Track Runner’s Pacing Assistant

ECE445 Design Document

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1 Introduction

1.1 Objective

One of the biggest problems that new distance runners face is learning to pace themselves. Whether you are a high school track or cross country runner or just a casual 5K runner, you have probably experienced this issue. The most effective way to run a race over 1500 meters is to keep a constant speed the entire time, and if you are not doing this, it will dramatically hurt your performance [1]. A lot of beginners will end up running too fast at the start of the race and have to slow way down by the end. While this issue affects beginners more dramatically, even very experienced runners have trouble with this as well. When looking to shave every possible second off of your time, perfect pacing matters a lot.

Our solution will create a device to help distance runners pace themselves perfectly along a standard running track. Our proposed solution is to create a miniature car that can maintain a precisely constant and adjustable speed on any standard running track in the world. It would utilize IR sensors to follow the lines around the track, and connect to a smartphone app where the user could input distance, pace, and time. The runner would then run behind this car in order to maintain a constant pace throughout their run. We may also implement an option for more advanced users to start or finish their workout at a faster speed, in order to simulate an actual race.

1.2 Background

Extensive research has been done on the subject, and researchers unanimously agree that maintaining a mostly constant speed throughout a distance race will lead to the fastest times [1]. There may be some slight exceptions depending on the race length and strategy, such as starting and ending the race faster than the middle [1]. Nonetheless, if a runner can develop the muscle memory for their desired race pace prior to the actual race, they can give themselves the best chance to run their fastest times.

In an effort to understand how important pacing is, even for Olympic level runners, we can analyze Haile Gebrselassie’s world record attempts for the marathon. Gebrselassie broke the world record at the 2007 Berlin Marathon, but was determined to run even faster at the 2008 Dubai Marathon. Starting overly eager, he completed the first half of the race in 61:27 which was 30 seconds faster than he ran in Berlin [2]. Unfortunately, this had detrimental effects on the second half of the race, which took 63:26, and caused him to miss his own world record time by nearly 30 seconds [2]. This goes to show that even a small error in pacing dramatically affects the outcome of a race. On that day in Dubai, Gebreselassie may very well have had the aerobic capacity to break the world record again, but his eagerness to go out too fast hurt him in the end. Luckily for him, he was able to learn from this mistake and break the world record again at the 2008 Berlin marathon [3], this time with splits of 62:04 and 61:55.

This example shows why pacing devices such as GPS watches are so popular today, among serious and casual athletes alike. However, GPS watches can't provide very instantaneous feedback and are sometimes inaccurate, especially going around turns [4]. They also can't provide visual motivation like having a pace car in front of you would. These are the two issues our group plans to solve with our pacing assistant.

There is no shortage of athletes that could benefit from this technology. The NCAA estimates there are over 800,000 high school track and cross country athletes in the U.S. alone [5]. Aside from that there many more college and professional runners, not to mention the casual 5K runner that just wants to run their fastest times. Our pacing assistant would be an incredibly helpful tool to many thousands of runners across the world.

1.3 High Level Requirements

- The robot must have adjustable speed ranging from 1 to 10 mph, and be able to operate for at least 30 minutes at 6mph.
- The robot must follow all typical Olympic track lane markers at all times using IR sensors.
- The smartphone app must have a display showing set speed, distance travelled, and time elapsed. Distance, pace, and time must each be correctly displayed with an allowable error of 5%.

2 Design

Our design consists of four main subsystems including User Interface, Control, Motor Control, and Power distribution. Figure 1 shows a block diagram of the system overview.

The power distribution revolves around a 7.4V lithium polymer battery and a voltage converter to provide power to the microcontroller, sensors, and motors.

The motor control subsystem takes a PWM signal from the microcontroller to regulate the speed of the DC motor.

The control system holds the brains of this project. It includes the IR sensors to ensure the car is following its path, the speed sensor to ensure the car is maintaining the desired speed, and the microcontroller to run the PID control system to make it all possible. It also includes the bluetooth module which will connect to our smartphone app.

Finally, the user interface subsystem includes the smartphone app where the user can input their desired workout settings. There will also be an emergency stop button to cut all power to the car in case of misoperation.

