Hands-Free Following Cart

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Design Document

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Contents

1 **Introduction** **2**
1.1 Objectives 2
1.2 Background 3
1.3 High-Level Requirements 4

2 **Design** **5**
2.1 Block Diagram 5
2.2 Physical Design 6
2.3 Block Descriptions 7
2.3.1 Power Subsystem 7
2.3.2 Drivetrain Subsystem 8
2.3.3 Control Subsystem 9
2.3.4 Mobile Application 10
2.4 Block Requirements 11
2.5 Tolerance Analysis 14

3 **Cost and Schedule** **16**
3.1 Cost 16
3.1.1 Labor 16
3.1.2 Preliminary Parts List 16
3.1.3 Total 16
3.2 Schedule 17

4 **Ethics and Safety** **18**

5 **References** **19**

1 Introduction

1.1 Objectives

Maintenance, gardening, and custodial duties often result in execessive labor and time wasted in transporting resources between locations. Moving heavy loads often takes multiple trips involving multiple people and thus becomes very inefficient. A study found that adding one robot to a geographic area reduces the need for six workers [1].

Our solution, the Hands-free Following Cart, aims to alleviate workers from carrying such loads and to reduce the manpower required for labor intensive tasks. Additionally, it will help increase safety standards in the workplace, as minimizing the need to move heavy loads will reduce the risk of injury, since lifting heavy objects and manually handling materials puts workers at risk for back injuries - more than 111,000 related injuries in the United States requiring days away from work were recorded in 2017 [2].

The Hands-free Following Cart will track and follow a person while simultaneously carrying a load. The cart is designed to navigate wherever a person is able to go, including ramps and elevators. The user can choose between two options to operate the cart. As previously mentioned, the cart can follow the user at a predetermined distance. However, the cart can also follow a predetermined route in an environment that has already been mapped.

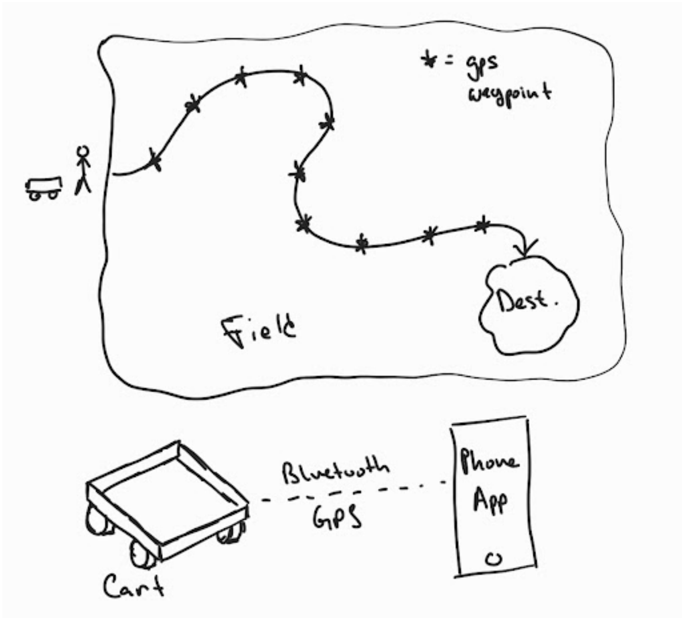

Figure 1: Overview of Project

1.2 Background

Tools exist that allow workers to transport heavy loads when necessary, such as wheelbarrows, heavy duty dollies and hand trucks. However these are all tools that require manpower to operate and pose safety hazards and increase risk of injury in the work environment. Another factor to take into consideration is transporting and loading of such tools. An automated tool that is both able to carry loads and is mobile would eliminate all of these hazards and inconveniences in the work environment and can be marketed as such. It would also be able to navigate up a ramp into a vehicle, making it easy to transport.

A similar existing product, Automated Guided Vehicles (AGVs), are computer controlled, wheeled transporters that operate on shop floors without a driver or operator and are able to move heavy loads. AGVs are able to navigate a facility by following magnetic strips or wires placed in the floor using vision cameras or lasers for navigation. However, these machines are extremely expensive, costing over $5000 per unit. Our Handsfree Automated Cart will have a production cost of just $400. Moreover, it will have additional functionality in that the cart will be able to safely follow a person at a distance of approximately 2.5 meters while also being able to navigate a predetermined route.

