# Auto-following Luggage Platform

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# 1 Introduction

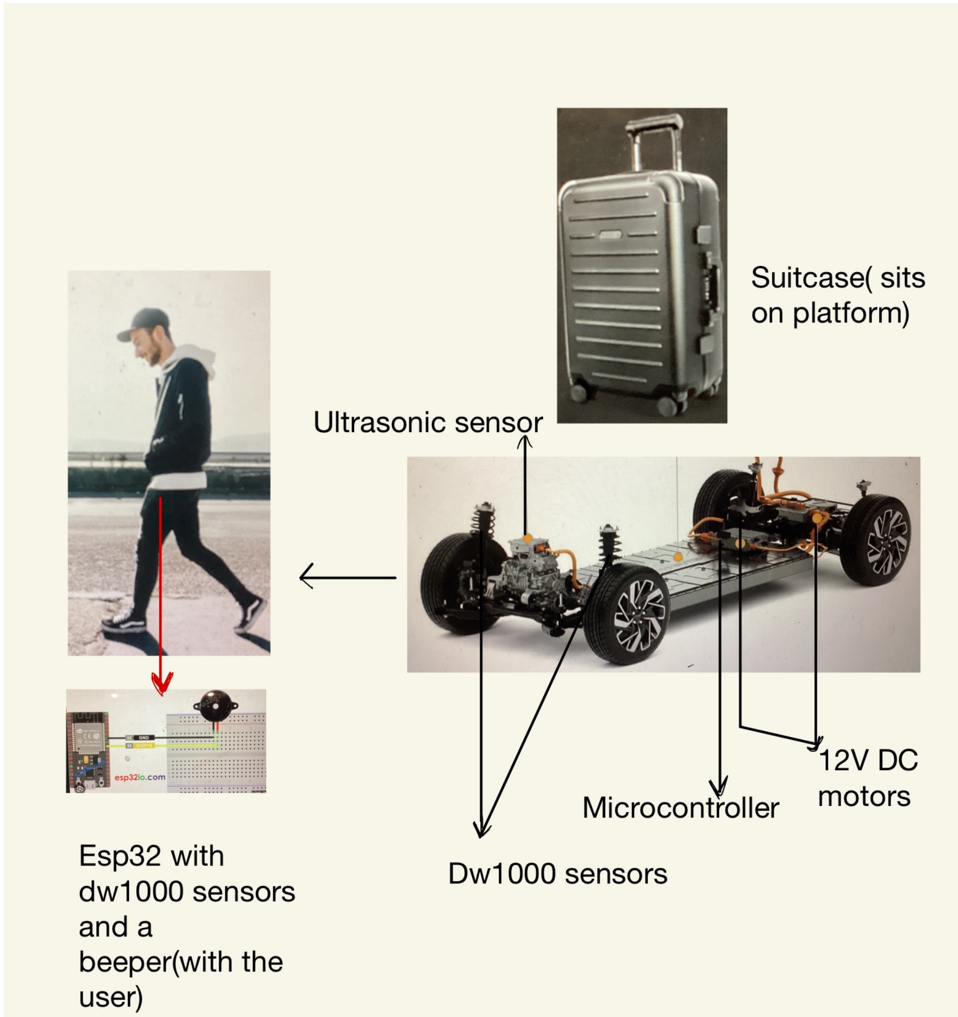
## 1.1 Problem

Imagine traveling with 2 - 50 lb check-in items of luggage and a carry-on bag along with a bag pack all ALONE. It can be 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.The need for smart luggage has surged in response to the evolving demands of modern travelers. With features like user follow, and GPS capabilities offer peace of mind and accessibility to travelers, simplifying their experience. We are actively working on developing more cost-effective solutions to ensure that smart luggage becomes increasingly affordable and accessible, thereby revolutionizing the way we approach travel.

## 1.2 Solution

Our proposed solution is a luggage system that autonomously follows the user while avoiding obstacles and adjusting its direction as needed. The four DW1000 sensors will provide triangulation data for accurate positioning via the ultra wide band transceiver technology. These four sensors would be on the luggage system and are called "anchors' '. We will have a tag that the user will carry. This tag would be another ESP32 along with a DW1000 sensor. Now, the anchors along with the tag can accurately create a local positioning system. Ultrasonic sensors will detect obstacles, including people, while the ESP32 microcontroller processes sensor data and calculates the optimal path. The motorized system comprises two motors (differential drive) and two 360-degree wheels as support.

