PERSON-FOLLOWING LUGGAGE SYSTEM

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Abstract

This paper describes in detail a smart luggage platform system that automatically follows a passenger, therefore mitigating the hassle of carrying his/her own luggage during travel. The paper starts off with a discussion of the background of the problem and the proposed solution. Then it describes the desired functionalities, benefits and components of this project. This section will also introduce the high-level expectations of the overall system. Next, the paper elaborates on the overall design of the project by covering the design details and requirements for each subsystem. After that, the paper discusses the testing and reliability approaches for each of the subsystem requirements listed in the previous section. The paper also covers the cost analysis of the project. Lastly, there is an overview of the successes and challenges, uncertainties, ethical considerations, and future work of the project.

Contents

1. Introduction

1.1 Motivation

Sometimes carrying luggage might be the most unsatisfactory part of a trip. Moreover, this can get annoying if there are multiple heavy luggage to be carried without the help of any transportation tool. It becomes a hassle, especially in an airport environment when the passenger is stressing about where to go for their next flight. Even if there is a cart available, it is inconvenient to carry it around everywhere due to its size. Though there are so-called “smart luggage” made for sale with different features including USB-port for charging, GPS localization etc., the price is too high for the public to afford [1], and only a few of these have been able to achieve the fully automatic following feature. Therefore, there is a need for low-cost smart systems that track the passenger and avoid any obstacles.

1.2 Solution

The paper proposes the Smart Person-Following Luggage System project as a solution to the problem mentioned above. More specifically, the passenger will carry a device called ‘tag’ that calibrates itself with the luggage platform. The ‘tag’ as well as the platform contain ultra-wide-band sensors that provide accurate relative positioning data. Ultrasonic sensors will also be placed on the platform to detect obstacles. Based on the relative change in distance between the platform and the passenger, the platform will vary its speed and direction. This will be implemented by a bi-directional differential drive motor system consisting of 2 motors.

The advantages of this solution compared to the “smart luggage” available in the market are as follows. Firstly, our solution is much cheaper than the ones available on the market, consisting of cheaper and more efficient components. Secondly, this solution can be extended to many other items, as it is an autonomously moving platform rather than luggage.

1.3 Visual Aid

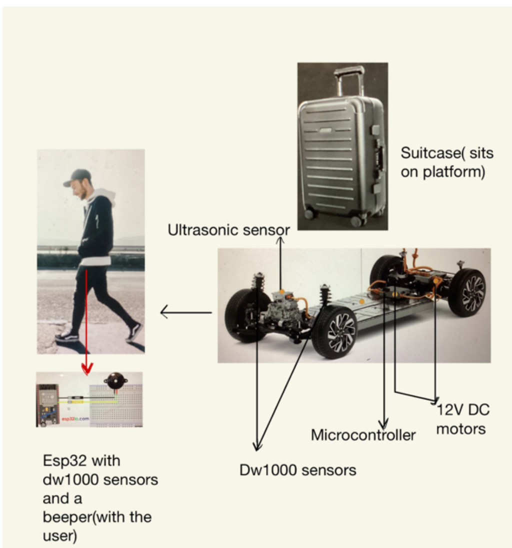

Figure 1: Visual Aid

1.4 High-Level Requirements

The final targets of the project are as follows:

- The system achieves a user-following accuracy of 1 – 1.2 m with an error of ± 50 cm, ensuring the luggage consistently follows the person.
- The system should follow the person with real-time updates in the path with a latency of no more than 1s, allowing for swift adjustments in the luggage's movement to keep pace with the user.
- The system should avoid collisions if obstacles show up in front of the device (up to 0.5m). If the person goes out of bounds of the device, the person should be alerted that the luggage is left behind (> 10 m).