1.3 High-Level Requirements

- Must be able to self start and move up to 200 lbs of payload without external assistance.
- Follow users GPS points at a distance of 2 meters at up to 4mph while avoiding collisions that cause damage to cart or to property. Or follow preset GPS points with an accuracy of less than 2.5 meters.
- Stay operational for 30 minutes under normal use. Use is defined as carrying 150 pounds at 4 mph.

2 Design

2.1 Block Diagram

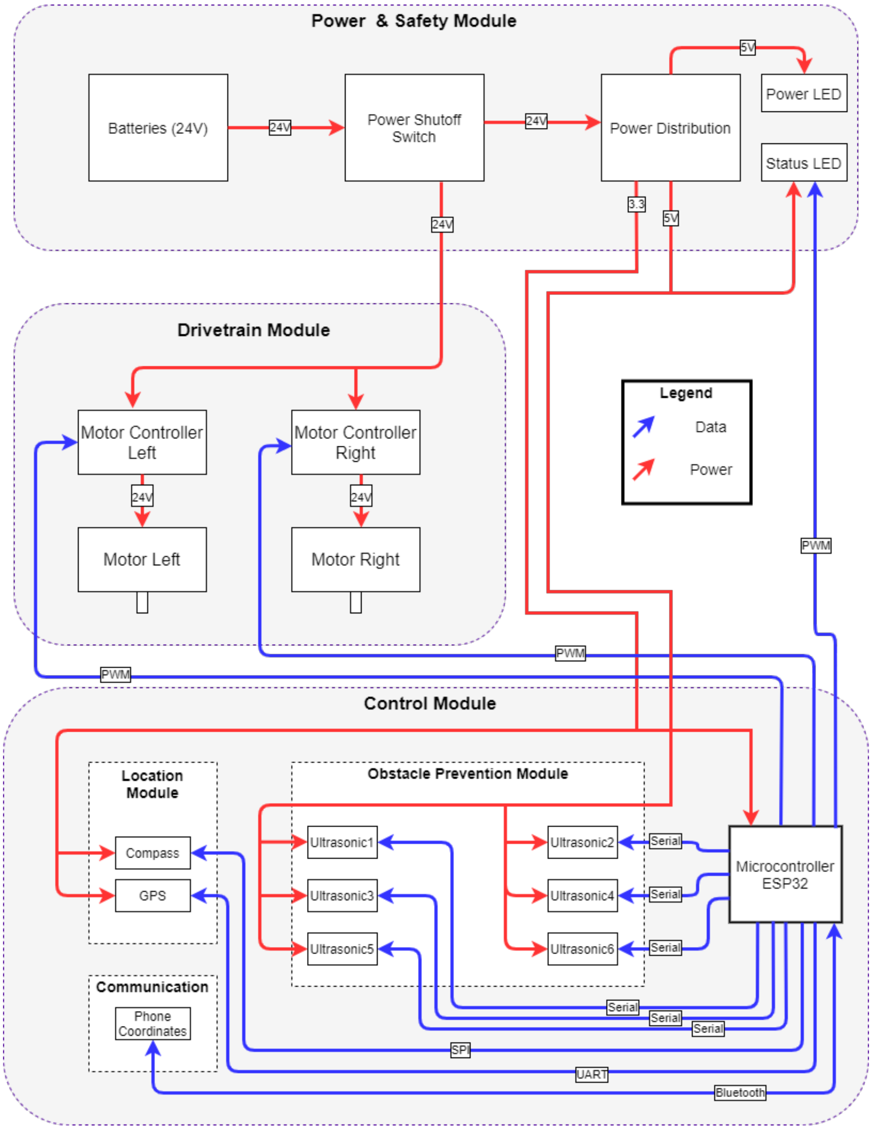

Figure 2: Block Diagram of Hands-free Following Cart

2.2 Physical Design

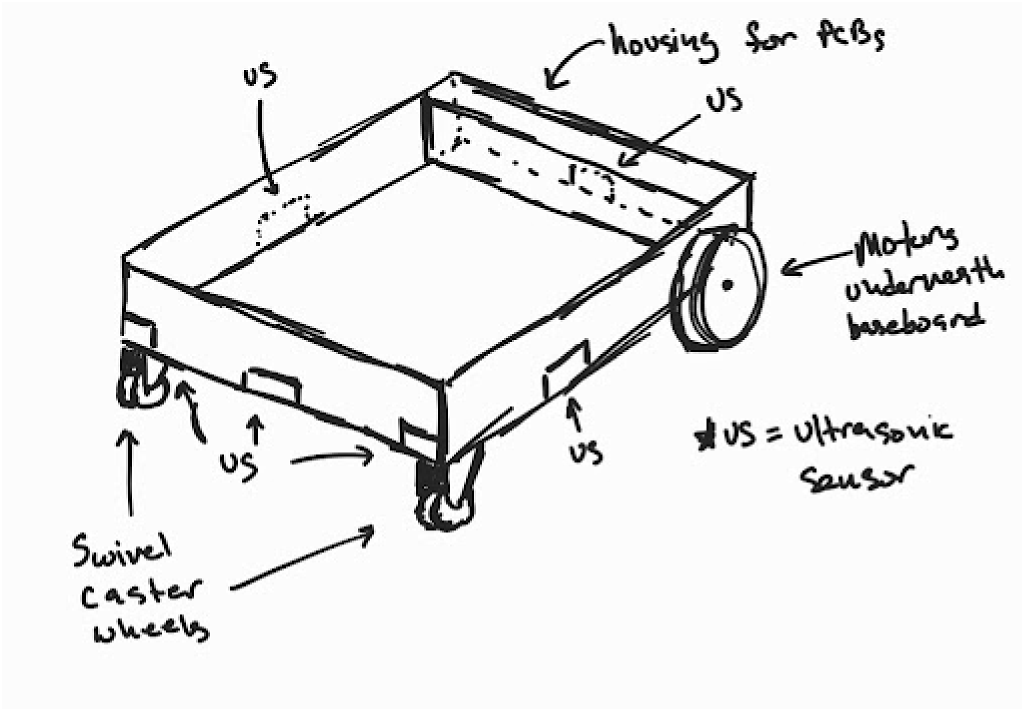

Figure 3: Physical Design Sketch of Hands-free Following Cart

2.3 Block Descriptions

2.3.1 Power Subsystem

Lead-acid batteries will provide the power and voltage necessary to the components within the control module and drivetrain module, as well as other accessories. The battery capacity and configuration will allow the cart to be operational for 30 minutes at a minimum.

- Batteries:
  - Two 12V batteries configured in series provide power to all electrical components. The batteries will provide an input voltage of 24V and have a 12Ah capacity. Based on the preliminary power analysis (refer to figure 4), under normal use the battery configuration should provide power for up to 30 minutes of constant load and mobility.
- Power Shutoff Switch:
