arduino's discussion forums, as shown here [9]. The Arduino Uno is responsible for processing user input and driving the output display. The system includes a 4x4 keypad connected to GPIO ports D4 through D11, which allows the user to input data, such as club distances or the distance to their next shot. The microcontroller processes this input and stores it for future calculations. Output is displayed on an LCD, which is connected via the I2C communication protocol to the Arduino Uno through pins D20 (SDA) and D21 (SCL). The system interprets the input data, converts it into ASCII characters, and sends it to the LCD for clear and accurate user feedback.

The Arduino Mega will be connected to two REYAX UWB modules (receivers) for User Tracking. The receivers must be powered by the central power source through the 3.3 V connection of the voltage regulator board. Communication will be done through the receiver/transmitter ports on the control unit. One receiver will be connected to ports D14/D15 (left sensor), and the other will be connected to D16/D17 (right sensor). User tracking is the most important feature of the system, so the data received from the UWB modules will be considered a top priority for processing. Since each receiver is mounted on a different side of the caddy, the MCU will be able to determine the direction of the user and drive the motors to follow the user's position. The speed and direction of the caddy will be determined based on the strength of the signal received from the UWB modules. The weaker the signal, the more we will have to drive the motors. For the first implementation, we will make the motors run at a set speed when a signal is received from the UWB modules. Once that is working as intended, modifications of the software on the control unit will be made to drive the motors at different levels based on the strength of the signal received.

Five fixed ultrasonic sensors are used by the obstacle detection system to keep an eye on the caddy's surroundings. Three sensors face forward: one at 44 cm to detect impediments at higher levels, and two at 24 cm height and 40 cm spacing to cover the caddy's 80 cm width. To compensate for the caddy's limited turning capabilities caused by the simple MOSFET circuit motor driver, two additional sensors are positioned at 45 degrees on each side to enhance side coverage and enable smoother navigation. The detecting range of each ultrasonic sensor is 45 degrees conical. An Arduino Mega 2560 microprocessor is linked to the sensors, and a controlled power supply provides the GND and 5V electricity. Digital pins D22, D24, D26, D28, and D30 are linked to the trigger pins, and D13 through D9 are linked to the echo pins. By removing noise from moving parts, this fixed arrangement increases system stability, albeit obstacle angles can still affect detection accuracy. See design/connection_diagrams/obstacle_detection_connections.png for comprehensive wiring.

Two brushed DC motors that are each coupled to an Arduino Mega 2560 for speed and direction control power the motor control system. Pin D6 is linked to Motor 1, and pin D7 is linked to Motor 2. The MCU can control the forward motion of the motors by sending HIGH and LOW signals through these digital pins. The 12V Li-ion battery (Three 3.7V nominal 18650 batteries in series) powers the motors directly, guaranteeing enough torque for mobility over various surfaces. Two UWB receivers that follow the user's position provide the signal input that first sets the motors' speed to a fixed setting. As the project develops, the motor control system will be improved to dynamically modify speed in response to the UWB units' signal distances. This technology guarantees rapid modifications to user position changes and seamless navigation.

Power and Charging System

The Power and Charging System for the Auto Caddy serves as the central energy source for all components in the design except for the Arduino. The central energy source consists of 3.7V 3300 mAh 18650 batteries connected in both series and parallel to ensure the correct voltage and current needed for the entire system. The source contains six individual battery packs that have three of the 18650 batteries in series, producing a voltage of 11.1V nominal. The six battery packs are connected in parallel to obtain a high enough current capacity, ensuring the caddy can operate for 8 hours on a full charge. There are two power wires and two ground wires that connect the caddy to power. One set of power and ground goes to the motor driver to power the motors, while the other set is connected to the voltage regulator board to power the other components in the system. See design/calculations/PowerandMotorCalculations.pdf and design/calculations/PowerandMotorCalculations.xlsx for detailed calculations and specifications.

The power system integrates with the motor control, user tracking, and obstacle detection subsystems through a voltage regulator created by our team. The voltage regulator consists of three different voltage regulators (8V, 5V, and 3.3V) that allow every part in the system to be powered by the central energy source. The LCD and the five ultrasonic sensors are connected to the 5V output on the regulator, and the two ultra-wideband sensors are connected to the 3.3V output.

