# ECE445

# Project Proposal

# The ILLINI Wagon

**Team #39**

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# 1. Introduction

## 1.1 Problem

Bringing in groceries can be challenging for the elderly, and hauling a cooler, chairs, and other gear to the beach can be a hassle. Carrying heavy packages from the car, transporting picnic or camping supplies, and lugging gear for outdoor events can quickly become exhausting. Parents juggling strollers, diaper bags, and toys during outings could use an extra hand, while festival-goers and tailgaters often struggle with chairs, food, and drinks. Hikers and campers could travel farther without the strain of carrying supplies, and warehouse or delivery workers would benefit from extra support moving boxes and equipment. Whether for daily tasks, outdoor adventures, or work-related needs, the Illini Wagon can take the load off, making life more convenient.

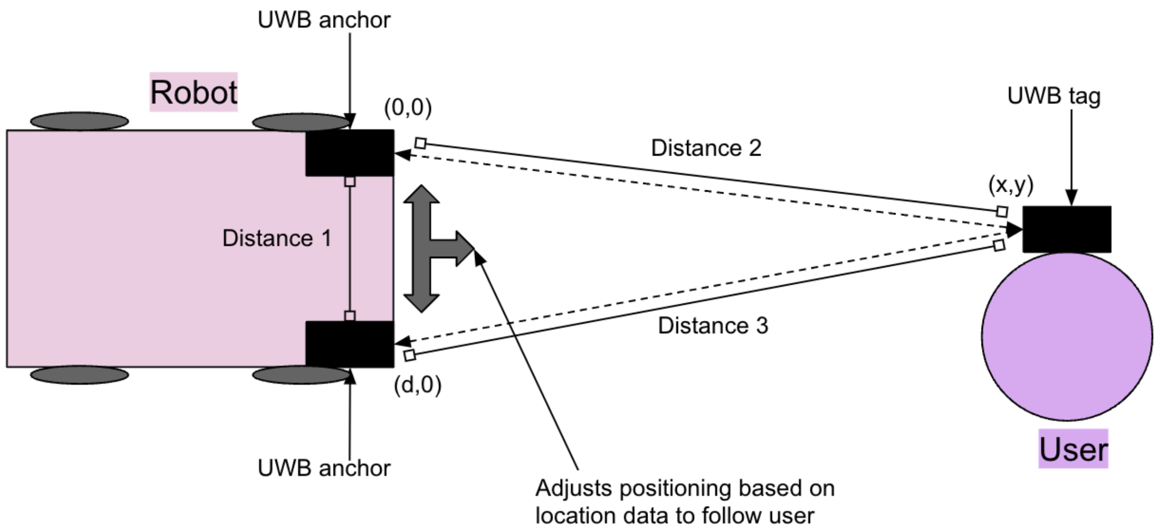
While similar products are available on the market today, they are often either too expensive, lack true autonomy, or both, making them less practical for everyday use. Many require manual operation or remote control, which still places a burden on the user. Others rely on computer vision which drives up costs and limits their accessibility. For people who need a simple, affordable, and truly hands-free solution, there are practically zero options available. The Illini Wagon will be both cost-effective and fully autonomous in order to fill this gap, providing a practical tool for a wide range of users.

## 1.2 Solution

Our proposed solution is an autonomous, self-following wagon designed to carry loads for users in both indoor and outdoor environments. The wagon will employ an Ultra-Wideband (UWB) tracking system to accurately follow the user without requiring direct manual control. This system will consist of a UWB Tag and Anchor setup, where two UWB tags will be mounted on the wagon, and the user will carry a remote with an embedded UWB anchor. By utilizing the Two-Way Ranging (TWR) method, the system will determine the user's real-time position and distance through Time of Flight (ToF) calculations.

To enhance navigation stability, the wagon will incorporate additional sensors such as IMUs (Inertial Measurement Units) for motion estimation and ultrasonic or LiDAR sensors to detect obstacles and prevent collisions. A combination of onboard processing and real-time feedback loops will ensure responsive and reliable tracking, even in dynamic environments. This solution provides a hands-free alternative to traditional rolling carts and backpacks, reducing physical strain while seamlessly adapting to urban and campus landscapes.