  - Input power will go through an appropriately rated electrical switch which will be used to turn on or shut off power to the cart manually and to be used in case of emergency. This switch will be rated for over 100A as the peak current draw of our motors is 80A, which is the peak current draw of our system.
- Power Distribution:
  - The power distribution module will take input power from the batteries and then step down the voltages to multiple voltage rails (5V and 3.3V) using buck converter IC's, and these voltage rails are connected to all the sensors and the microcontroller. Refer to figure 4 for recommended voltage specifications for each component.

Part Name	Communication Protocol	Number Needed per board	Supply current per device [A]	Supply Current per board [A]	Supply Voltage Min [V]	Supply Voltage Typ [V]	Supply Voltage Max [V]	Estimated Power Consumption [W]
ESP32-WROOM-32UE	Multiple available	1	0.5	0.5	3	3.3	3.6	1.65
GPS Module	UART	1	0.025	0.025	2.8	3.3	4.3	0.0825
Compass	SPI	1	0.00045	0.00045	2.8	3.3	3.6	0.001485
Ultrasonic Sensors	SERIAL	6	0.015	0.09		5		0.45
Motor Drivers	PWM	2	0.1	0.2	5	5	30	1
LEDs	PWM	60	0.025	1.5	4.8	5	5.1	7.5
								0
Motors (Max RPM)	PWM	2	18.4	36.8	24	24	24	883.2
				0				0
				0				0
				0				0
				0				0
Max/Total		60	18.4	36.8	24	24	30	893.883985

Figure 4: Power Analysis of Components based on Datasheets

2.3.2 Drivetrain Subsystem

The Drivetrain module is where motor controllers take input pwm signals from the microcontroller and input power from the batteries to control the speed and direction of the motor rotation.