### 1.3 Visual Aid

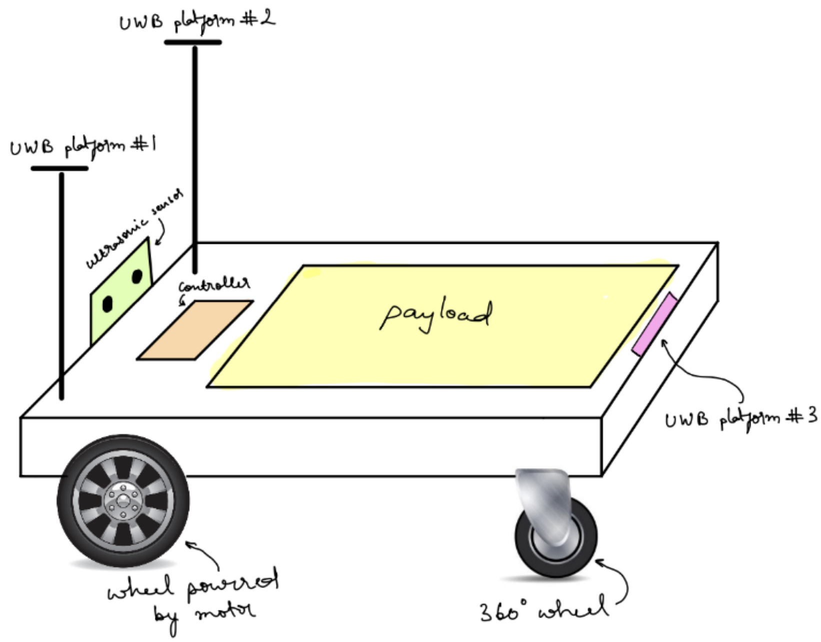



### 1.4 High-level requirements

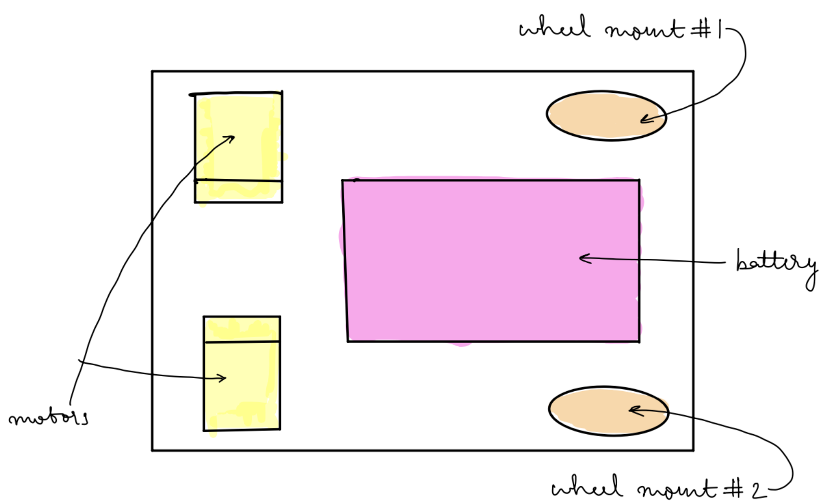
1. **Accuracy of user following**: The system must achieve a user following accuracy at a distance of 1 m to 1.2 m with error of ±50 centimeters, ensuring that the luggage consistently follows the person.
2. **Real-Time Responsiveness**: The system should follow the person with real-time updates in the path with a latency of no more than 1000 milliseconds, allowing for swift adjustments in the luggage's movement to keep pace with the person.
3. **Collision Avoidance**: Avoid collisions if obstacles show up in front of the device (0.5m). If the person goes out of bounds of the device, the person should be informed that the luggage is left behind (10m).