## 1.3 Visual Aid



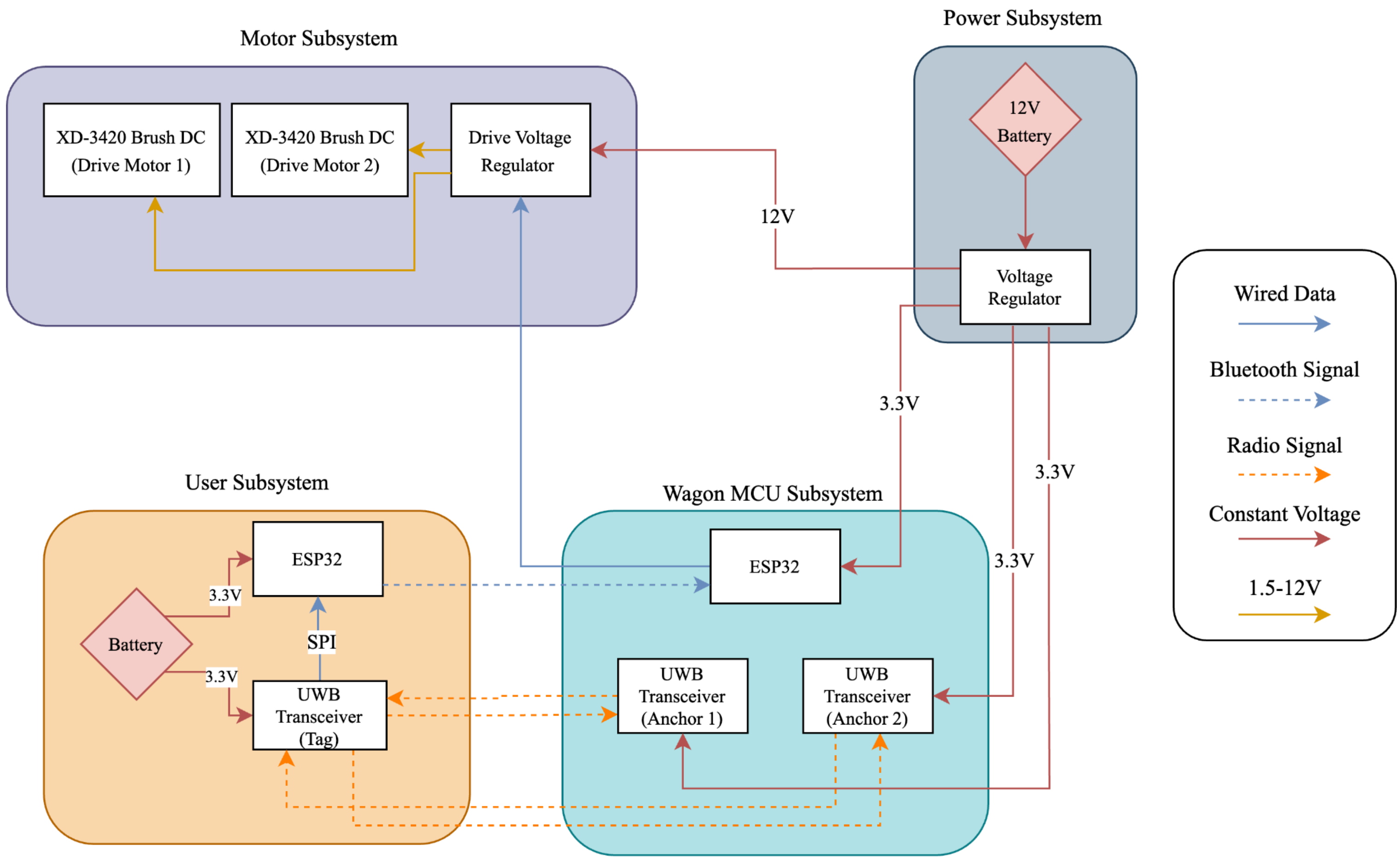

## 1.4 High Level Requirements

1. Wagon can follow user in an open, outdoor space with no obstacles.
2. Wagon is able to follow user around a 135° bend/corner.
3. Wagon is able to carry a load between 10-15 lbs.
4. Wagon is able to maintain a distance of <2m between itself and user.
5. Wagon can be turned on/off.
6. Wagon is able to navigate around a singular obstacle placed in its path.

A successful project will complete the first 5 goals, with the sixth goal being a reach goal. To demonstrate and test the robot, we will run the robot in the main quad with weighted items.