- Motor Controllers:
  - The motor controller will receive power from the batteries and input signal from the microcontroller in order to drive the motor at the right rpm (based on wheel size and gearbox reduction for speed calculations). Refer to figure 5 for motor and drivetrain calculations. Furthermore the motor controllers will be rated for above the continuous current specification of the motors and the peak current of the motors. In our case, the motor controller will be able to handle 30A continuous and 80A peak for up to 1 second.
- Motors:
  - The motors will receive power from the motor controllers and spin the shaft attached to the wheels. The motors will have a driving rpm of 300RPM or above as this will allow the cart to have a maximum speed above the average walking speed of a human. Refer to figure 5 for motor calculations and power consumption.

Parameter	Value	Units
Motor Shaft Speed	300	RPM
Motor Sprocket	1	teeth
Wheel Sprocket	1	teeth
Wheel Size	8	in
Motor Voltage	24	VDC
Nominal Current	18.4	A
Torque	1.7	Nm
Cart Speed	7.139983304	MPH
Gear Reduction Ratio	1	:1
Motor Output Power	331.2	W
Output Torque	1.7	Nm

Figure 5: Drivetrain Calculations for the Hands-free Following Cart

2.3.3 Control Subsystem

The Control Subsystem takes input data from various sensors and then processes the information to compute a path following instructions and relay data to the user via Bluetooth.

- Microcontroller (ESP32):
  - Takes in data sent from GPS, Bluetooth, and ultrasonic sensors to determine where the cart will go and sends signals to the motor controller. It will also be used to compute the path to take and remember the way points to follow. The ESP32 has built in Bluetooth for us to utilize instead of having a separate module. Furthermore the ESP32 has a wide range of communication protocols to take input data and send output signals. We will mainly be using UART, SPI, Serial and PWM for our system.
- Ultrasonic Sensors:
  - Determine obstacles in the path of the cart based on sound waves. Distance measured from the sound waves is relayed to the microcontroller to process the motor signals.

- Compass:
  - Triple axis magnetic sensor to compute the heading direction of the cart. This will allow the motor control to be refined as we know which way the cart is aligned relative to the input GPS coordinates.
- GPS Module:
  - Will retrieve the position of the cart on earth and that data will be relayed to the microcontroller for path following.

2.3.4 Mobile Application

The cell-phone application will be the main user interface for the cart.

- Phone Application:
  - The application will use the device's GPS and Bluetooth to send location data of the user to the microcontroller. If the cart is stuck, it will use the app to alert the user if within Bluetooth range. The application will also have an enable/disable feature that allows the user to choose whether or not to follow the user or to navigate a predetermined route. Apart from a physical kill switch, the soft kill switch will also be available on the application.

2.4 Block Requirements

Module/Subsystem		Requirements	Verification
Power & Safety System	Batteries	1. Provide ample input power to use the cart under normal conditions for up to 30 minutes. 2. Input voltage between 24 to 27 volts 3. Hardcase, non-spillable	2. Use a voltmeter to measure and confirm battery output is between 24-27 volts.
	Power Shutoff Switch	1. Hard wired to the input power source to cut off power to all subsystems. 2. Rated for 2x the max current of the whole system. 3. Easily accessible by the user	1. Connect power to at least one subsystem through the shutoff switch. Flip switch and determine if the power was cut off from the subsystem.
	Power Distribution Board	1. Step down the input voltages to: a. 5V +/- 0.2V b. 3.6V +/- 0.2V c. 3.3V +/- 0.1V	1. Use a voltmeter to check each output pin of the power distribution board and confirm they are the correct voltage.
Drivetrain Subsystem	Motor Controllers	1. Rated for up to 60A under stall conditions 2. Control the rpm with a tolerance of +/- 3 rpm	1. A. Run motor under stall conditions B. Use an ammeter to confirm less than 60 A present.
	Motors	1. DC motor with enough power to start moving a max load of up to 200 pounds. 2. Output shaft compatible with standard wheels hubs without any need for custom adapters 3. Shaft must be able to spin both directions	1. A. Load cart B. Drive motors to confirm they can move 3. A. Use test code to drive in forward direction B. Then switch the backward direction
Control Subsystem	Compass	1. Tells the system the direction of the cart with an accuracy of 1-2 degrees.	1. A. Print cart's compass reading to screen B. turn the module C. measure rotation and

