

TROLL E: TRACKED ROBOTIC OUTDOOR LOAD-LUGGING ESCORT

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Abstract

The TROLL E project is designed to act as a self-driving vehicle, with its main function being a trolley to store carry-on items that would be considered inconvenient to carry on hand. Being able to support up to a projected 20lbs, this trolley will follow the user via beacon, navigating terrain and detecting obstacles that impede the following mechanism, and finding another path to take to avoid the obstacles. The trolley will have LiDAR sensors to detect obstacles at various angles to see directly in front of and to each side, choosing the unobstructed path to follow the user's beacon. The following distance will be set to around 5-10 feet, with an average speed of 2-3 mph.

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1. Introduction

Often in everyday life, people want to carry items but cannot bring everything they want to. In many cases, people may not have the strength/capability to haul their items over variable distances. People of all ages and abilities can still experience struggle with transporting their belongings, and older individuals may endure even more labor to do so.

TROLL E aims to relieve users of the responsibility of carrying items. We plan on TROLL E being used under various loading conditions, including carrying groceries, sporting equipment, picnicking items, and beach gear. While not entirely strenuous, all these could be high in volume, so being able to offload some to a carrier will greatly improve the user's overall experience wherever they are. The current projected load that TROLL E can support is 20 lbs and will be subject to change after initial testing phases.

Along with assisting in carrying load, TROLL E aims to avoid objects and other obstacles that may be easily collided with. TROLL E will utilize a meccano wheel drivetrain along with LiDAR and Ultrasonic sensors to effortlessly recognize optimal pathing and move across the ground/floor with ease. Since we are dedicating a motor to each wheel within the drivetrain, this will allow for ample power when carrying variable loads.

TROLL E will also follow the user via Ultra-Wideband(UWB) to make sure it follows the user at a good trailing distance while traveling at a safe speed. There will be between 2 or 3 anchor beacons mounted on TROLL E, with the user holding an additional beacon for the mounted sensors to triangulate and determine how far the user is from the trolley, moving accordingly to close or extend the distance.

With this, TROLL E's objective is met as a Tracked Robotic Outdoor Load-Lugging Escort.

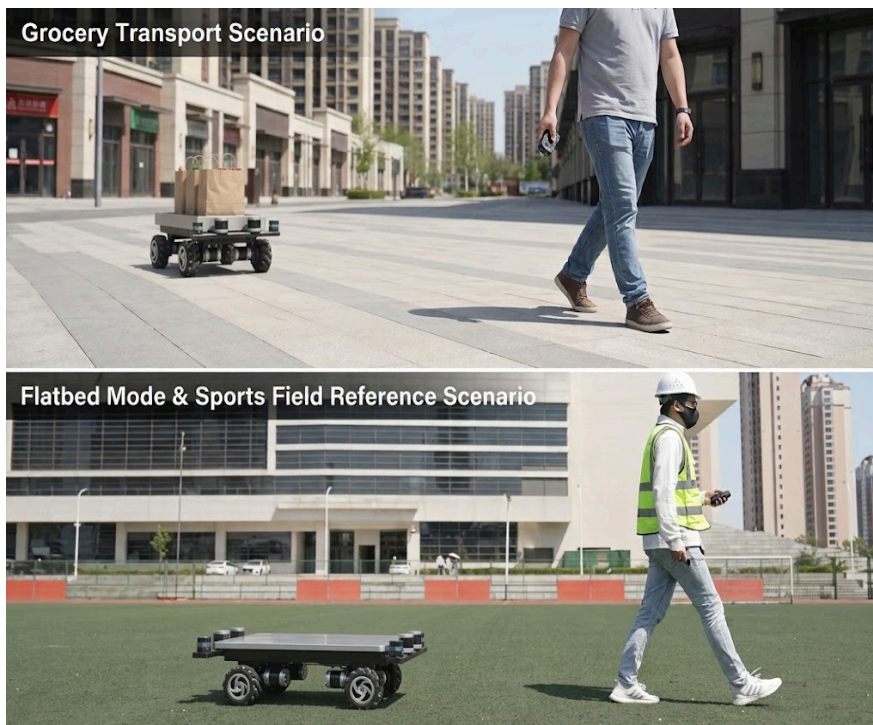


Figure 1. Conceptual TROLL E image showing grocery transport and outdoor load-carrying.