1.5 Block Diagram

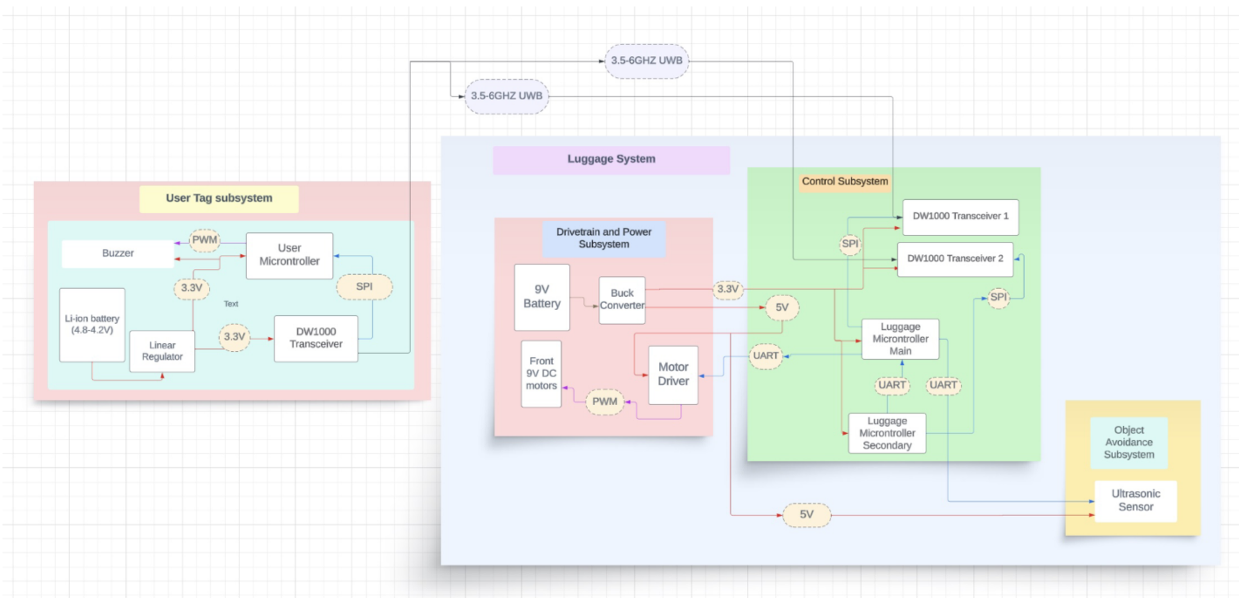

Figure 2: Block Diagram

1.6 Sub-System Overview

1.6.1 Power and Drivetrain Subsystem

This subsystem is responsible for providing power to the entire system and accurate operating voltages to the individual components as well as providing motion to the platform. It consists of 9V and 4.8V batteries, buck converters, linear regulator, motor driver and DC gear motors.

1.6.2 Control Subsystem

The Control Subsystem, centered around an ESP32 microcontroller with a triangulation algorithm, orchestrates seamless integration, precise distance measurements, and obstacle response.

1.6.3 User Tag Subsystem

This subsystem is responsible for helping the anchor transceivers on the cart get an accurate location of the person. This tag is carried by the person and buzzes if the cart is left behind. This subsystem is essential for the control subsystem to get the required values to do its triangulation.

1.6.4 Obstacle Avoidance Subsystem

This subsystem consistently delivers reliable distance values between the obstacles and the luggage itself. It consists of an ultrasonic sensor. This subsystem is responsible for providing accurate distance measurements between the luggage and objects in its path to prevent collisions.

1.7 Conclusion

In conclusion, the smart luggage system's efficacy relies on the synergy of its defined subsystems. The Control Subsystem, powered by an ESP32 microcontroller, facilitates seamless integration, ensuring precise triangulation for accurate user tag positioning and obstacle avoidance. The Obstacle Avoidance Subsystem, equipped with an ultrasonic sensor, enhances safety by providing reliable distance measurements. The Drivetrain and Power Subsystem enables efficient motion control and power distribution through motors, a 12V battery, and a buck converter. Lastly, the User Tag Subsystem, with an ESP32 and DW1000 transceiver, plays a crucial role in reflecting signals and performing triangulation for accurate positioning. Together, these subsystems create a compact, intelligent luggage system that prioritizes user experience and operational reliability.

2 Design

The project design consists of 4 subsystems as shown in the block diagram. They are discussed in detail below:

2.1 Power and Drivetrain Subsystem

2.1.1 Overview

The primary purpose of this subsystem is to provide motion to the system. It will be possible to achieve linear as well as differential motor control through this subsystem. It will also provide power to the microcontroller, motors and motor drivers.

This subsystem consists of a 12V battery to power the luggage subsystem and a 4.8V battery to power the user tag subsystem. A buck converter will convert the 12V to 3.3V and 5V. The 3.3V will be required to power the ESP32. The 5V will power the motor driver IC and the ultrasonic sensor. On the user tag subsystem, a linear regulator will drop the voltage down to 3.3V from 4.8V. This subsystem also consists of 2 motors and casters that will move the luggage system around. The esp32 microcontroller will send PWM signals to the motor drivers that will initiate the forward movement of the system. Both the motors will function independently with separate motor drivers and gate signals. A proportional controller will be implemented where feedback will be used to determine each motor's speed to cause left and right turning. A schematic is shown below in figure 3.