Furthermore, a 3.7V 800 mAh LiPo battery, along with a 3.3V voltage regulator, is used to power the ultra-wideband tag on the user. The small and compact battery was chosen for portability and is easily rechargeable for long use. A 5V USB battery pack is used to power the Arduino, as the 8V port on the voltage regulator board drops slightly in voltage due to the motors being connected to the same power source. The Arduino Vin port needs a minimum voltage of 7.5V, meaning when the voltage drops below that value, the Arduino does not have sufficient power and turns off. The 5V external USB battery pack provides sufficient power to allow the Arduino to use the sensor input to drive the caddy in the direction of the user. See design/hardware_diagrams/voltage_regulator.png for the voltage regulator schematic.

List of Parts

Purpose	**Part**	**Link**
Control Unit	Arduino Mega 2560 MCU	http://surl.li/aagrul
Control Unit	Arduino Uno	https://store-usa.arduino.cc/products/arduino-uno-rev3
UWB Sensors	RYUW122_Lite UWB	https://www.amazon.ca/RYUW122_Lite-Interface-Antenna-Transceiver-Evaluation/dp/B0CBTBYH87
Obstacle Detection Sensor	HC-SR04 Ultrasonic Sensor	https://www.amazon.ca/Ultrasonic-HC-SR04-Detector-Ranging-Distance/dp/B09PBJ4ZY1
Motors	12V DC Motor	https://www.amazon.ca/Permanent-Magnet-Motor-MY6812-Pulley/dp/B07YWYJ497

User Interface LCD	Sunfounder 12C LCD 1602 Module	https://www.amazon.ca/SunFounder-Serial-Module-Display-Arduino/dp/B019K5X53O?dib=eyJ2IjoiMSJ9.YlGQFAImPO1px1UBaduci0IUY8Qtd9R_8kYQ16KzEqTPOjeW75n32NpU5L0bYd7TRKCHgBlU2Qh3L9bvK5uel6RpmDRuVMRRTANJqxAgbM-aN5z3MfEaTu16yiB_8bgaeOUL-JRnTLXGW-F1nCOtovZEGOlOXraFioC-2scVQ3DTzBGv1TAObhyesTJr3dAB-v9yRmoUbJvgf4JR_v-irXrIO7HndsR4Q5yVnY68haJOYIpy0u6L_CSw3RL5gKimyTwe198Qs-34DG2YbRYDTDJkW4phoNuHuf4n4ebiLcc.fiOENzA-EnpCZzGejyk-K_reWyXHsgl7LS4Pm7JhvQI&dib_tag=se&keywords=lcd%2B1602&qid=1743785369&sr=8-8&th=1
User Interface Keypad	4x4 DIYmalls Keypad	https://www.amazon.ca/Matrix-Membrane-Keyboard-Arduino-Microcontroller/dp/B086Z1ZXNJ?crid=9QDYJGG3RF59&dib=eyJ2IjoiMSJ9.Ee__r7gd3nCMAyTMWCyYuWz87FsZVTDj_ABVOiPTZbBtHw8sxxpxgSumaWrsJAxBjeL3IOMbcOjADJYBee310JWYHKO7d5LxEw1_qTO2gGcwc4PqbcXHTH6gLs9eGalymtDT_1hzUa5nBmEqgz_8j3cLEFIKdtE5GPvttXURgvjO2HQRyvSam1yo0uIm4VTSCRT0JDOTDRwF5joM5WzgcQDFWsN3UtQKi4rg6Bmu1noWtpojKF3LGUJ_rordoNS_mKr3X_xUHuxm1dknBqNMWHVPq_m7K_uFVHN82YLwdeM.Bry0HkHClB8Y1r3Xc

		s0MXPGm7b1bDW3WdRdqUVJO4qw&dib_tag=se&keywords=keypad+arduino&qid=1743785526&sprefix=keypad+arduino%2Caps%2C140&sr=8-5
Frame	Sun Mountain 3-wheel cart	N/A
System Battery	3.7V 3300 mAh 18650 battery	https://www.amazon.ca/Rechargeable-Battery-Batteries-Flashlights-Headlights/dp/B0D9D9L5H1
User Battery	Fytoo 3.7V 800 mAh Lipo Battery	http://surl.li/zdvhlw

Table 1: List of Parts

Development Environments

The software development of the caddy was done using the Arduino software. This allowed our software team to easily test new versions as they were developed. Our software utilized the serial connections available on the Arduino Mega 2560, allowing us to communicate with external sensors and output terminals when a laptop or PC is connected to the USB port of the Arduino. This allowed for easy debugging and verification of sensor data through printing the data from the sensors to the output terminal.