2 Design

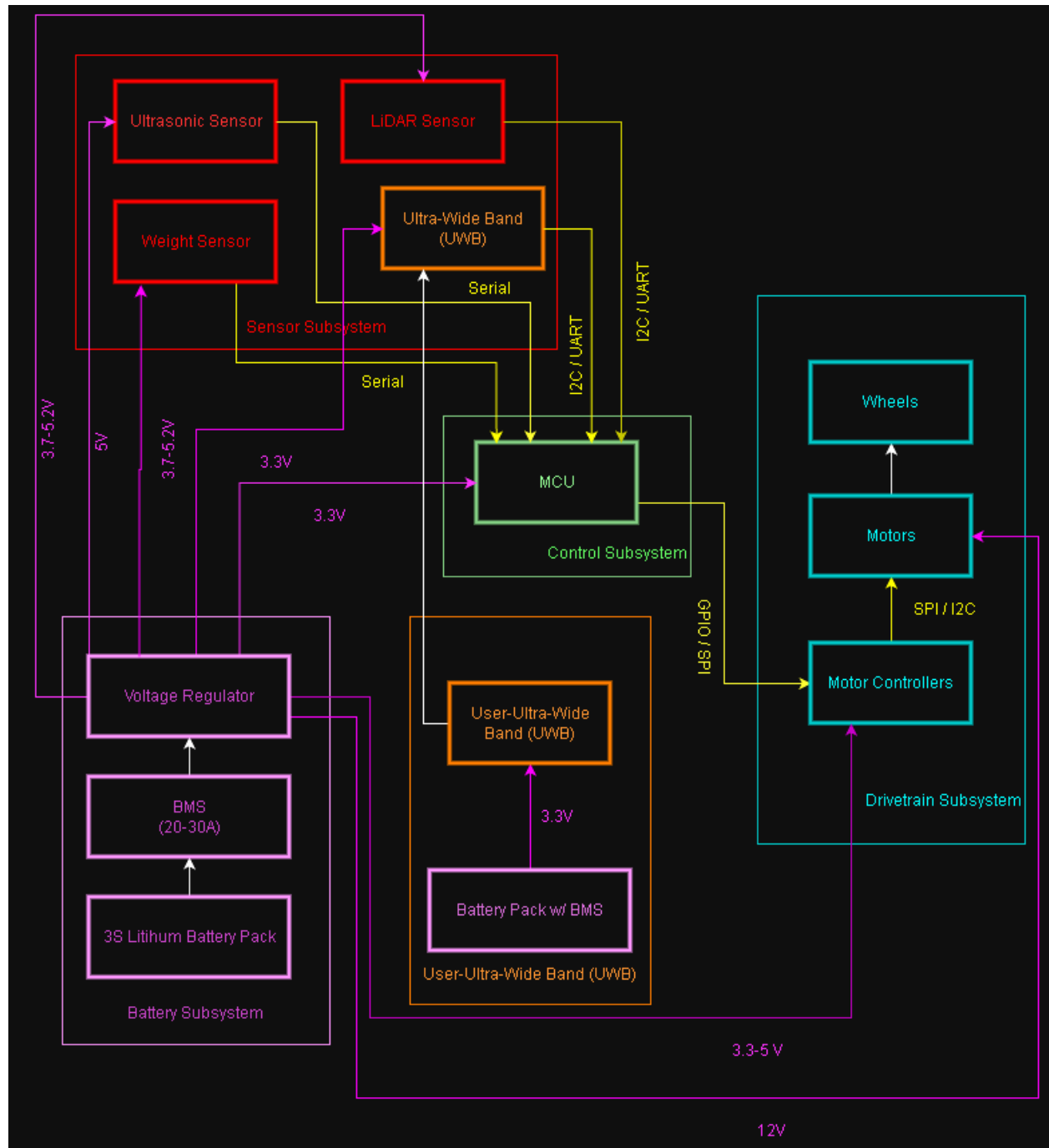


Figure 2. TROLL E system block diagram

2.1 Sensing Subsystem

To develop an autonomous design, TROLL E needs sensors to detect obstacles that impede the following path to the user. We will focus on forward detection; however, we will also consider rear detection for