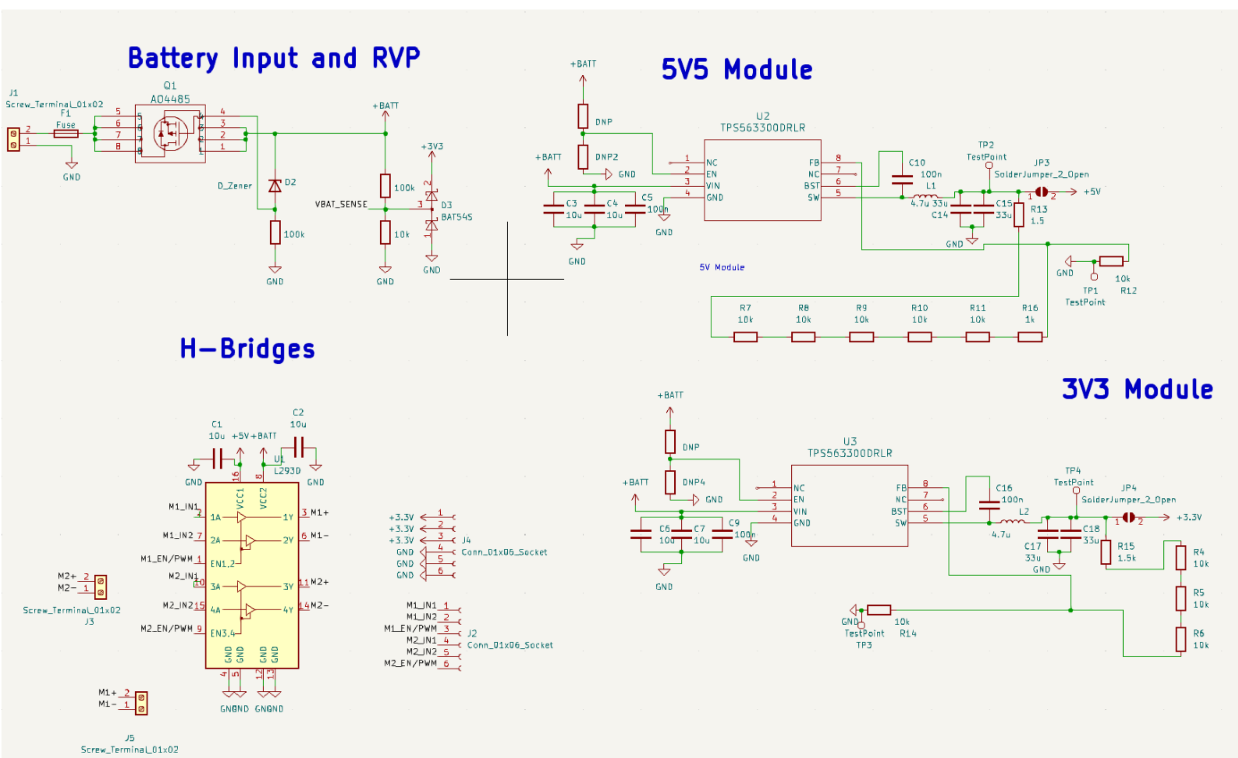

Figure 3: Power and Drivetrain Subsystem Schematic

2.1.2 Requirements

The essential requirements of this subsystem are:

1. A 12V input must be lowered down to 3.3V and 5V.
2. With the battery fully charged, the platform should be able to actively perform tasks, including following the passenger, stopping in front of an obstacle, and estimating the passenger distance, for at least 30 minutes.
3. It should be able to carry a load of 20 kg.

2.1.3 Design Choices

A 9V battery is chosen keeping in mind the operating voltage of the DC motors. On the other hand, the 4.8V battery on the user tag subsystem is chosen to be an input to a linear regulator that steps down the voltage to 3.3V. The closer the input and desired output voltage are, the lesser is the power dissipation. For the voltage step-down, a TPS563300DRLR buck converter was selected. The desired output voltage can be obtained using a resistor divider equation, which is a part of the internal circuitry of the converter IC. The equation is outlined in Equation 1:

$$R_{FBT} = \frac{V_{out} - V_{REF}}{V_{REF}} \times R_{FBB} \tag{1}$$

The values of V_{REF} and R_{FBB} are intrinsic to the IC and are 0.8V and 10kΩ respectively. To obtain output voltages of 3.3V and 5V, these values are plugged into V_{OUT}. For the 3.3V case, we have Equation 2:

$$R_{FBT} = \frac{3.3 - 0.8}{0.8} \times 10k = 31.3k\Omega \tag{2}$$

For the 5V case, we have Equation 3:

$$R_{FBT} = \frac{5 - 0.8}{0.8} \times 10k = 52.5k\Omega \tag{3}$$

With the AP2112K linear regulator, the 4.8V battery was stepped down to 3.3V. The datasheet for the device mentions a dropout voltage of 0.4V. Therefore, the battery provides sufficient headroom voltage for the operation of the component. The datasheet also mentions the maximum allowable temperature of the device for operation to be 110°C. Performing tolerance analysis for the junction temperature of this device, we have Equation 4:

$$T_{ja} = i_{out} \times \left(V_{in} - V_{out}\right) \times \Theta_{jc} = 0.6 \times (4.8 - 3.3) \times 96 = 86.4^{\circ} C \tag{4}$$

The values for the parameters were taken from the datasheet of the linear regulator. Based on this tolerance analysis, it is feasible for the linear regulator to operate.