The hardware of the system included a series of sensors and the Arduino Mega 2560 development board. The sensors in the design include HC-SR04 Ultrasonic sensors and REYAX RYUW122 Ultra-wideband sensors, which were used in the Obstacle Detection and User Tracking subsystems, respectively. The ultra-wideband sensors were connected to the transmit and receive ports on the Arduino to allow for easy communication between the sensors and the development board.

Testing and Test Results

Each of the subsystems below relates to the System Test Plan that can be found in appendices/g1_system_specifications.pdf. The specific test that each subsystem addresses can be found in the heading in braces (e.g. User tracking {1} corresponds to the first test in User Tracking).

Object Detection System (Response Time Testing {2})

Five HC-SR04 ultrasonic sensors were used to test the object detection system in a variety of scenarios, including variations in surface types (rough and smooth), angles of incidence (0° to 90°), and object sizes (the smallest identifiable object was 2 cm^2 at 1.45 m). To guarantee statistical reliability, each test was carried out ten times at each angle interval. The detection effectiveness was expressed as a binary or fractional value (1 = detected, 0 = not detected, 0.5 = partially detected) in the format of an array (e.g. [trial1, trial2, trial3, etc]).

Detection Efficiency Based on Surface Type and Angle

Rough Surface (Textured, High Reflectivity)

0° - 15°: 98% - 100% (near-perfect detection due to strong reflection)
15° - 30°: 95% - 98% (slight decline but still highly reliable)
30° - 45°: 85% - 95% (reflection weakens slightly)
45° - 60°: 40% - 70% (significant signal loss, inconsistent detection)
> 60°: 10% - 30% (high signal deflection, unreliable readings)

Smooth Surface (Low Reflectivity)

0° - 15°: 95% - 100% (strong detection due to direct reflection)
15° - 30°: 75% - 95% (some signals deflect away)
30° - 45°: 40% - 75% (significant decline in detection)
45° - 60°: 10% - 40% (most waves reflect away, weak signal return)
> 60°: 0% - 10% (almost no detection due to signal loss)

Raw Detection Data

Rough Surface

0° – 15°: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1] → 100%

15° – 30°: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1] → 100%

30° – 45°: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1] → 100%

45° – 60°: [0, 1, 1, 1, 1, 1, 1, 1, 0.5, 0.5] → 75%

60° – 75°: [1, 0, 1, 1, 0, 0, 1, 0, 0, 0] → 40%

75° – 90°: [0, 0.5, 1, 1, 0, 0, 0.5, 1, 0, 0] → 30%

Smooth Surface

0° – 15°: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1] → 100%

15° – 30°: [0.5, 1, 1, 1, 1, 1, 1, 1, 1, 1] → 90%

30° – 45°: [0.5, 1, 1, 0.5, 0.5, 0, 0.5, 1, 1, 1] → 65%

45° – 60°: [1, 0, 1, 0.5, 1, 1, 0, 1, 1, 1] → 70%

60° – 75°: [1, 1, 0, 0, 0, 0, 1, 0, 1, 0] → 30%

75° – 90°: [0, 0, 0, 0, 0, 0, 0, 0, 0, 0] → 0%

Important Points

- On both smooth and uneven surfaces, the device operates best at low angles (0° to 30°) with a detection efficiency of >95%.
- Up to 45°, rough surfaces retain >85% efficiency, whereas smooth surfaces lose 40%–75% of their effectiveness in the same range.
- Detection is unreliable after 60° (less than 30% on rough surfaces and less than 10% on smooth ones).
- High sensitivity under ideal circumstances was confirmed by the smallest observable object, which was 2 cm² at 1.45 m.