edge cases in navigation. To achieve this, we are considering a combination of LiDAR sensors to see farther and identify obstacles early, and Ultrasonic sensors to detect smaller obstacles closer to the ground or those that LiDAR may miss. The sensing subsystem will be supplied by a regulated 5V power supply capable of providing at least 500 mA continuously.

2.1.1 LiDAR

The LiDAR sensor will be mounted at the front of TROLL E, one on each corner, parallel with the ground. These sensors will be the main eyes behind our design, intended for seeing farther in front of itself and identifying obstacles early on before actually reaching them. This gives TROLL E more time to find a better path than going straight, allowing it to follow the user more seamlessly. We are planning on using the Benewake TF-Luna as a reference. Each TF-Luna can operate from 3.7 to 5.2 V, with an average current of up to 70 mA and a peak current of 150 mA [1]. Because we plan to use two LiDAR sensors, the LiDAR portion of the sensing will normally draw about 140 mA, with a possible peak of about 300 mA. A regulated 5 V supply will be used for the LiDAR sensors. This sensor will communicate with the MCU using either I2C or UART, with our preference for I2C.

2.1.2 Ultrasonic

Now that we can see far ahead and identify larger obstacles early, we need sensors to detect lower to the ground in case there are smaller obstacles that LiDAR missed. These could be meaningless, like small rocks that wouldn't impede TROLL E, but there is also potential for more dangerous obstructions, like nails or glass. Because of this, we want to use Ultrasonic sensors to act as a backup to LiDAR, stopping the cart when any obstacle is detected and moving to a side until the obstacle is out of view. This will need to be intentionally coded to avoid moving over any obstacles that could damage the underbelly of TROLL E, where this sensor will be housed. We are planning to use the HC-SR04 as a reference. Each ultrasonic sensor operates at 5 V and draws approximately 15 mA during operation [2]. If two ultrasonic sensors are used, it will require 30 mA during normal operation. These sensors will need a serial connection to the MCU.

2.1.3 Weight Sensor

The weight sensor will continuously measure the load placed on the cargo platform and send that information to the MCU. The MCU will compare the measured weight value with the 20 lb limit. If the weight exceeds the limit, TROLL E will remain stopped and ignore normal movement commands until the load is reduced below the allowed weight limit. We are planning to use the load-cell system with an HX711 amplifier as a reference. The HX711 can operate from 2.7V to 5V and draws less than 1.5 mA during normal operation [3]. A 5 V supply can be used for the load-cell circuitry, while the digital interface can be matched to the MCU's logic voltage. This sensor will use a serial connection to the MCU.

2.1.4 Sensing Requirements

1. The sensing subsystem can detect obstacles in front of the TROLL E early enough for the control system to stop or adjust the device's path before a collision occurs.
2. The LiDAR sensors can detect obstacles from a longer range than the ultrasonic sensors, to detect large obstacles before reaching them.

3. The ultrasonic sensors can detect close-range obstacles that were not detected by the LiDAR sensor, such as small obstacles on the ground.
4. When an obstacle is detected within an unsafe distance (no closer than 6 in), the sensing subsystem can send the obstacle information to the control system so that TROLL E can stop or change direction.
5. The sensing subsystem can detect and react to obstacles of different sizes and heights.
6. The weight sensor can measure the total weight of the load on TROLL E.
7. TROLL E will not begin autonomous movement when the measured load exceeds 20 lb.
8. When the load exceeds 20 lb while TROLL E is already moving, the control system can stop the drivetrain and prevent further movement until the load is reduced below the weight limit.