An L293D motor driver was chosen to operate both motors through digital signals simultaneously. It has 2 input pins for each motor and 1 enable pin. By applying a voltage HIGH to one pin and LOW to the other pin while keeping the enable pin HIGH, the motor spins in the clockwise direction. On the other hand, applying a voltage LOW to the first pin and HIGH to the second pin, the motor spins in the counterclockwise direction. The enable pin can take in PWM input signal that varies the voltage being provided to the motors and therefore varying their speed. Therefore, the motor driver effectively allows both motors to operate to implement the control algorithm.

Lastly, the motors were chosen such that the platform could keep in pace with an average human, whose speed was determined to be 2mph. The 12V Greartisan DC Gear motors were rated for 100 RPM along with 30cm wheel diameter. Therefore, the linear speed can be calculated as shown in Equation 5:

$$V_{max} = \omega\pi d = 100 \times 3.14 \times \frac{0.3}{60} = 2.52mph \quad (5)$$

2.1.4 Design Changes

Initially, a luggage platform had been designed made of wood and capable of placing a suitcase. However, due to misalignment of motors, the platform was unable to move in a straight line. Even with linear correction, it was not possible to obtain a straight-line path.
With these constraints, the platform was scaled down to a simple car chassis. The car chassis was unable to match the torque requirements. However, the UWB sensors were giving clean data, and the motor control algorithm could enable the car to move in a straight path.

2.2 Control Subsystem

2.2.1 Overview

The Control Subsystem serves as the central processing unit for the smart luggage system, featuring two ESP32 microcontrollers, one of them equipped with a triangulation algorithm. This subsystem plays a pivotal role in seamlessly integrating various components, including two DW1000 transceiver modules, the drive train and power subsystem, and the obstacle avoidance subsystem. Its primary function is to ensure precise control and movement of the luggage by facilitating accurate distance measurements between the two anchors on the luggage and the user's tag. In addition to overseeing triangulation, the Control Subsystem manages the coordination of movements and responds to obstacles obstructing the luggage's path.

2.2.2 Requirements

The Control Subsystem demands these numerical requirements to ensure its optimal performance within the smart luggage system:

1. **Integration and Coordination:** Seamlessly integrate DW1000 transceivers, drive train, and obstacle avoidance subsystems under the control of the ESP32 microcontroller.
2. **Distance Measurement Accuracy:** Ensure accurate distance measurements between luggage anchors and the user's tag for precise triangulation, with a maximum ±10cm error rate.
3. **Obstacle Response:** Implement effective obstacle detection and response mechanisms to control luggage movements in the presence of obstacles.

2.2.3 Design Choices

Originally, our design featured a single ESP32 microcontroller responsible for overseeing all functionalities. This included managing two SPI connections to distinct DW1000 sensors and concurrently controlling an ultrasonic sensor. The ESP32 processed the sensor data and generated signals to drive the motors based on these inputs.

2.2.4 Design Changes

A significant design change involved transitioning from a centralized control structure to a distributed one. Initially, a single ESP32 managed all aspects, but we found this approach less efficient. The revised design featured two ESP32s, each linked to its own DW1000 sensor. The two microcontrollers communicated via UART, enhancing modularity and communication efficiency. The main ESP32 utilized data from both its DW1000 sensor and the secondary ESP32 to make informed decisions. This adjustment not only improved overall system efficiency but also allowed for more effective coordination between subsystems, particularly in the context of the drivetrain subsystem.

2.3 User Tag Subsystem

2.3.1 Overview

The User Tag Subsystem is a crucial element of the smart luggage system, incorporating an ESP32 microcontroller, a DW1000 UWB transceiver, and a 3.3V power supply. Housed in a portable enclosure, it utilizes a buck converter for stable power. The subsystem facilitates effective communication between the user's tag and the luggage, reflecting signals for distance measurements through triangulation. With features like a buzzer for user notification in case of a forgotten bag, this subsystem significantly contributes to the system's intelligence and user-friendly operation.

2.3.2 Requirements

The User Tag Subsystem demands specific numerical requirements to ensure its optimal performance within the smart luggage system:

- Power Supply: Maintain a stable 3.3V power supply through a Linear Regulator to support the ESP32 microcontroller and DW1000 UWB transceiver.
- Distance Measurement Precision: Provide EM Shielding to the UWB sensor to facilitate accurate distance measurements within a specified range.
- Buzzer Alert: Set the buzzer to produce an audible alert at a predefined sound level to effectively notify the user if the luggage is more than 10m away.