User Tracking System (Navigational Testing {1, 2})

The user tracking testing process included testing three UWB modules both individually and coherently. The individual testing included measuring and observing the raw distance measurement from each anchor on the caddy. This was completed by measuring distances using a tape measure and holding the UWB tag at the distance and observing the reading from the anchor by printing the result to a terminal using a serial connection with a PC connected to the Arduino Mega. This allowed our team to measure the accuracy of each UWB anchor and adjust the calibration as necessary. Furthermore, our team tested the bilateration output from both anchors and the tag on the user by measuring distances and angles relative to the caddy. The results were observed using serial output and compared to our measured distances and angles. The results can be seen below:

Individual UWB Testing:

Actual Distance (cm)	Average UWB Reading (cm)
10	8
30	36
80	84
100	112
150	158
200	190
300	294
400	392
500	501

Table 2: Ultra Wide Band Testing Results

As seen in the table above, the results show the UWB distance angles are accurate to within 10 cm of the actual distance. This is accurate with the datasheet specification and allows for accurate tracking of the user location by utilizing bilateration.

Bilateration Output Testing:

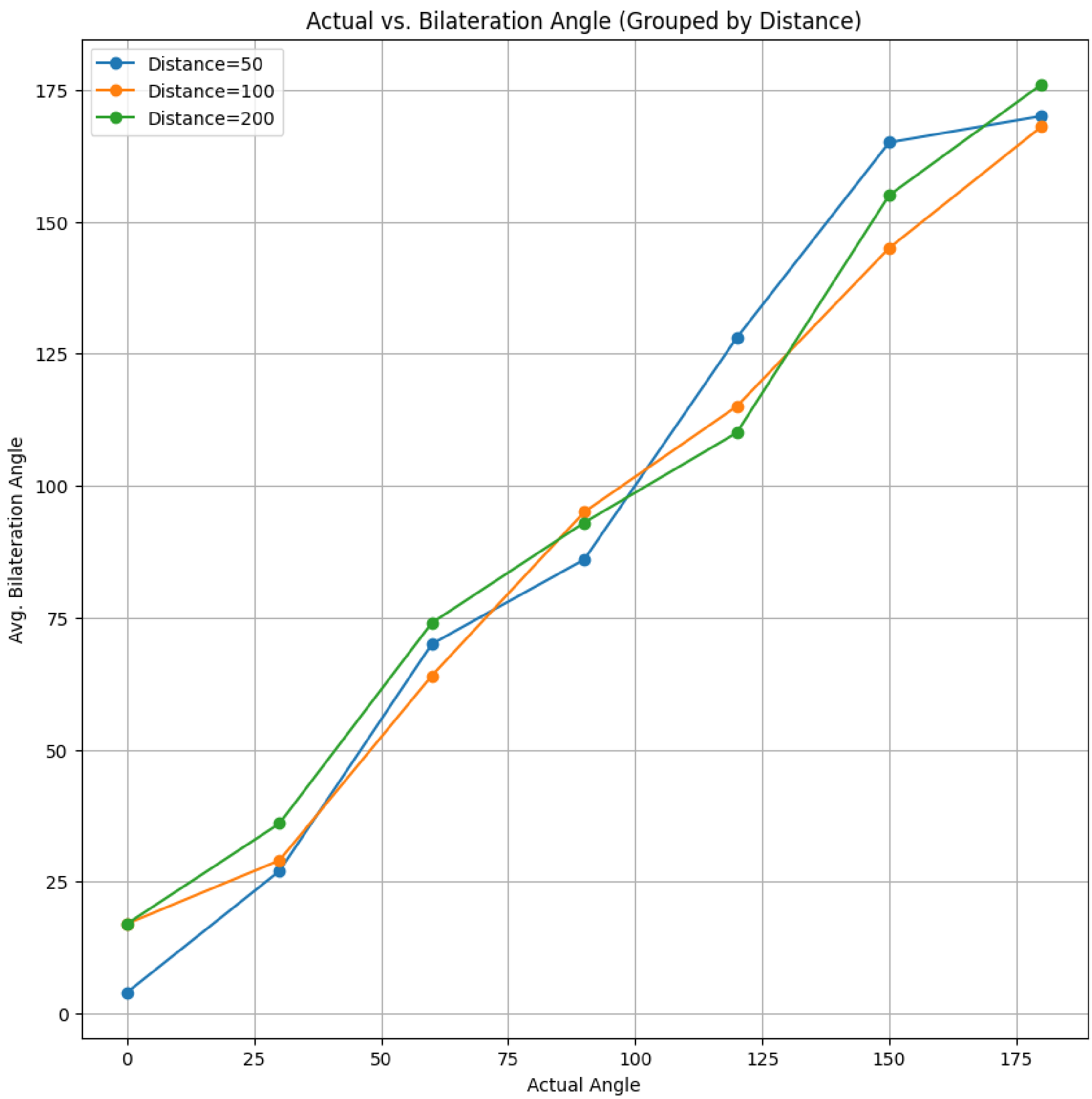

Figure 6: Actual vs. Bilateration Distance

As seen in the figure above, the angles produced by the bilateration algorithm are consistent among all the tested distances with an error of about 15 degrees. This problem was solved by partitioning the output angles in the software to 0, 30, 60, 90, 120, 150, and 180 degrees to drive the caddy in the direction of the user. This resolved potential inaccurate angles from fluctuations in UWB sensor readings and allowed the caddy to still operate smoothly during turning.