2.2 Following Subsystem

With the sensors navigating past obstacles, we can now choose where we want to go. Using a beacon design, we want TROLL E to identify where the user is and follow at a trailing distance of about 5ft, subject to change after testing.

2.2.1 Ultra-Wideband(UWB)

Following the user is our ideal method of pathfinding, where TROLL E will have 2-3 anchors mounted on it at key points, with the user holding another for the mounted sensors to detect and triangulate. Our method of decision-making with our following system will be to trail at about 5-10 feet, using the triangulated position as a reference and aiming to stay in this range behind the user. This will allow for a safe distance between the user and TROLL E, protecting against sudden movements made by the user. We are planning to use the MaUWB_DW3000 Chipset as a reference. The DW3000 requires 3.3V power with working currents at 34mA[4]. It supports up to 8 anchors and 64 tags, well within our scope, and 850kbps with up to a 100 Hz refresh rate. It can use both UART and I2C communication protocols, so we have the option to choose between them. We can step down our 5V to 3.3V for this component, and if we use 2-4 UWB sensors, this will draw 68-136mA of current.

We will need to also power the UWB tag that the user will be holding, which can be seen with the MaUWB_ESP32S3 UWB module that uses the same chip as above[5].

2.2.2 Potential Issues to Consider

With this design, a major issue is that a trailing cart is prone to being missed by other pedestrians or people operating any form of vehicle. By staying several feet behind the user, TROLL E may find itself in situations where something or someone could hit it from the side if it is driving forward into a potential traffic area.

To address this, a failsafe to prevent similar situations that may require the user to make a decision for TROLL E can be included by adding a switch to turn the user's beacon off. Then, TROLL E will stop in place if it is not reading the user's beacon signal, and will wait until the beacon is reactivated to restart traversal.

2.3 Drivetrain Subsystem

The drivetrain subsystem is responsible for moving TROLL E based on commands from the control system. Since TROLL E must follow the user while avoiding obstacles, the drivetrain must be capable of various motions. The current design uses four mecanum wheels, each equipped with its own motor, so the device can move forward, backward, sideways, and rotate in place. This should give TROLL E the maneuverability to adjust its path without needing a large turning radius.

2.3.1 Mecanum Wheels

Mecanum wheels were chosen because they allow movement in multiple directions without requiring the device to turn first. This will be useful for TROLL E because the cart has to make many position adjustments while following the user to avoid obstacles and people. The ability to rotate in place also reduces the amount of space needed for position adjustments, which could be useful in tighter environments.

The only tradeoff is that mecanum wheels depend on all four wheels being controlled properly. If one wheel is moving at the wrong speed or direction, the device will not move in the direction the control system expects. Because of this, the motor speeds need to be controlled together so that the intended motion is consistent with the expectation.

2.3.2 Motors

Each mecanum wheel will be driven by its own motor, allowing the control system to change the speed and direction of each wheel independently. The motors will receive commands through motor drivers rather than directly from the microcontroller, since the motors require more current than the microcontroller can provide.

For the current design, the Pololu 100:1 37D 12 V metal gearmotor is being used as a reference [6]. The motor operates at 12 V and draws about 0.2 A with no load and approximately 0.72 A near its maximum-efficiency operating point. Its stall current can reach 5.5 A, so the motor drivers and battery will need enough current capacity to handle short periods of higher current without relying on the stall operation [6]. With four motors, it is expected to draw about 2.9 A during normal loaded operation based on this reference motor. The drivetrain power interface will provide 12 V to four motors and support at least 3 A continuously, with additional current capacity for motor startup and short-duration load changes.

The motors will need to provide enough torque to move TROLL E while carrying its intended load. They also need a quick response time to changes in direction so the cart can follow the user and stop when an obstacle is detected. The final motor choice will depend on the weight of the cart, the maximum load limit, and the amount of torque needed to move the device.