2.3.3 Design Choices

In our initial design, we planned on strategically integrated a microcontroller and linear regulator on a printed circuit board (PCB) to efficiently control the various components of the smart luggage system. The chosen battery, with a voltage rating of 4.8V, was tailored to meet the power requirements of the microcontroller and peripherals. The buzzer, a crucial user notification element, was directly attached to the PCB, optimizing the overall compactness of the final tag. To achieve a streamlined and portable design, the breakout board of the UWB sensor was closely connected to the main PCB, resulting in a small card-like tag that users can conveniently carry.

2.3.4 Design Changes

During testing, we encountered electromagnetic (EM) noise adversely affecting sensor readings. To address this, we increased the physical separation between the ESP microcontroller and the DW1000 sensor, successfully implementing EM shielding. This adjustment, while enhancing data accuracy, led to a trade-off by increasing the overall size of the design compared to the initial compact configuration.

Despite the bulkier form, prioritizing EM shielding was crucial for maintaining the accuracy and dependability of the smart luggage system, showcasing the iterative nature of design in response to real-world challenges.

2.4 Obstacle Avoidance Subsystem

2.4.1 Overview

The obstacle avoidance subsystem consistently furnishes dependable distance measurements between obstacles and the luggage entity. Comprising an ultrasonic sensor, this subsystem assumes the responsibility of supplying precise distance metrics between the luggage and obstacles within its trajectory to avert collisions. The subsystem is equipped with an HC-SR04 sensor, operating at a voltage of 5V with a working current of 15 mA. It ensures accurate distance measurements within the range of 2 cm to 400 cm.

2.4.2 Requirements

The primary specifications for the subsystem are delineated as follows:

1. Upon detection of an object within the trajectory of the luggage, ascertained at a distance of 0.5 meters by the obstacle avoidance subsystem, it is imperative to produce an output signal directed towards the General-Purpose Input/Output (GPIO) interface of the ESP32 microcontroller.
2. If the luggage is impeded by an obstacle and the individual traverses beyond a range of 10 meters, the subsystem is obligated to refrain from further locomotion of the luggage. Instead, it is mandated to generate a signal to notify the user.

2.4.3 Design Choices

In pursuit of optimal miniaturization for the designated subsystem, deliberate consideration was given to the selection of the HC-SR04 sensor characterized by an Operating Voltage of 5V, Working Current of 15 mA, and an effective Distance Range spanning from 2 cm to 400 cm. Additionally, compatibility was ensured with the drivetrain subsystem, which furnished a 5V output.

2.4.4 Design Changes

No modifications were implemented in the design, as the sensor exhibited optimal performance and consistently delivered accurate data. Additionally, all power requisites were satisfactorily fulfilled.

3. Design Verification

See Appendix A for complete Requirements and Verification Table.

3.1 Power and Drivetrain Subsystem

3.1.1 Voltage Verification

With an input voltage of 12V, the subsystem should be able to output 3.3V and 5V. To verify this, an input of 12V was applied to the system through the testbench power supply. The designated test points on the circuit were probed with a multimeter to test the output voltage values. We were able to achieve almost accurate results as shown in figure 4 below.

Figure 4: Multimeter Readings of Voltage

3.1.2 Battery Verification

The objective was to ensure that the battery could power the entire system for at least 30 min. To test this, the entire system was powered by the battery and allowed to function normally. During this time, the platform was following an individual, directed towards obstacles to enable it to stop as well as programmed to vary its speed. The measurements of the battery voltage were continuously performed every 5 minutes to ensure that the battery does not die out. The data is presented in Table 1 below. Based on this data, it is fair to infer that the battery has enough life to power the system for 30 minutes.

Table 1: Battery Voltage Readings at Different Operation Time

Operation Time (min)	0	5	10	15	20	25	30
Battery Voltage (V)	9.06	9.02	9.01	8.98	8.96	8.96	8.94

3.1.3 Torque Verification

To verify whether the drivetrain subsystem can provide enough torque (150 $N\ m$ according to Appendix A) to drive the entire platform up to a maximum speed of 2.52 mph, we first tried to directly measure whether the motor is able to provide a torque of 150 $N\ m$. As illustrated in Appendix A, we hung weights down the wheel and started the motor, and then we examined whether the motor could rotate the wheel and counteract the weight. To see whether one motor can provide 150 N m torque with approximately 30 cm wheel, the weight needed should be 10.6 kg approximately. As we gradually increased the weight hung down the wheel from 2 kg to 15kg, we did not see any sign of the motor having difficulty lifting the weight. This is an indication that our motor is powerful enough to drive the platform under a maximum speed of 2.52 mph with no problem. We later proved our assumption by loading a total weight of 20 kg onto the platform and driving it under 2.52 mph using the manual control mode.