		2. Updates faster than 60Hz 3. I2C communication	determine if it's within 1-2 degrees
	GPS Module	1. Establish the current position of the cart outdoors within a 2 meter accuracy 2. Must update faster than 10Hz 3. UART communication	1. A. Get the value of position from the module B. compare with known accurate reading, i.e. phone application 2. Check speed at which updates happen and determine if they're faster than the required speed 3. Connect through UART
	Bluetooth Transceiver	1. Send and receive data between the cart and a phone within 30ft 2. UART or I2C communication	1. Stand within 30ft and check connection to module 2. Communicate using UART or I2C
	Ultrasonic Sensors	1. Range of up to 7 meters 2. Accuracy greater than 3 cm 3. Wave direction of up 45 degrees or greater	1. Move away from ultrasonic sensors. Measure the location of where the sensor stops reading. Determine if it is greater than 7 meters. 2. A. Move an object in front of an ultrasonic sensor. Mark its location. B. Move it and compare its new location with the sensor's readout. C. Move it in increasingly small increments. Determine if the sensor is accurate up to 3cm. 3. Place the object in front of the sensor, move it to the sides. Until it's no longer visible to the sensor. Measure the angle and determine if it's greater than 45 degrees.
	Microcontroller	1. Must be able to receive data from all the above sensors and modules and	1. A. set up sensors B. print sensor values to screen

		send data to certain modules 2. Must be able to compute a path direction given new points within 2 seconds. 3. Must be able to store gps waypoints in memory for cart to follow 4. Must be able to notify user if it notices an error or be able to change LED color to notify user of cart status	C. change GPS transmitter location and confirm changes D.move objects in front of each US sensor to confirm detection 2. A. Manually input 2 coordinates for calculation B. compute and check time elapsed 3. A. Move GPS transmitter to get waypoints B. print waypoints as received C. after three waypoints, print stored values D. compare with previously printed waypoints 4. A. Create stalled setup with sensors B. confirm LED's change Bluetooth 1. Develop a simple application that sends a signal to the microcontroller, probe the V_{in} using an oscilloscope to determine if a pulse was registered. 2. Repeat the above steps, test for a distance of 10meters.

2.5 Tolerance Analysis

One major part of the project that requires a tolerance analysis would be determining the location and with the GPS and compass modules. The compass module has a tolerance of 1 degree. The GPS has a tolerance radius of less than 2.5 meters and can update, at the slowest, once every second. Assuming average walking speed is 4mph, in one second a human can get 1.79m away from the starting point.

A waypoint that is updated behind the cart would be a bad error. This is possible because the cart's distance to the way point, 1.79m, is actually within the GPS tolerance radius of 2.5 meters.

Now, if we assume that the angle of the error way point is pointed out to the side and that the compass will also give an error of a 1 degree larger angle, then it will create an error way point that is even farther. However, this error way point, is less than 10cm larger, so the error from the compass is negligible.

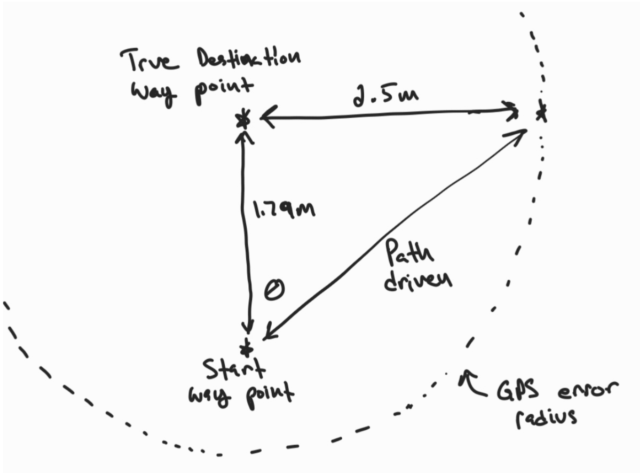

Figure 6: Diagram of GPS Location Error

$$tan(\theta) = 2.5m/1.79m$$
$$\theta = 54.3973$$

However, if we assume the compass gives a full 1 degree error, then

$$\theta = 55.3973$$
$$tan(55.3973) = Path/1.79m$$
$$Path = 2.59449m$$

Finally, these way points come from the users phone application, so the location and path of the cart don't actually affect the coming errors. Because these errors don't propagate, are all within relatively small distances, and other safeguards, such as the ultrasonic sensors, to avoid crashing, we believe these errors are tolerable.

3 Cost and Schedule

3.1 Cost

3.1.1 Labor

For each engineer, a $50/hour salary with a project completion time of 300 hours gives $37,500. With 3 design engineers, this comes out to $112,500.