2.3.3 Drivetrain Requirements

The Drivetrain Subsystem should meet the following requirements:

1. TROLL E can move forward, backward, sideways, and rotate in place using the four mecanum wheels.

2. The drivetrain can move TROLL E while carrying the maximum intended load of 20 lb.
3. TROLL E can operate at a maximum speed of 2- 3 mph.
4. When a stop command is given, the drivetrain can bring TROLL E to a complete stop within 6 in while traveling at its maximum operating speed.
5. The four motors are being controlled independently so that the drivetrain can perform the wheel-speed combinations needed for omnidirectional movement.
6. The drivetrain can travel on intended terrains without the motors stalling under the maximum load.

2.4 Control Subsystem

The control subsystem will bring all the other subsystems together. It will take in information from the LiDAR, ultrasonic, UWB, and weight sensors and use that data to decide what TROLL E should do next. Depending on what the sensors detect, the device will continue to operate, adjust its path, slow down, or stop completely.

This subsystem will also handle safety-related situations. If the user's beacon signal is lost, the weight limit is exceeded, an obstacle is detected, or the emergency stop is activated, the control system will respond and react accordingly before resuming normal operations. Once a decision is made, the MCU will send the necessary commands to the motor drivers so the mecanum wheels move in the correct direction at the proper speed.

2.4.1 MCU

The central microcontroller will be how TROLL E communicates with each of its peripheral devices. It will need to read all the data from each sensor to accurately make decisions about its next action, including the path it will take to follow the user and stop signals for dangerous conditions. We plan on using either SPI or I2C connections where feasible to conserve wiring connections, but depending on the specs of the devices we finalize our design with, other communication protocols like UART can be implemented as well. Our MCU will also communicate with motor controllers, which will help run the motors.

2.4.2 Decision Logic

TROLL E will need to start by reading distance data from the LiDAR and Ultrasonic sensors. This will help compute a pathfinding algorithm to reach the beacon the user holds on to, which is obtained through the Ultra-Wideband sensors. Through the combination of triangulating the user's position along with data on the surroundings, TROLL E will decide to follow the user with any adjustments in pathing or to come to a stop. Finally, with these decisions made, the MCU will need to tell the motor controllers how to act in order to follow the path laid out post-computation. The motor controllers will then spin the motors in their predetermined directions to execute the pathing that the MCU decided on.

2.4.3 Control Requirements

The Control Subsystem should meet the following requirements:

1. Testing each communication protocol to validate data transmission using LEDs.
2. The MCU can receive data from the sensors and process it.

3. The control subsystem can send independent commands to all four motor drivers so that TROLL E can move forward, backward, sideways, and rotate in place.
4. If an obstacle is detected, the control system can stop or redirect TROLL E before allowing normal operation.
5. If the UWB beacon signal is lost or turned off, the control system can stop TROLL E and keep it stopped until the signal is restored.
6. If the weight sensor detects a load greater than 20 lb, the control system can prevent the drivetrain from operating.
7. The emergency-stop input can override all movement and halt the drivetrain when activated.

2.5 Power Subsystem

The power subsystem will provide the energy to the motors, sensors, microcontroller, and other electronics on TROLL E. A rechargeable lithium battery will be used as the main source of power, with its output distributed to the drivetrain and control electronics, and voltage regulation used where lower voltages are needed by the sensors and microcontroller.

2.5.1 BMS

A battery management system will also be implemented to protect the battery from unsafe conditions such as overcharging, over-discharging, excessive current, and overheating. The drivetrain will be drawing a large amount of current when all four motors are operating at the same time, and the power system must be able to support the peak current demand of the motors while still providing stable power to the control and sensing subsystems.

2.5.2 Lithium Battery

The lithium battery will supply the main power for TROLL E. It must provide enough voltage and current to operate the motors under load while also supplying power to the electronics through a regulated voltage. The final battery size will depend on the motor requirements, expected load, and the ideal operating time before TROLL E needs to be recharged.