3.2 Control Subsystem

3.2.1 Sensor Verification

We used a UWB sensor and moved it around in front of the two stationary anchor tags on the control subsystem and verified their values compared to the actual distance between the specific anchor and the tag sensors. The data is presented in Figure 5 below.

Figure 5: Data from DW1000 sensors

3.2.2 Integration Verification

Conducted functional tests to assess how well the ESP32 microcontroller integrated and coordinated the DW1000 transceivers, drive train, and obstacle avoidance subsystems by displaying all values on the monitor screen and the response of the system to these values.

3.3 User Tag Subsystem

3.3.1 Battery Life Verification

To ensure the efficiency of our power management system, we conducted rigorous battery life verification tests. These tests involved measuring the discharge rate of the 4.8V battery under various usage scenarios, simulating real-world conditions. By monitoring the voltage drop over time and assessing the power consumption of the system components, we could accurately estimate and verify the expected battery life under typical operating conditions, as shown in Figure 6 below.

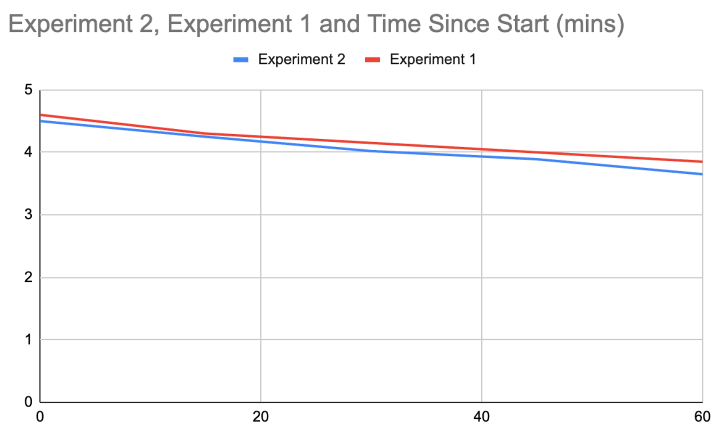

Figure 6: Battery Life Verification

3.3.2 Distance Accuracy Verification

The accuracy of distance measurements is critical for the effective functioning of the system. We employed a controlled testing environment with known distances between the user's tag and anchor tags. Through careful data collection and analysis, comparing the expected and measured distances, we verified the precision of the DW1000 sensor and its integration with the ESP microcontroller, as shown in Figure 7 below. This validation process ensured that the system provided accurate and reliable distance information for effective triangulation and user positioning.

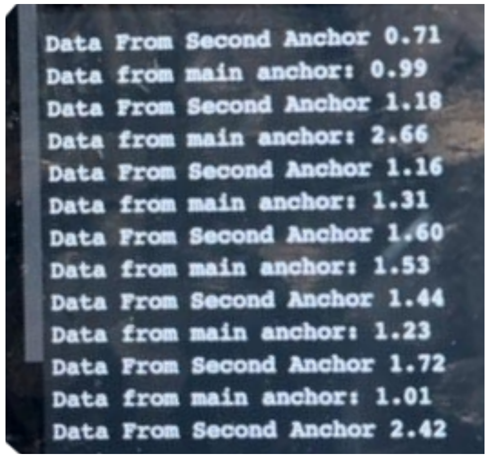

Figure 7: Distance Data from DW1000 sensors

3.3.3 Buzzer Functionality Verification

To confirm the reliability of the user notification system, we conducted thorough tests on the buzzer functionality. The ESP microcontroller's internal firmware was programmed to monitor the distance between the user and anchor tags. We simulated scenarios where the distance exceeded 10 meters, triggering the buzzer alert. Through systematic testing and verification, we ensured that the buzzer functioned as intended, providing a clear and timely alert to the user in case of a potential separation from the luggage.

3.4 Object Avoidance Subsystem

3.4.1 Obstacle Response Verification

The verification process encompassed the simulation of obstacle scenarios, during which we meticulously observed and assessed the system's capacity to detect and respond effectively to impediments. In these simulated scenarios, the system demonstrated a critical safety feature, wherein it promptly halted its operation upon nearing a wall, thereby mitigating the risk of collisions and avoiding potential crashes. This meticulous examination of the system's response mechanism ensured not only its capability to identify obstacles but also its proactive and reliable counteraction, aligning with the safety standards and specifications set forth in the design requirements.