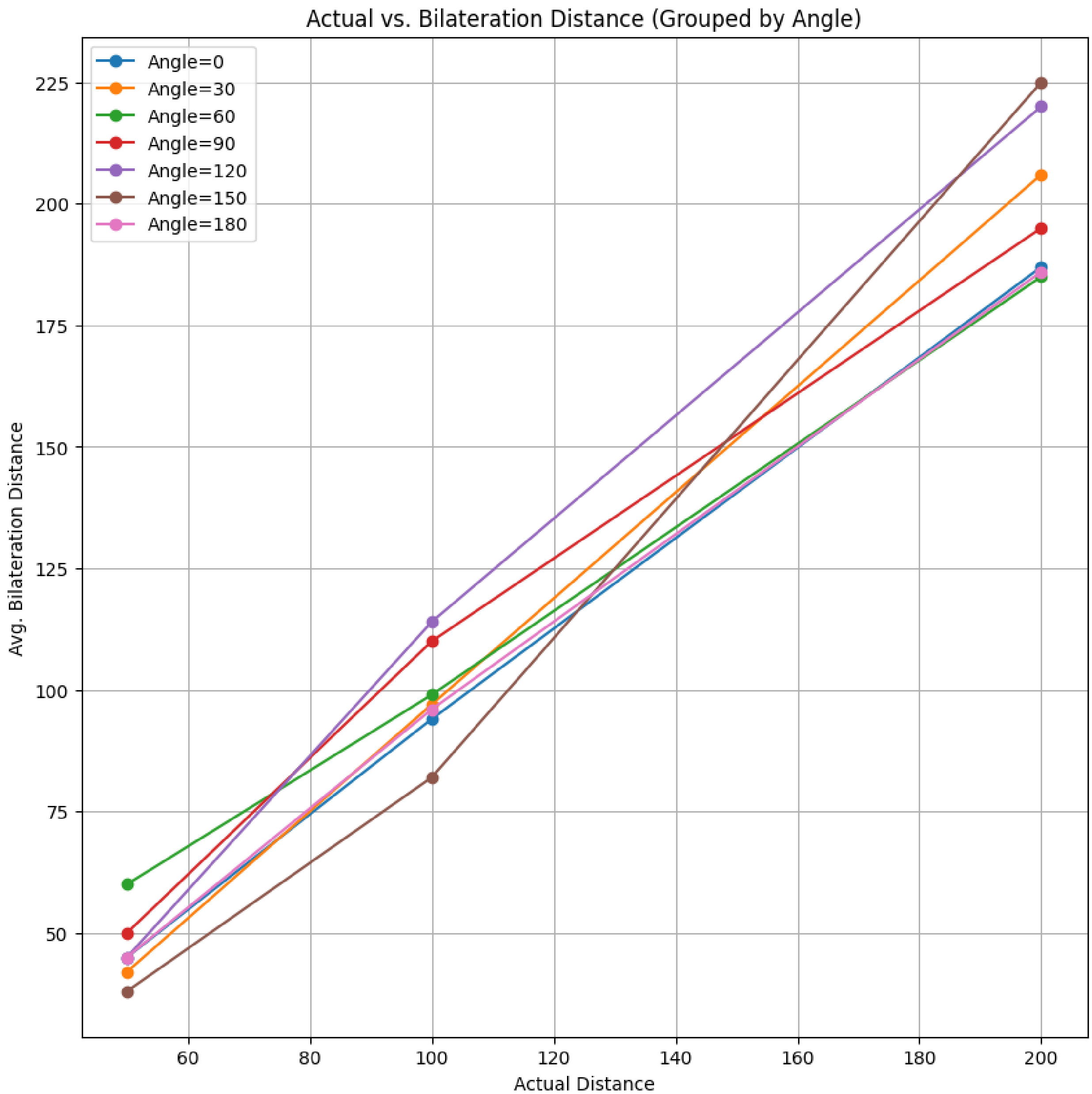

Figure 7: Actual vs. Bilateral Distance

As seen in the figure above, the output distances from the bilateration algorithm vary depending on the angle the user is positioned relative to the caddy. For shorter distances, the dispersion of all the measured angles is smaller. As the user gets further away from the caddy, the distances vary based on the angle the user is relative to the caddy. Our results showed that the distances were more accurate when the user was standing directly in front of the caddy at a 90-degree angle. As the user moves towards the sides of the caddy, the distance measurements become less accurate. However, the distance readings are not as significant when the user is beside the caddy, as the main operation of the caddy in these intervals is turning.

Power and Charging System (Usability Testing {3})

The Power and Charging system testing includes testing the caddy for an 8-hour duration on a single charge. This was completed by using the caddy for 2 hours a day for 5 straight days without recharging the 18650 batteries, the USB power bank, or the Lipo battery. Before starting the testing, we charged each component to 100% capacity to simulate a user charging the caddy overnight before a golf round. During each day of use, we used a timer to track the time the caddy was turned on and in operation. These times were limited to exactly 2 hours each day. At the end of the testing period, we measured the voltage levels of each of the 18650 batteries, the Lipo battery, and the USB power bank. The 18650 batteries showed a voltage of 3.6V while having a 50% capacity (found using the 18650 battery charger). The USB power bank still maintained 80% capacity, as its only responsibility was to power the Arduino Mega and Arduino Uno. The Lipo battery also maintained a near full charge, as the UWB tag draws very little power (stayed around 90% charge).

Advising System (Response Time Testing {1})

For the advising system, testing was done on the keypad and the LCD to ensure responsiveness. The Advising System is a separate system on the Arduino Uno to make up for the Mega's drawbacks. We made sure to test that it will be constantly displaying what information is needed. LCD testing made sure that the information displayed by the user would not disappear unless the reset button was pressed. Testing on the keypad was done to make sure that it would immediately display what the user wanted onto the LCD.