2.5.3 Voltage Regulations & Power Distribution

The power subsystem will have voltage regulators or converters to provide the required voltage to the different parts of the system. Parts such as the motor may operate directly from the main battery voltage, while the MCU, UWB system, LiDAR, and ultrasonic sensors will operate using the lower regulated voltages. The power distribution design also needs to make sure the sudden motor current changes do not cause the MCU or sensors to lose power or reset.

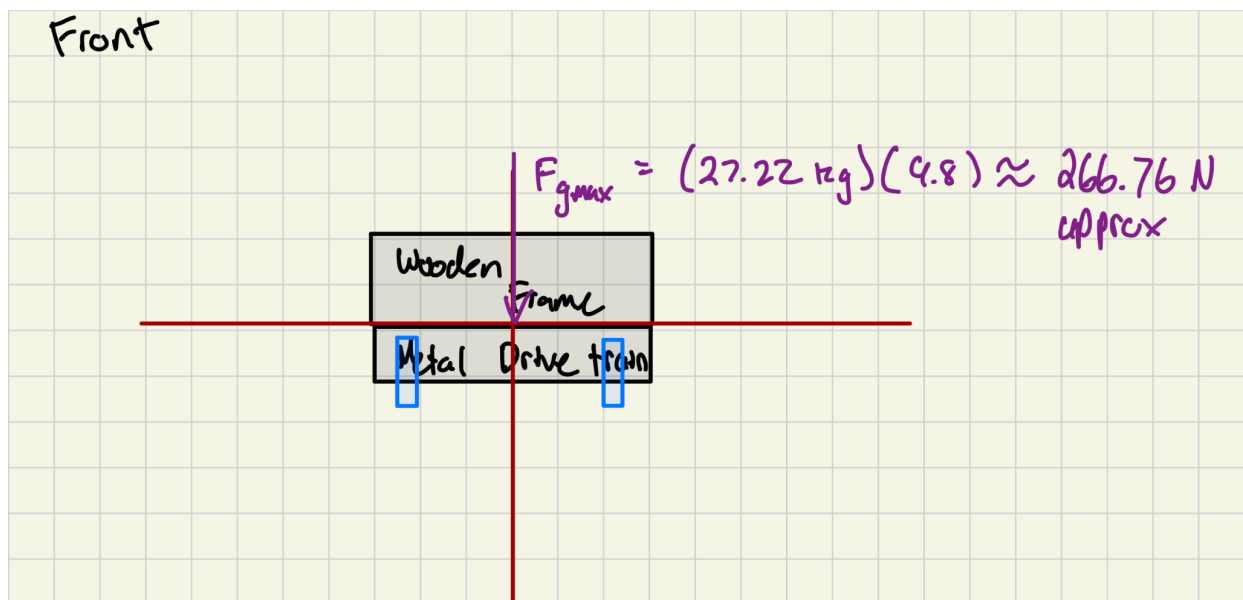
2.5.4 Power Requirements

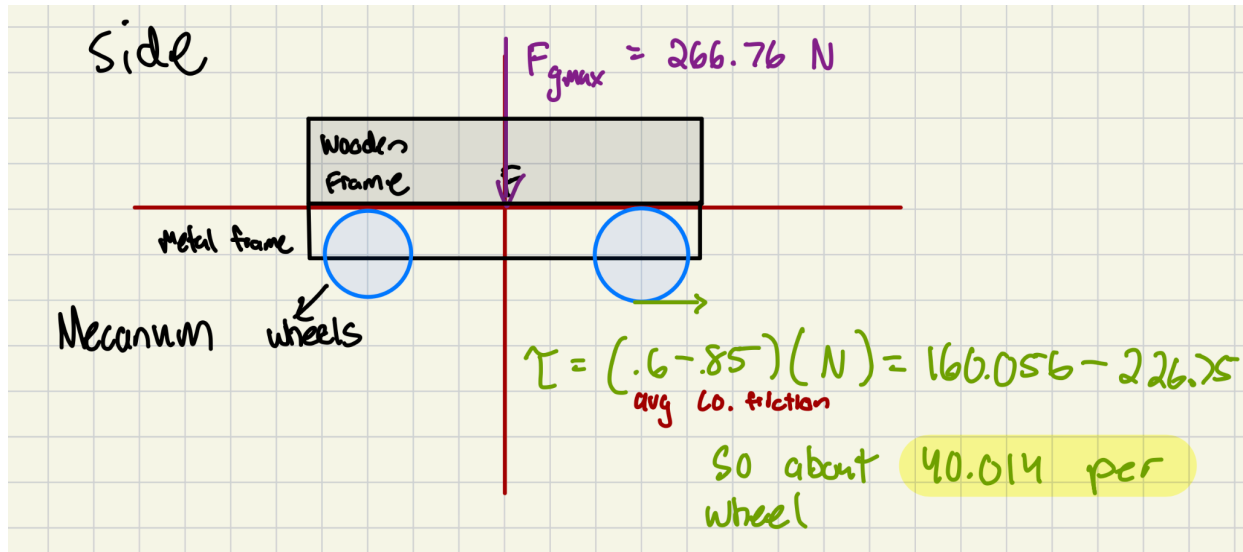
1. The power subsystem can provide enough current to operate all four motors and the control electronics at the same time under the maximum intended load.
2. The battery can provide at least 30 minutes of continuous operation under normal use.
3. The power subsystem can provide the required regulated voltage for the MCU and sensing components.

4. The battery management system can protect the lithium battery from overcharging, over-discharging, overcurrent, and overheating.
5. The power subsystem can continue supplying stable power to the MCU and sensors during motor operation and changes in motor current.
6. Battery wiring and connections can remain secure during normal vehicle movement and vibration.

2.6 Tolerance Analysis

One of the more prominent risk components is the motors and the drive shaft. A lot of the weight will be distributed amongst the joints of TROLL E, and with this comes reliability related to the structural integrity of the frame and wheels. The rigidity of the wheels and the strength of the frame are both things that we have already considered, and we have manufactured a frame with competent wood supplies as well as understanding the amount of support wheels needed in order to evenly spread the force placed upon different loads of the cart. We drew up simple force diagrams and concluded that the easiest way to mount wheels was to place them on all corners of the frame, as well as under the frame. This allows for more down force on the wheels instead of applied torque on the sides if mounted otherwise. Along with this, we saw that this helped with the possibility that the center of gravity of TROLL E may not be even at times since all wheels were on all corners, as well as the center of gravity always being between the wheels of the frame.