# 2 Design

## 2.1 Physical Design

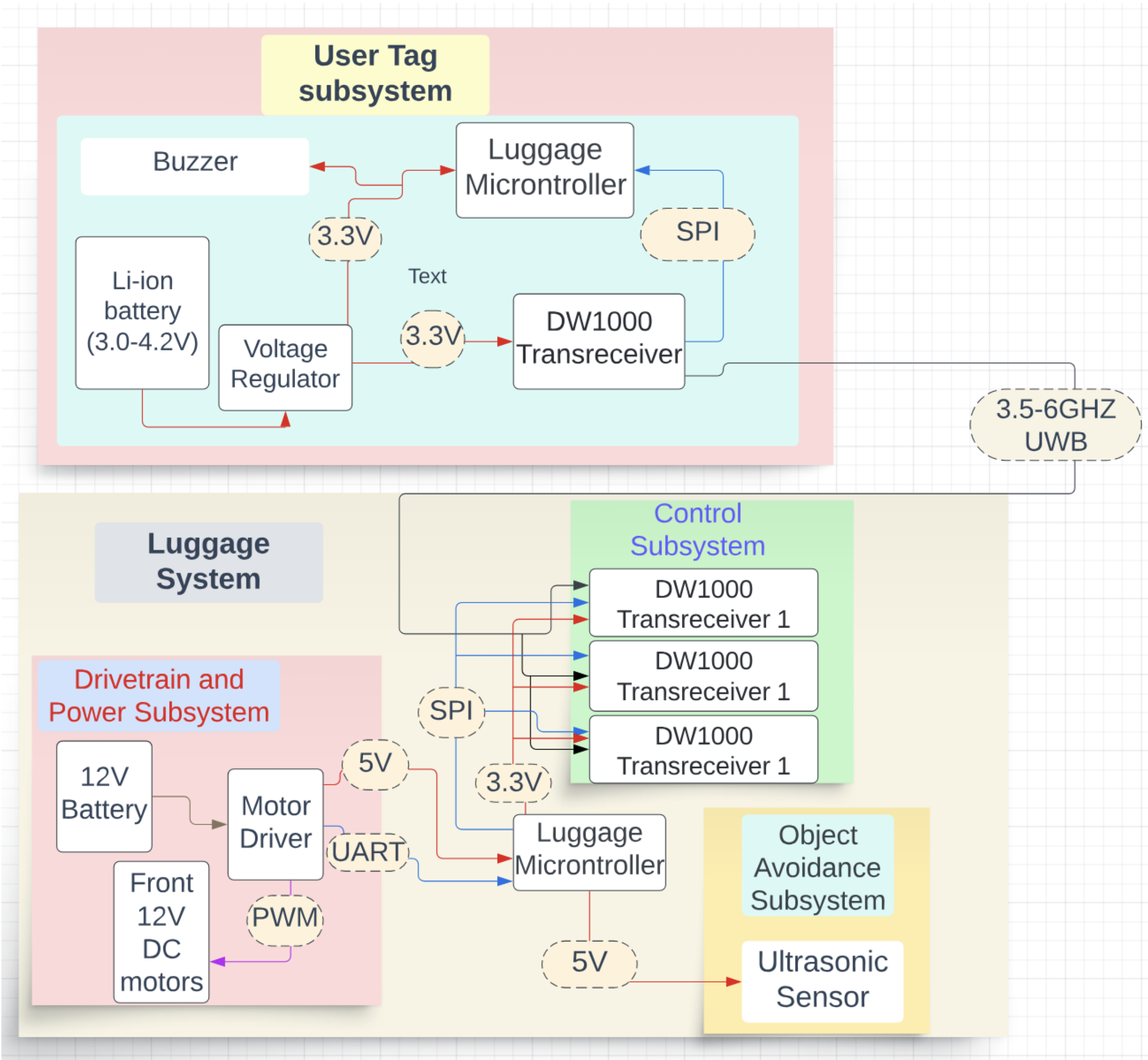



Physical device




Bottom view

## 2.2 Block Diagram



## 2.3 Subsystem Overview

### 2.3.1 Control Subsystem

Description: This is the central processing unit of the luggage. This subsystem mainly consists of an ESP32 microcontroller with a triangulation algorithm in it along with the peripherals of integration as per the purpose below. This unit controls and coordinates all the other subsystems.

Purpose: It plays a pivotal role in seamlessly integrating the three DW1000 transceiver modules on the luggage, the drive train and power sub-system, and the obstacle avoidance subsystem with the ESP32 microcontroller. Its primary function is to ensure accurate distance measurements between the 3 anchors on the luggage and the tag carried by the user to triangulate the user's position in order to facilitate precise control and movement of the luggage. Additionally, it also controls the movement of the luggage in case of an obstacle obstructing the path of the luggage.

| Requirements | Verification |
|---|---|
| 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.<br>● Connect a Voltmeter to the output of the converter and ensure voltage reading falls within the required threshold.<br>● Turn the power supply off and on.<br>● Repeat experiment 10 times and ensure that voltage reading falls within the expected threshold at least 9 out of 10 time |
| 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.<br>● We will measure the distance between each sensor and the distance should be the same as the given values. |
| 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.<br>● With the scale we will be able to check the accuracy of the output. |

| | |
|---|---|
| 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.<br>• We will perform the same test when both the tag and luggage systems are moving. |

**2.3.2 Obstacle Avoidance Subsystem**

Description: This subsystem consistently delivers reliable distance values between the obstacles and the luggage itself. It consists of an ultrasonic sensor.