4. Costs

4.1 Parts

Table 2: Analysis of Costs

Part	Manufacturer	Retail Cost ($)	Quantity	Total Cost ($)
Greartisan DC Gear Motor	Greartisan	14.95	2	29.90
ESP32 Microcontroller	Espressif Systems	6.95	4	27.80
DW1000 UWB Sensor	Qorvo	8.18	3	24.54
9V Energizer Max Battery	Energizer	4.55	2	9.10
4.8V	Dantona Industries	5.93	1	5.93
L293D Motor Driver	STMicroelectronics	8.10	1	8.10
2-inch Swivel Caster Wheel	HOLKIE	4.00	4	16.00
Total				**121.37**

4.2 Labor

The team comprises 3 people, each an ECE major. Assuming an average hourly salary of an ECE graduate to be $50, and each working 8 hours for a span of 11 weeks, the total labor cost is outlined in Equation 6:

$$Total\ Labor\ Cost\ =\ \$\ 50 \times 3 \times\ 8\times\ 11\ =\ \$\ 13,200 \tag{6}$$

5. Conclusion

5.1 Accomplishments

The luggage cart was propelled effectively utilizing a differential drive train powered by a 9V battery and DC motors, with sufficient energy storage to sustain continuous operation for a minimum of 30 minutes. An algorithmic mechanism was implemented to ascertain if the tracked individual exceeded predefined spatial constraints. In the event of a breach, the system promptly notifies the user. Additionally, an obstacle detection system was integrated, enabling the cart to cease motion in order to avert potential collisions.

Real-time state updates of the cart were achieved at 1-second intervals. The cart adeptly discerned the tracked person's location, modulating its speed to maintain proximity.

Despite achieving 90% accuracy with one ultra-wideband sensor, the performance of the second sensor was limited to 60%, precluding precise tracking of the person. This discrepancy, compounded by structural imperfections in the cart construction, hindered straight-line motion, necessitating a transition to a more compact cart design.

5.2 Uncertainties

Our project encountered three primary uncertainties. Firstly, in the context of our utilization of ultra-wideband (UWB) sensors employing time-of-flight principles for precise distance measurements, a delay factor is introduced. This delay factor, contingent upon the microcontroller's processing speed and crucial for accurate calibration to real distance, is stored in EEPROM. The risk of corruption in the stored delay factor exists, necessitating a re-flashing of the microcontroller to rectify potential inaccuracies in distance measurements should this corruption occur.

Secondly, the implementation of a triangulation algorithm [3] utilizing only three sensors introduces spatial limitations wherein certain points cannot be distinguished. Consequently, situations may arise, such as a user executing a sharp turn and positioning themselves directly behind the cart, where the algorithm fails to function appropriately. In such instances, the expected behavior, specifically the depiction of reverse movement, may not be accurately represented.

Thirdly, exposure to an environment characterized by excessive electromagnetic (EM) noise poses a significant threat to the effective operation of the triangulation system. This is particularly pronounced in the case of UWB sensors, as their reliance on EM waves renders them susceptible to malfunction in the presence of pronounced EM noise, leading to compromised accuracy in distance output.

5.3 Ethical considerations

Throughout the course of the project, strict adherence to the Code of Ethics delineated by the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM) was maintained. Concomitantly, efforts were made to ensure equitable distribution of workload and foster a workplace environment devoid of discrimination and racism, as stipulated by the IEEE Code of Ethics II

[1]. The paramount importance of upholding equal rights and fostering mutual respect was consistently underscored during the project's execution. Furthermore, due appreciation was accorded to all external assistance received. The guidance provided by course Teaching Assistants (TAs) and professors was earnestly considered and sincerely acknowledged. Rigorous citation and crediting procedures were meticulously observed for external works that contributed to the project's advancement.
In addressing the safety considerations inherent to the project, specific attention was directed towards the potential hazards associated with the utilization of a lithium battery. Consequently, comprehensive safety protocols were implemented to mitigate any conceivable adverse events arising from the operation of the lithium battery [1]. These protocols encompass, but are not limited to, maintaining the battery temperature within the prescribed safety range of 50 to 150 Fahrenheit and averting sudden and drastic movements of the battery carrier. Additionally, given the presence of a mobile component at ground level, the prospect of inadvertent collisions with humans necessitates the imposition of precautionary measures. Hence, the maximum movement speed of the project will be restricted to 1 mph to mitigate injury risks in the event of collisions. A heightened emphasis on the safety assurance subsystem will be placed to proactively prevent collisions under all conceivable conditions.

5.4 Future work

This study addresses three primary concerns pertaining to a luggage cart system. Firstly, it is imperative to meticulously rectify the alignment of the motor clamps on the luggage cart to achieve a linear and accurate differential drive, ideally without recourse to linear correction within the firmware.

Secondly, there is a critical need to augment the safety features associated with the transportation of luggage atop the cart. Given that the cart's movement aligns with the pace of a pedestrian, the susceptibility of the luggage to theft is heightened. The implementation of a belt-like locking mechanism is proposed as a deterrent to such security breaches.