Being fully reliant on the wooden frame as structural support isn't something we decided on however, as we will be mounting the wheels on a metal drivetrain that will mostly house all of the motors, battery, and controller components. To ensure that each component is safe, we decided on implementing further structural support like cross bars and drive shafts, outside of the wooden frame.

Another thing that required some mathematical analysis was the amount of torque needed to move a max load of 30-50 pounds distributed across 4 wheels to move about 3 mph. With this, we learned that a good motor that can generate about 150 rpm and a minimum of 2 N*m allowed for easy clearance of this hurdle. We found that overestimating what we need allows for more comfortability when implementing.

3. Ethical, Safety, and Societal Impact

3.1 Ethical Considerations

TROLL E is designed to reduce the physical effort required to transport loads by autonomously following the user. Because the device operates independently around people and carries heavy objects, the team has an ethical responsibility to prioritize the safety of users and bystanders throughout the design process. A malfunction in the tracking, control, sensing, or drivetrain systems could cause the vehicle to move unexpectedly and collide with a person or an obstacle. For this reason, we will consider safety throughout both the design and testing of the project.

The IEEE Code of Ethics emphasizes protecting the safety, health, and welfare of the public and identifying conditions that could put people or the environment at risk [7]. Following the IEEE Code of Ethics, the team will not continue testing a feature that is known to behave unsafely just to prove that the prototype works. If testing shows that a feature is unreliable or creates a safety concern, the team will correct the issue before continuing development.

The IEEE Code of Ethics also states that engineers should be honest and realistic when presenting technical claims and should acknowledge and correct errors when they are found [7]. Because of this, the team will not claim that TROLL E can operate safely in conditions that have not been tested. The team will clearly state and communicate limitations such as terrain, maximum payload, operating speed, following distance, and obstacle detection to the user.