Purpose: This subsystem is responsible for providing accurate distance measurements between the luggage and objects in its path to prevent collisions.

| Requirements | Verification |
|---|---|
| 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.<br>• Connect the correct GPIOs to ESP32.<br>• Provide an obstacle in front of the senor.<br>• Check the output voltage of the ESP32 designated GPIO to be 0V. |
| 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.<br>• Power the sensor with 3.3V and GND.<br>• Connect the correct GPIOs to ESP32.<br>• Provide no obstacle in front of the senor.<br>• Check the output voltage of the ESP32 designated GPIO to be 0V. |

**2.3.3 Drive-train and Power Subsystem**

Description: This subsystem consists of the two motors and two casters that will move the luggage system around. A 12V battery will be used to power the entire system. 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. 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. The battery will be responsible for supplying power to the microcontroller and all other electronics in the system.

Purpose: 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. Moreover, it will provide power to the microcontroller, motors and motor drivers.

| Requirements | Verification |
|---|---|
| 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.<br>● 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. |
| 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.<br>● Then, we will begin thefunctioning of the system while behind the passenger such that the machine will always be in the mode of following the passenger.<br>● 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. |
| 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.<br>● We will keep adding weights and examine whether the motor is capable of driving the system forward..<br>● If the motor fails to create motion, we can then calculate the torque as total_weights * wheel_diameter.<br>● The requirement is met if the calculated torque exceeds 150 N*m. |

**2.3.4 User Tag Subsystem**

Description: This is the “tag” that the user will carry around, i.e. the luggage will follow this tag. This sub system consists of an ESP32, a DW1000 (Ultra Wide Band) transceiver and a 3.3V input to power it. Since we are using a buck converter, we will ensure that the exact 3.3V is supplied to this subsystem. Additionally we will have a buzzer to inform the user if the luggage is left behind. This sub system is portable and will be encapsulated in a box.

Purpose: This subsystem is crucial as it informs the local positioning system about its distance from various UWB sensors on the luggage by reflecting the signals back to the luggage. By calculating the time of flight and processing delay, we can get the distance of the tag from each of the “anchors” on the luggage after which we can perform triangulation.

| Requirements | Verification |
|---|---|
| The tag should be able to communicate with the other transceivers. | • Power user tag<br>• Power control subsystem<br>• Calibrate the user tag with the anchors<br>• Get reading from serial output of ESP32<br>• This reading should be +/- 20 cms of actual scale reading. |
| The tag should be able to alert the user upon going out of range (10m). | • Take the tag out of range of the luggage<br>• Power user tag<br>• Power control subsystem<br>• The buzzer should beep |
| 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.<br>• Then start the calibration process.<br>• The calibrated distance should be within the tolerance level of the true distance which is +/- 20 cms. |

## 2.4 Software Design

### 2.4.1 Triangulation and Motor Control

We will follow the triangulation algorithm based on the paper “ULoc: Low-Power, Scalable and cm-Accurate UWB-Tag Localization and Tracking for Indoor Applications” [3]. Based on the algorithm we will send control signals in the form of power waves to the differential motor drive.

### 2.4.2 Out of range alert system

We will be using ESP32’s ESP-NOW technology to communicate with user tag. The software will compare the distance received from the tag against a threshold of 10m. If it exceeds the threshold, the program will send an alert to the tag via the ESP-NOW protocol based on TCP over Wifi.

## 2.5 Tolerance Analysis

*Maximum Velocity:*

We will be using a high-torque gear motor with 100 rpm connected to roughly a 20 cm radius wheel through an axle. It is possible to calculate the maximum velocity of our system:

$$V_{max} = 2 * \Pi * r * w = 2 * 100 * \Pi * 0.15 / 60 = 1.57 \text{ m/s} = 3.5 \text{ mph}$$

In comparison, the average walking speed of an adult is about 3 mph. Therefore, our system has the ability to increase or decrease its speed based on the speed of the passenger.