Thirdly, the electromagnetic (EM) shielding of both the user and luggage tags necessitates refinement to facilitate the compaction of the user tag into a more compact and portable form, suitable for pocket storage. The optimization of EM shielding concurrently ensures precise distance measurements, contributing to the overall efficacy of the luggage cart system.

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Appendix A: Requirement and Verification Table

Power and Drivetrain Subsystem

Requirements	Verification	Y/N
The converter must be able to provide 5V and 3.3V from 12V to power the other subsystems. (+-0.2V)	☐ Using a power supply, we will provide a 12 V input to the buck converter. ☐ We will then connect a voltmeter to the output of the converter at the designated test points of 5V and 3.3V and ensure voltage reading falls within the required threshold.	Y
Since the subsystem also powers the entire system, when the battery is fully charged, the platform should be able to actively perform tasks (following the passenger + stopping in front of an obstacle + locating the passenger distance) for at least 30 min. (approximate time for one cycle of use)	☐ We will first fully charge the battery before the verification process. ☐ Then, we will begin the functioning of the system while behind the passenger such that the machine will always be in the mode of following the passenger. ☐ We also plan on introducing obstacles in the way of the platform. The requirement is met if the platform can remain active for more than 30 minutes.	Y
Torque provided by each motor must be at least (with coefficient of friction of) 150 N*m to drive the entire system forward under full load of 20kg with a speed of 3 mph.	☐ We will hang weights using a string at the edge of the tire and then turn the motor on. ☐ We will keep adding weights and examine whether the motor is capable of driving the system forward. ☐ If the motor fails to create motion, we can then calculate the torque as total_weights * wheel diameter. ☐ The requirement is met if the calculated torque exceeds 150 N*m.	Y

Control Subsystem

Requirements	Verification	Y/N
The 5V-3.3V converter should be able to output 3.3 V (±0.3V).	□ Using a power supply, provide a 5 V input to the 5 V- 3.3 V Converter. □ Connect a Voltmeter to the output of the converter and ensure voltage reading falls within the required threshold. □ Turn the power supply off and on. □ Repeat experiment 10 times and ensure that voltage reading falls within the expected threshold at least 9 out of 10 time	Y
All 3 DW1000 Sensors on the luggage subsystem should always be equidistant from each other and they should stay equidistant from each other throughout the working of the device.Sensor 1 is 25 cm away from Sensor 2 and 75 cm away from Sensor 3. Sensor 2 should be 75 cm away from Sensor 3 as well.	□ We will move the Luggage system and check if all sensors still give the same constant distance values throughout the test. □ We will measure the distance between each sensor and the distance should be the same as the given values.	Y
The subsystem should be able to communicate with the User Tag Subsystem accurately with a max ±10cm error rate.	□ We will keep a scale and check if the output from the User Tag Subsystem is accurate even when we move it around within the error rate. □ With the scale we will be able to check the accuracy of the output.	Y
Path of the user should be recorded accurately as he/she moves. The system should record every 1 second and clearly define the path in a queue type format.	□ We will run our algorithm on the Luggage Microcontroller and see if the path by the user is accurately stored. One of the teammates will move with the tag and another teammate will try to check the output logs and see if the path shown is the same as the path taken by the user. □ We will perform the same test when both the tag and luggage systems are moving.	

User Tag Subsystem

Requirements	Verification	Y/N
The tag should be able to communicate with the other transceivers.	□ Power user tag. □ Power control subsystem. □ Calibrate the user tag with the anchors. □ Get reading from serial output of ESP32. □ This reading should be +/- 20 cm of actual scale reading.	Y
The tag should be able to alert the user upon going out of range (10m).	□ Take the tag out of range of the luggage. □ Power user tag. □ Power control subsystem. □ The buzzer should beep.	Y
Tag's distance calibration with the luggage - user should be able to calibrate the tag before using the luggage system.	□ Keep the tag on the designated mark on the cart. □ Then start the calibration process. □ The calibrated distance should be within the tolerance level of the true distance which is +/- 20 cms.	Y

Object Avoidance Subsystem

Requirements	Verification	Y/N
When the obstacle avoidance subsystem detects that there is an object within the path of the luggage (0.5m), it should output to GPIO of ESP32.	□ Power the sensor with 3.3V and GND. □ Connect the correct GPIOs to ESP32. □ Provide an obstacle in front of the senor. □ Check the output voltage of the ESP32 designated GPIO to be 0V.	Y
When the luggage is obstructed by an obstacle and the person goes out of range (10m), the subsystem should not still move the luggage but generate a signal to alert the user.	□ Keep the tag at a distance > 10m. □ Power the sensor with 3.3V and GND. □ Connect the correct GPIOs to ESP32. □ Provide no obstacle in front of the senor. □ Check the output voltage of the ESP32 designated GPIO to be 0V.	Y