Additional Testing

In addition to the subsystem testing, system testing was performed to address the following goals in our System Test Plan:

Reliability Testing

1. Ensure that the caddy can operate in terrains such as short (0.5 inch) and long (1.25 inch) grass, concrete, gravel (¼'' minus gravel), elevation change (15 degrees), snow (0.2 inches), rain, and dew conditions by placing the caddy in such conditions and manually testing its functionality.
2. Ensure the caddy can operate in a temperature range of -10 to 40 degrees Celsius (ambient) by adjusting the temperature of a room and testing the functionality of the design.

Usability Testing

1. Ensure the caddy can support a golf bag of up to 30 lbs by adjusting the number of clubs in the bag and observing its functionality.
2. Ensure the caddy operates under 60 dBs by using a sound level meter.
3. Give the user manual to someone not involved in the project and observe how they use the caddy.

Reliability Testing {1, 2}

Due to the time frame and scope of the project, demonstration and testing were completed in an indoor environment. While our system was designed and built to withstand the conditions stated in these requirements, we did not explicitly test the conditions as they were not attainable given the climate of Saskatchewan during the Winter season.

Usability Testing {1, 2, 3}

{1} - Our golf caddy can support golf bags of up to 30 lbs, however, the effectiveness of the caddy was reduced. Our frame was designed to hold a golf bag, but the operation of the motors on the caddy was limited due to the added weight, making the starting acceleration and turning more difficult for the caddy during operation.

{2} - Using a mobile phone application decibel meter, we measured the caddy to produce about 67 dB of noise during operation. While this number is higher than our desired goal of 60 dB, we only tested the noise of the caddy in an indoor environment on a tile floor. The noise is a result of the wheels having friction against the tiles, with the majority of the noise coming from the back swivel wheel. This noise would likely be reduced when the caddy is operating in outdoor conditions such as fairway or rough grass.