*Sensor Angle:*

The average width of a luggage is about 16” (= 0.4 m). We plan to maximize the distance between the passenger and our system at 0.8 m. Based on this, we can calculate the hypotenuse of the triangle formed between the passenger, a sensor and the midpoint between the 2 sensors on the luggage.

$$\text{hypotenuse} = \sqrt{(0.2)^2 + (0.8)^2} = 0.83 \text{ m}$$

The angle between the hypotenuse and the perpendicular can be derived using inverse trigonometric functions:

$$\text{min angle} = \cos^{-1}(0.8/0.83) = 15.63°$$

Our firmware algorithm will ring a buzzer to the user as soon as this angle falls below 15.63°. We can therefore control the maximum allowable range of displacement between the passenger and the system.

# 3 Costs and Schedule

## 3.1 Cost Analysis

**Physical Cost**

| Name | Quantity | Total |
|---|---|---|
| DW1000 | 4 | $32 |
| ESP32 MCU - VROOM | 2 | $11.5 |
| Greartisan DC 12V 200RPM Gear Motor High Torque Electric Micro Speed Reduction Geared Motor Eccentric Output Shaft 37mm Diameter Gearbox | 2 | $29.98 |

| | | |
|---|---|---|
| Circuit Components (Diodes, MOS, resistors) | - | $15 |
| PS1440P02BT (Buzzer) | 1 | $0.78 |
| | | |
| | | |
| **Grand Total** | | **$99.28** |

**Labor Costs**

Our team comprises 3 people, each responsible for circuit schematic, firmware and controls and algorithm respectively. We would assume the average salary of an ECE graduate to be $50. We would expect a time commitment of 6 hours a week. Since the project execution will take about 8 weeks, the labor cost that arises is:

Total Labor Cost= $ (50*3) * 6 * 8 = $ 7,200

## 3.2 Schedule

| Week | Date | Task | Person |
|---|---|---|---|
| 7 | 10/2 - 10/8 | Receive feedback on design document and schematic. Make necessary changes. Complete final schematic with necessary parts | All |
| 8 | 10/9 - 10/15 | Complete PCB layout. Order all components by the due date | Shubham & Jai |
| 9 | 10/16 - 10/22 | Finish ordering all parts. Meet with ECEB Parts shop to finalize mechanical design | Varun & Jai |
| 10 | 10/23 - 10/29 | Receive orders from vendors | Jai |
| 10 | 10/23 - 10/29 | Test PCB design - wave 1 | Jai |
| 11 | 10/30 - 11/5 | PCB design - User PCB and Luggage PCB | Shubham & Varun |
| 12 | 11/6 - 11/12 | Continue working on the project - begin motor control algorithm design. Begin sensor subsystem design. | Shubham & Varun |
| 12 | 11/6 - 11/12 | Solder elements on the PCB - Test - Reorder | Jai |

| | | | |
|---|---|---|---|
| 13 | 11/13 - 11/19 | Finish sensor detection and triangulation algorithm. Finish motor control algorithm. | Shubham & Varun |
| 14 | 11/20 - 11/27 | Integrate the entire project. Begin testing and debugging, if needed. | All |
| 14 | 11/20 - 11/27 | PCB final iteration | Jai |
| 15 | 11/28 - 12/4 | Write final papers. Present the project. | All |

## 4 Discussion of Ethics and Safety

In the pursuit of our project's development, we are unwavering in our commitment to upholding the moral imperatives delineated in the Codes of Ethics established by the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). As we embark on this endeavor, we pledge our strict adherence to these ethical guidelines, ensuring that our actions and decisions reflect the highest standards of professionalism and integrity.

As outlined in the IEEE Code of Ethics II [1], we consider it our foremost duty to maintain an equitable distribution of tasks among team members and cultivate a work environment characterized by inclusivity and devoid of prejudice in any form. To achieve this, we will vigorously champion the principles of equal rights for all parties involved and promote respect and collaboration among our team members. We also extend our gratitude to the Teaching Assistants (TAs), professors, and all course staff for their invaluable support, recognizing their indispensable contributions to our project's success.

We will implement a secure belt system for fastening luggage, effectively preventing theft during transportation.

Safety remains a paramount concern in our project, particularly due to our utilization of lithium batteries. We acknowledge the potential catastrophic events that can arise from mishandling lithium batteries and are committed to adhering to comprehensive safety protocols [2]. These safety measures encompass maintaining the battery's temperature within the recommended safety range of 32 to 130 degrees Fahrenheit, preventing sudden and drastic movements of the battery carrier, and implementing strategies to minimize the risk of thermal runaway. Furthermore, we are dedicated to the responsible disposal and recycling of batteries at the end of their lifecycle, ensuring environmental sustainability.