# 2. Design

## 2.1 Block Diagram



## 2.2 Subsystem Overview

### 2.2.1 Power Subsystem

The power subsystem is responsible for supplying voltage to both the motor subsystem and the wagon MCU subsystem. It consists of a 12V battery and a voltage regulator. The voltage regulator provides 3.3V to each component in the wagon MCU subsystem and 12V to the drive voltage regulator in the motor subsystem. Controlled by the ESP32 microcontroller in the wagon MCU system, the drive voltage regulator ensures the correct voltages are delivered to each respective motor. The correct voltage sent to each of the drive motors will be calculated by the data sent from the ESP32. The voltage must be variable in order to control the rate at which the drive motors spin. Further testing is required to accurately measure these voltages, as accounting for the wagon's load and wheel resistance makes precise voltage estimation challenging.

### 2.2.2 Motor Subsystem

The Illini Wagon's motor subsystem will be responsible for controlling its speed and direction of movement. It will consist of 2x 12V XD-3420 Brush DC (hereafter referred to as drive motors) which will all be powered by 1x ML7-12 SLA 12V battery. The voltage sent to the drive motors is generally directly proportional to both the RPM and torque of the wheels, although factors like load and motor efficiency can influence the exact relationship. In order to steer the wagon, the amount of voltage sent to each motor will vary. To determine the exact values, we will conduct tests to identify the optimal settings. In general, the farther the user is from the wagon, the faster it will move (within reasonable limits). If the user is positioned to the right of the wagon, the left motor will receive a higher voltage than the right, and vice versa.

The distance and angle between the user and the wagon will be provided by the user and wagon subsystems. The wagon will always attempt to maintain a constant distance from the user. If possible, we will implement obstacle detection, which will primarily affect the steering motor.

### 2.2.3 User Subsystem

This subsystem has three main components: a DWM1000 UWB transceiver, an ESP32 module, and a mini power system with a 3 V battery. The User Subsystem communicates the distance information to the Wagon Subsystem, which then translates the information to send to the Motor Subsystem. The UWB transceiver acts as a tag in this subsystem and will be carried in the user's pocket. The UWB tag essentially sends signals to the anchors on the robot to calculate distance.

The tag initially transmits a message to the anchors, the anchors receive the message and transmit responses back to the tag, and the tag finally receives the response and records the receive timestamp. The tag will store this timestamp data, which will be sent to the ESP32 module for further processing using the methodology described below. Once this distance calculation has been completed, it will be transmitted to the ESP32 module on the robot, which will send out information to the motor system.

We will be using the two-way ranging methodology for calculating distance. The following equations were provided through the Decawave DW1000 two-way ranging implementation document [3].

$$TOF = \frac{t_2 - t_1 - t_{reply}}{2}$$

Equation 1: Time of Flight Calculation

$t_1$: $time\ of\ initial\ transmission$

$t_2$: $timestamp\ of\ response\ receival$

$t_{reply}$: $delay\ from\ anchor\ transmitting\ response$

$$distance = C * TOF$$

Equation 2: Distance Calculation

$TOF$: $calculated\ time\ of\ flight\ value$

$C$: $speed\ of\ light$

### 2.2.4 Wagon MCU Subsystem

The Wagon Control Subsystem is responsible for communicating with the user, receiving the user’s absolute location, and converting it into commands for motor movement. The Wagon Control Subsystem comprises UWB anchors that communicate with the user's UWB tag and an ESP32 microcontroller, which receives distance data from the user's tag and sends navigation commands to the motor subsystem.

This subsystem consists of two key components: two DWM1000 UWB transceivers and an ESP32 module. The DWM1000 transceivers serve as anchors, while the user's DW100 functions as a tag, utilizing a two-way ranging method to determine the user's absolute position relative to the wagon.

Once the ESP32 module receives distance data, it calculates the necessary motor movements. Based on the computed distance, the system adjusts the voltage supplied to the motor subsystem to regulate speed via RPM and wheel torque. Additionally, if a turn or slight course correction is needed, the system determines the appropriate motor angle and adjusts the right and left wheel speeds accordingly to ensure precise navigation.