{3} - The user manual can be found in appendices/g1_user_manual.pdf.

Project Schedule

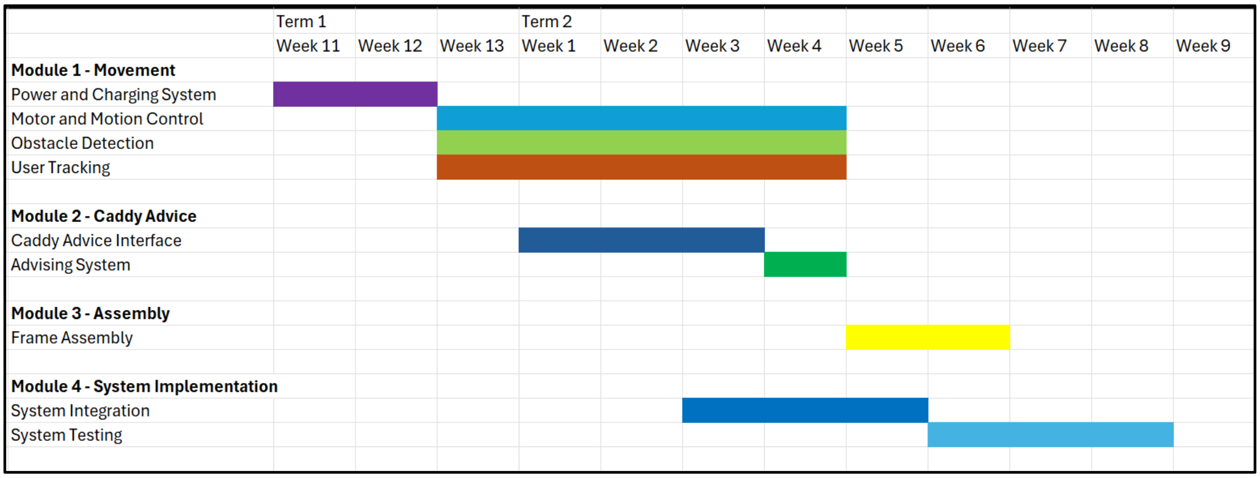

Figure 8: Expected Project Schedule

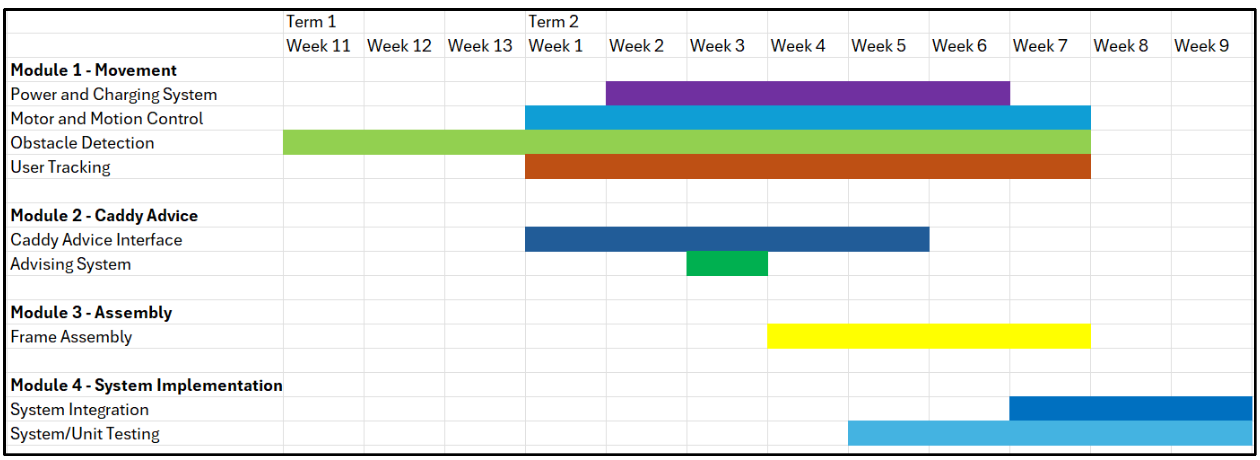

Figure 9: Actual Project Schedule

Group Member	Planned Hours	Actual Hours	Main Tasks (Task IDs only)
Ogo Alege	110	240	User Tracking, Obstacle Detection System, Motor and Motion Control, Power and Charging, Frame and Assembly, System Integration
Zachary Szakacs	110	225	User Tracking, Motor and Motion Control, Power and Charging, System Integration
Yusup Guldadov	145	197	Obstacle Detection System, Motor and Motion Control, Frame and Assembly, System Integration
Hasin Raihan	105	105	User Interface, and Frame and Assembly