For a machinist with $75/hour salary and project manufacturing and assembly time of 35 hours gives $6562.50.

3.1.2 Preliminary Parts List

Part Name	Manufacturer/Supplier	Part Number	Link	Unit Price	Quantity	Total Price
GPS Module	Quectel	L76-M33	Mouser	11.88	2	$23.76
24V SLA Battery	AJC MotoTec	T9FB1793821	Amazon	25.99	4	$103.96
Battery Isolater Switch	Shin Chin	A23-7B	Mouser	13.8	1	$13.80
Compass	Memsic Inc	MMC5983MA	Digi-Key	4.04	2	$8.08
Ultrasonic Sensors	Adafruit Industries LLC	3942	Digi-Key	3.95	9	$35.55
24V Motors	Unitemotor	MY1016	Amazon	59	2	$118.00
Motor Drivers	Cytron	RB-CYT-133	RobotShop	34.38	2	$68.76
Bluetooth Module	Microchip	RN42HCI-I/RM	Digi-Key	19.04	2	$38.08
LEDs	Amazon	WS2812B	Amazon	15.99	1	$15.99
8" Pneumatic Wheels	Haul-Master	47638	HarborFreight	8.99	2	$17.98
8" Swivel Caster Wheels	Haul-Master	69852	HarborFreight	7.99	2	$15.98
ESP32	Espressif	ESP32-WROOM-32UE	Digi-Key	3.6	2	$7.20
						$0.00
					Total	$467.14
					Course Funding	$100.00
					Out of Pocket Group	$367.14
					Out of Pocket/Person	$122.38

Figure 7: Parts List and Price

Estimated Parts Total Cost: $467.14

3.1.3 Total

Grand Project Total Cost: $119,461.63

3.2 Schedule

Week	Anudeep	Vincent	Matthew
9/27	Work on sourcing parts	Work on Design Doc	Wireframe mobile app
10/4	Finish PCB layout and get TA approval	Buy Parts	Use lab devkit to figure out how to transfer data (ESP32 & phone)
10/11	Unit test & Develop ESP32, GPS, Compass, Bluetooth, Motor Drivers, Motors		
10/18	Cont. Unit test & Develop ESP32, GPS, Compass, Bluetooth, Motor Drivers, Motors		Figure out ESPBLUfi app and APIs for ESP32 and app, cont. work on the control unit and Android app
10/25	Get approval for Rev2 PCB and submit an order	Working on Rev2 Schematics	Continue working on Android application
11/1	Cont. Unit test & Develop ESP32, GPS, Compass, Bluetooth, Motor Drivers, Motors		Finish control unit, combine and test with the application.
11/8	Prepare for Mock Demo		
11/15	Final testing and adjustments for hardware and software		
11/22			
11/29	Demo, system testing and begin Final Report		
12/6	Work on Final Report		

Figure 8: Project Schedule by Week

4 Ethics and Safety

The ultimate goal of this project is to improve productivity and safety in the workplace. With this in mind, we need to take into consideration the possible risks that the automated cart will pose in a work environment, such as what actions will be taken in the event that a human being obstructs its path or when collision with an obstacle could result in injury. Thus, we must uphold #1 of the IEEE code of Ethics, which is 'to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to promptly disclose factors that might endanger the public or the environment,' [3] and also #9 in the code - 'to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses.' [3]

We aim to have the cart moving at a top speed of 7-8 miles an hour, double the average walking speed, and so it must be ensured that the cart is able to recognize positive and negative obstacles and react accordingly, so as to eliminate the chance of colliding with a worker. The event of a worker accidentally walking into the cart must also be taken into consideration, and so we cannot have any sharp objects protruding from the cart.

Our cart will be powered by a 12V lead acid battery, which can cause serious injury if not handled properly. Firstly, the battery releases highly flammable gases while charging (hydrogen and oxygen) which can result in an explosion. The acid in the battery is also very corrosive and can cause damage to property and injury if it comes into contact with skin. Thus, we must ensure the battery is stored/mounted in a cool, well-ventilated area and to never handle the battery near heat or open flames. We will also make use of a spill tray to avoid leaks and spills that could damage and short circuits. [4]

Throughout the course of the project, we will be very open-minded in respect to taking criticisms and suggestions to improve upon design and execution, and will give due credit to the individual(s) that give us assistance. Thus, we will adhere to #5 of the IEEE code of Ethics, which is to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to properly credit the contributions of others.' [3]

5 References

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