## 2.3 Subsystem Requirements

### 2.3.1 Power Subsystem Requirements

The power subsystem should be able to supply continuous power to the motor subsystem and the wagon MCU subsystem. It should be able to supply:

- 12 ± 0.5V to the drive voltage regulator in the motor subsystem
- 3.3 ± 0.1V to each of the components in the wagon MCU subsystem

### 2.3.2 Motor Subsystem Requirements

- Drive motors RPM is proportional to distance from user
- Steering motor point in the direction of the user within ± 0.15 radians and .5 seconds
- Wagon is able to maintain a constant distance of 1.5 ± 0.2 meters from user
    - Equivalently, the wagon should be able to stop when the user stops moving

### 2.3.3 User Subsystem Requirements

- Calculate TOF and distance information through data stored on the UWB tag.
- Transmit data back to the wagon MCU unit on the robot
- Since we are accounting for BLE data transmission, we aim for the location accuracy to be within 1.5m.
- The power system should supply a constant voltage of 3.3 ± .3 V

### 2.3.4 Wagon Subsystem Requirements

- The two UWB anchors should be able to send and receive signals from the user's UWB tag.
- They should calculate the appropriate motor speed and direction requirements and communicate with the power and motor subsystems.

## 2.4 Tolerance Analysis

One of the key risks to the project's success is whether the wagon motor can achieve the required speed and carry the expected load at that speed. The motor's ability to handle weight and maintain speed depends on its stall torque and maximum allowable current draw. The XD3420 motor has a rated torque of 19.6 N·m and a rated current of 400mA at 12V [2].

Given that the average human walking speed ranges from 2.5 to 4 mph, and the wagon is expected to carry 10 to 15 lbs, we can assess whether it can sustain the worst-case scenario.

In the worst case, the wagon carries 15 lbs (approximately 7 kg) and must accelerate from rest to 4 mph (about 1.8 m/s) within 1 meter of space, requiring an acceleration of 1.6 $m/s^2$. The torque required from the motor can be determined through the following calculations:

*Force Required to lift a 7kg load with acceleration of 1.07 $m/s^2$:*
$F = ma = 7*1.6 = 11.2N$

*Torque required:*
$T = Fd = 11.2*1 = 11.2N\text{-}m$

The torque required in this scenario is approximately 11.2 N·m, which is lower than the motor's stall torque of 19.6 N·m. This confirms that the XD3420 motor is capable of handling the operation.

The current draw from the battery can be calculated as follows:

*Convert RPM to radians/second:*
*1 RPM* x *2pi rad/rev* x *1 min/60 sec = 0.105 rad/sec*
$\omega$ *= 224 rev/min(estimated from the speed of 4 m/h)* x *0.105 rad/sec/RPM = 23.52 rad/s*

*Calculating the Power required for this operation:*
$P = T \times \omega = 11.2N\text{-}m \times 23.52\ rad/s = 263.42\ W$

*Calculate the Current draw from the battery:*
$I = P/V = 263.42\ W / 12V = 21.95\ Amps$

This current is lower than the motor's maximum allowable current draw, confirming that the motor can handle this scenario.

After conducting a tolerance analysis using the XD3420 motor manual, we conclude that the motor can sustain the worst-case scenario, as both the required torque and current remain within its limits. Therefore, the motor subsystem can provide stable movement while carrying up to 15 lbs, following a user at walking speed.

## 3. Ethics and Safety

Our primary demographic for this project is college students, hence the name 'Illini Wagon.' However, this product can also benefit other groups, including the elderly, individuals with mobility impairments, and families. Although our intention for this project is to create a product that makes carrying things easier, we must acknowledge the safety risks that come with autonomous movement, such as potential collisions or malfunctions.

Ensuring that this product is safe and ethical is one of our top priorities, as it will likely operate autonomously in public spaces. Ethically, the wagon must be designed to respect other pedestrians, avoid creating hazards, and function in a way that does not infringe on privacy or security. Since our design does not include computer vision, the Illini Wagon's navigation must be highly reliable, using sensors and fail-safe mechanisms to prevent collisions. Safety considerations include redundant braking systems, obstacle detection, and emergency stop features to prevent accidents. We will consult the US Department of Transportation's Automated Vehicles Comprehensive Plan[1] in order to make sure that our vehicle complies with this handbook's standards.

In designing the Illini Wagon, we prioritize both ethical responsibility and safety. While our goal is to provide convenience and accessibility, we recognize the importance of minimizing risks and hazards that our product may pose. By adhering to local regulations, implementing safety features, and ensuring through testing, we plan to create a product that is reliable and responsible. Ultimately, our commitment to ethical engineering will help ensure that the Illini Wagon is safe, practical, and beneficial.

## 4. Citations

[1] USDOT automated vehicles activities. U.S. Department of Transportation. (n.d.). https://www.transportation.gov/AV

[2] XD3420 motor datasheet

[3] Qorvo. (n.d.). The Implementation of two-way Ranging with the DW1000.

[4] Qorvo. (n.d). Getting Back to Basics with Ultra-Wideband (UWB)