Our project also incorporates the use of motors to facilitate the controlled movement of luggage. In this context, we are resolute in our commitment to deploying essential equipment and control systems to mitigate potential hazards, including collisions with humans or other objects. This entails integrating sensors, vision systems, and collision avoidance algorithms to guarantee the safe operation of the luggage transport system.

To safeguard against unforeseen challenges, such as signal interference from jammers, we have devised contingency plans. In the event of signal disruption or interference, we will implement countermeasures to restore system functionality promptly. We recognize that overburdening the motors without a signal could lead to operational issues. To address this concern, our system is equipped with safeguards to detect motor overload conditions. If such conditions are detected, the system will automatically halt all operations and activate an audible warning to the user by a buzzer.

Additionally, we are acutely aware of the importance of handling edge cases in our project. Our project's software design incorporates protocols to address these edge cases, ensuring the system's robustness and reliability in real-world conditions. We will switch our functioning from triangulation to path following conditions where triangulation will lead to collision. Example of such a case is moving around a table.

In conclusion, our project is guided by unwavering commitment to ethical conduct, safety, and technical excellence. We pledge to adhere steadfastly to the principles set forth in the IEEE and ACM Codes of Ethics while proactively addressing potential challenges and ensuring the highest standards of safety and performance. Our dedication to ethical and responsible engineering drives us to create a luggage transport system that not only functions effectively but also prioritizes the well-being and satisfaction of its users.

# 5 References

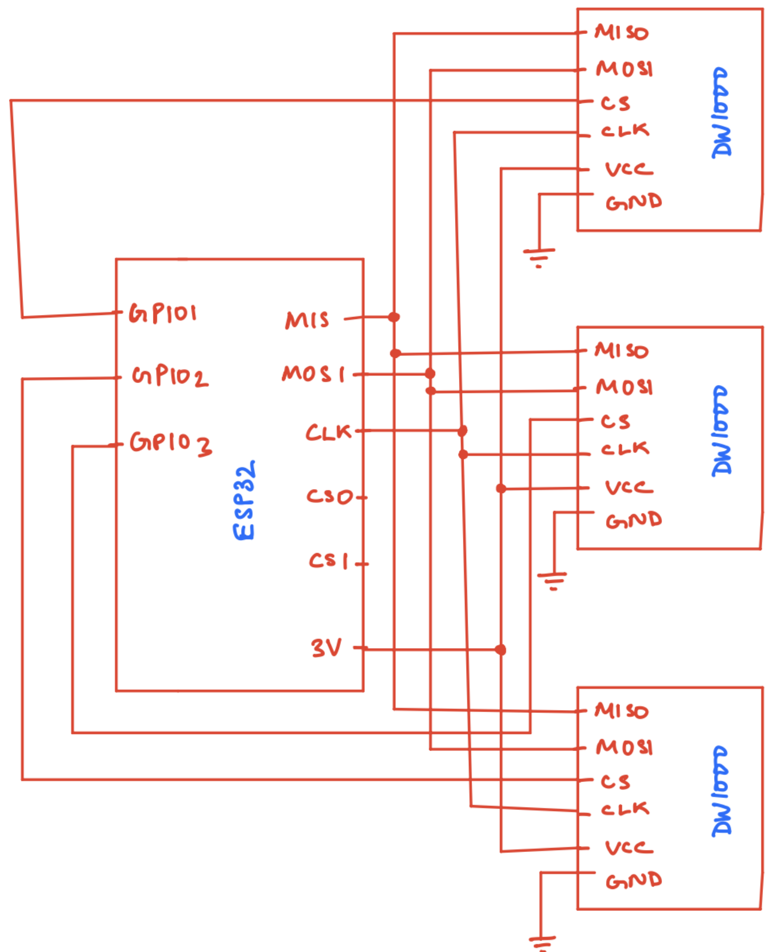
[1] “IEEE Code of Ethics,” IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed 8 Feb. 2023].

[2] Batteryuniversity.com, ‘Safety Concerns with Li-ion Batteries – Battery University’, 2023. [Online]. Available at: http://batteryuniversity.com/learn/article/safety_concerns_with_li_ion. [Accessed 8 Feb. 2023].

[3] “ULoc: Low-Power, Scalable and cm-Accurate UWB-Tag Localization and Tracking for Indoor Applications,” ACM. [Online]. Available at: https://dl.acm.org/doi/abs/10.1145/3478124. [Accessed 28 Sep. 2023].

# 6 Schematic

### Control sub-system connected to anchor UWBs



**Drive-Train and Power Subsystem**