The ACM Code of Ethics emphasizes avoiding harm and considering a system's possible effects before use, as well as its accidental and intentional misuse[8]. Accidental and intentional misuse must be considered as well. Accidental misuse includes overloading the cargo, blocking a sensor, or using TROLL E outside of the conditions it was designed for. Intentional misuse could include riding on the device, disabling the obstacle sensor, or changing the software so that the vehicle operates outside its tested limits. These cases will be considered outside the intended operation of TROLL E, and the team will add safety limitations in order to prevent such misuse from happening.

3.2 Safety Considerations

The main safety concerns for TROLL E come from its autonomous movement, mechanical drivetrain, electrical power system, and ability to transport significant loads. The most significant hazard is unintended vehicle motion. A failure in the user-tracking system, motor controller, or software could cause TROLL E to move in the wrong direction or continue moving after the user has stopped. This could result in a collision with a person or an obstacle.

To reduce this risk, LiDAR sensors will monitor the surrounding area for obstacles, and the control system will stop the motors when an obstacle is detected. An emergency-stop mechanism will also be implemented so the user can manually disable TROLL E's movement for emergencies. Since TROLL E is intended to operate near its user, its operating speed and following distance must allow enough time for the system to detect an obstacle and stop. Because of this, the obstacle-detection system should be

tested and verified under practical operating conditions before the device operates autonomously around other people.

Device stability is another safety concern because TROLL E will be carrying a significant load while moving. The mecanum wheels will allow the device to turn in place and move sideways without needing a wide turning space. However, the device could still become unstable if the load is unevenly distributed or exceeds the intended weight limit. To reduce the risk of tipping or falling, the frame will be designed with a low center of gravity and enough width to support and balance the expected load.

The battery and electrical system also create safety risks. Since TROLL E will use a lithium battery, the ECE 445 battery safety guidelines will be followed. The guideline lists overcharging, over-discharging, excessive current, heat, short circuits, and mechanical damage as major lithium battery hazards [9]. Wiring and electrical connections on TROLL E will also be insulated and secured so that movement and vibration do not cause wires or connections to become loose during operation. The team will also follow the ECE 445 procedures for reviewing and testing battery-related circuitry before connecting it to the system[9].

3.3 Impacts

TROLL-E could have a positive societal impact by giving users an additional way to transport loads during everyday activities. For general use, the device could help carry groceries, gardening supplies, tools, outdoor equipment, or other items that require repeated lifting or manual transport. It may also be useful for elderly individuals or people with physical disabilities who may have difficulty carrying heavier objects regularly. In commercial environments such as supermarkets, retail stores, malls, or storage areas, employees could use TROLL E to move clothing, inventory, merchandise, or other goods.

Economically, TROLL E would likely cost more than a traditional cart or wagon because it incorporates motors, mecanum wheels, sensors, a battery, control electronics, and a wireless user-tracking system. However, these additional components provide autonomous movement and reduce the need for the user to continuously push or pull the load. If the system were developed beyond the team's project design, the team would need to reconsider component cost and manufacturability to make the product economically practical.

TROLL E is electrically powered and therefore produces no direct exhaust emissions during normal operation. However, producing its battery, motors, electronic components, and structural materials still has an environmental impact. Battery disposal and electronic waste would also need to be considered at the end of the product's life. Designing the system so that individual components can be repaired or replaced, rather than replacing the entire device, could help extend its usable lifetime and reduce unnecessary waste.

The potential applications of TROLL E are not limited to one region because the need to transport groceries, tools, supplies, and commercial goods exists in many environments worldwide. However, operating conditions can vary significantly by location because of differences in terrain, infrastructure, climate, and available space. For this reason, the capabilities demonstrated by the TROLL E should only

be assumed for environments and operating conditions that the system has been tested on. Future versions could be adapted to better accommodate the needs and conditions of different regions.

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