Table 4: Planned and Actual Hours per Group Member

The discrepancies in the expected hours worked and the actual hours worked are a result of multiple parts of our design requiring multiple iterations to get fully integrated. The main issues resulting in the extra time spent included the motor control system and the power and charging system. Given that we are a team of software engineers, the motor control system caused our team difficulty. We initially ordered a motor driver for our system, but after very little use, a connection in the driver broke, resulting in a non-functional motor driver. To combat this issue, our team was forced to design and build our own motor driver with proper MOSFETs and heat sinks to ensure it could be functional for our design. Mounting the motors on the existing caddy caused many issues as well, as our design included mounting a rubber wheel on top of the existing wheels on the caddy. The pressure/friction of each rubber wheel on the caddy must be the same for the caddy to move in the forward direction, making the mounting process a very delicate and precise task. Furthermore, the power and charging system caused us many issues as the 18650 battery packs we obtained did not have secure and proper connections. This caused the batteries to disconnect during use. Solving this issue included finding new battery packs with the help of our supervisor and replacing the existing wires on the packs with wires that can handle higher current values.

Future Considerations

To develop a more intelligent, responsive, and user-friendly system, our autonomous caddy's next development will include cutting-edge computer vision and AI-powered object identification. We can do real-time obstacle recognition, path planning, and golfer tracking with significantly higher precision than with just ultrasonic sensors by including stereo cameras or depth-sensing RGB-D cameras. For dynamic obstacle classification, machine learning methods like YOLO (You Only Look Once) or SSD (Single Shot MultiBox Detector) might be used, and position estimation or facial recognition would allow for smooth golfer following without the need for human input. We also plan to add a mobile app that will control the advising system using a wifi communication protocol. This app will be able to turn the caddy on and even allow the user to create a database of their choosing.

We would switch from the Arduino Mega to a high-performance embedded system that can infer neural networks in real time, like the NVIDIA Jetson series or Raspberry Pi with a Coral AI accelerator, in order to handle this computationally demanding workload. Additionally, this improved processing unit would include Bluetooth and Wi-Fi connectivity, allowing the caddy and golfer to communicate in both directions using a specific mobile application. To improve convenience and safety, the app might provide customized follow modes, speed control, and obstacle alerts.

Although the existing DC motors are capable of providing sufficient propulsion, future versions might profit from torque-optimized gearing, precise encoders, and revised motor mounts to enhance control responsiveness. Smoother functioning on a variety of terrains would also be ensured by improvements and modifications to the weight distribution.

The next-generation caddy will provide autonomous dependability, user-friendly engagement, and adaptive navigation by combining state-of-the-art vision AI, powerful edge computing, and sophisticated electromechanical design. This will turn it from a useful assistance into an essential golfing companion.

Conclusion

Our project developed and tested an autonomous golf caddy, demonstrating a potential cost-effective solution for golf carts that track and follow a user under heavy load. Furthermore, our design has a user advising system and a built-in obstacle avoidance to allow the golf cart to navigate around an uncontrolled environment. While further refinement is necessary to address performance limitations in controlling the motion of the caddy, our prototype work can contribute to developing a low-budget solution to an autonomous golf caddy for recreational use.

Our design included the integration of ultrasonic and ultra-wideband sensors, a keypad and LCD, and brushed DC motors to allow the caddy to navigate and provide advice to the user. The ultra-wideband sensors were used to track the location of the user utilizing bilateration. This data allowed the motor and motion control system to be driven by our control unit, allowing for real-time following navigation. Furthermore, the ultrasonic sensors were used to detect objects in front of the caddy, allowing the system to navigate around the objects to continue to track the user. When the user gets to their desired location, they can utilize the club suggestion system through the keypad and LCD for advice on their next golf shot. These parts allowed our design team to implement an autonomous golf caddy using a budget-friendly approach while still meeting core principles of the design.

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