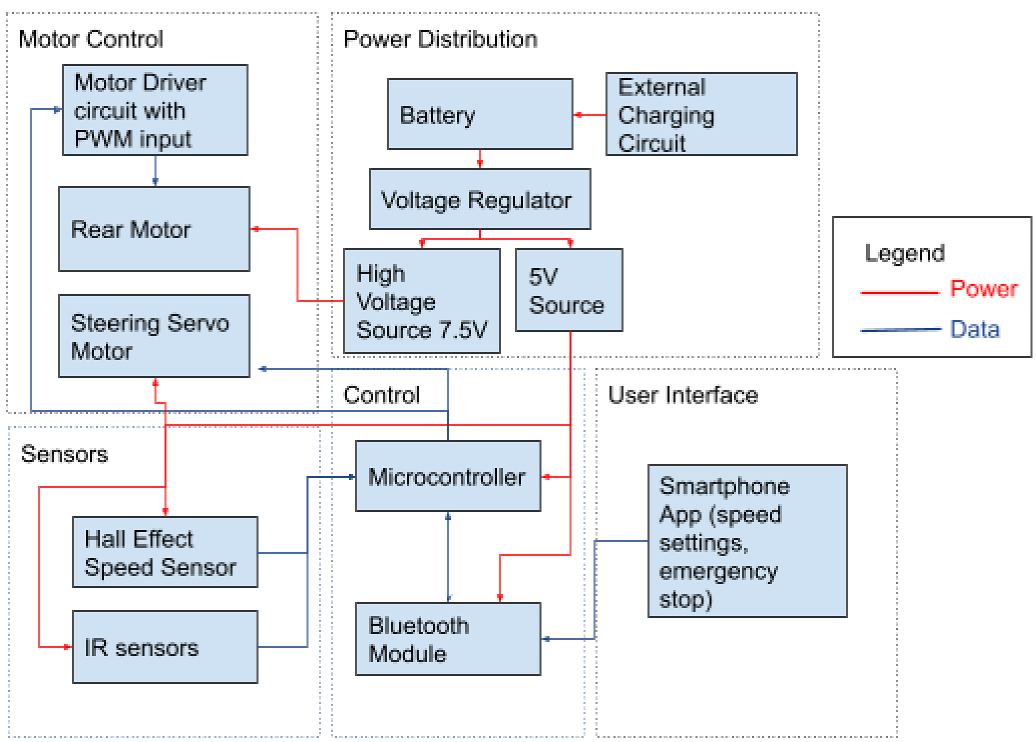

Fig 1. System Overview Block Diagram

Our design will use a prepackaged RC car as a base to build off of. The existing PCBs on the car will be scrapped and substituted with our own ATMega based control system. As many as five IR sensors will be mounted to the front of the car, and a hall effect sensor wheel will be mounted to the back. A spring will force the hall effect wheel into the ground to ensure traction is maintained at all times. Figures 2 and 3 show roughly what our design will look like.

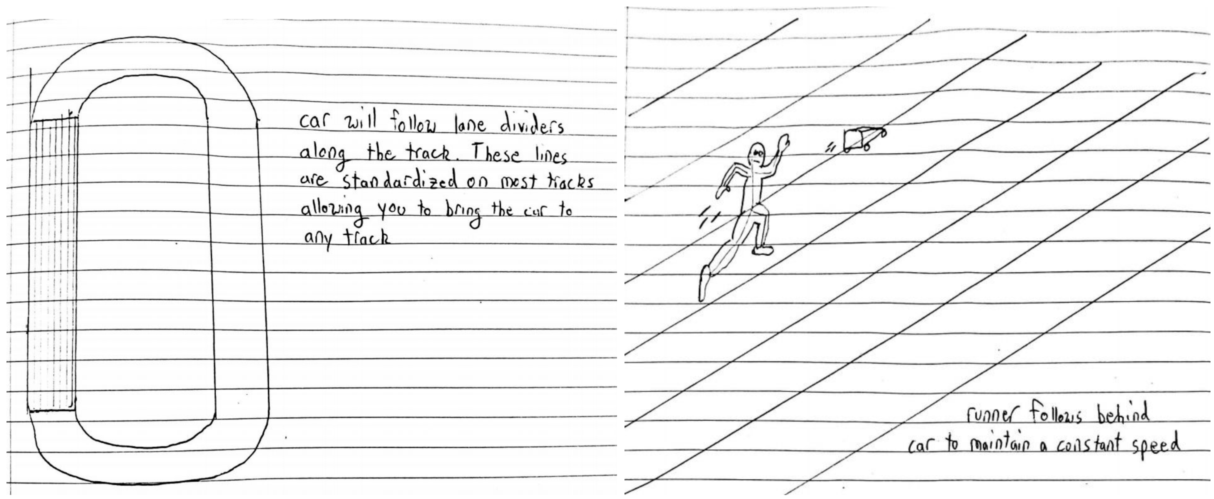

Fig 2. Idea Sketch

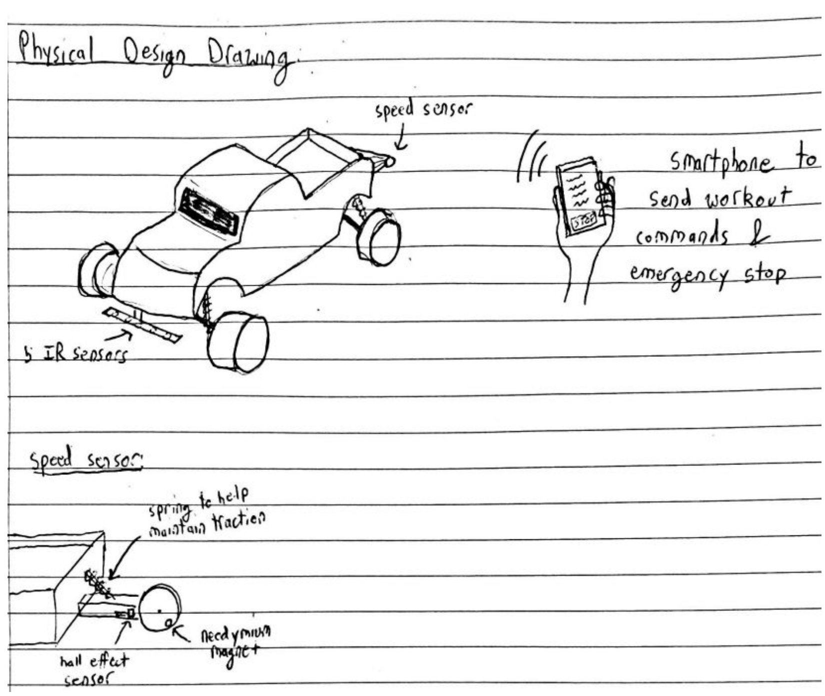

Fig 3. Physical Design of Car and Speed Sensor

2.1 Speed Sensor

A hall effect sensor and magnet will be used in order to measure the RPM of the car wheels and calculate the speed of the car. The magnet will pass the sensor exactly 1 time for each rotation of the wheels, so the period between each pulse from the sensor will be measured and the RPM and speed can be calculated. We will use omnipolar switch hall effect sensor DRV5033-Q1 and a small neodymium magnet. Figure 4 shows the state of the output pin vs the magnetic field sensed. Figure 5 shows the circuit diagram we will be using.

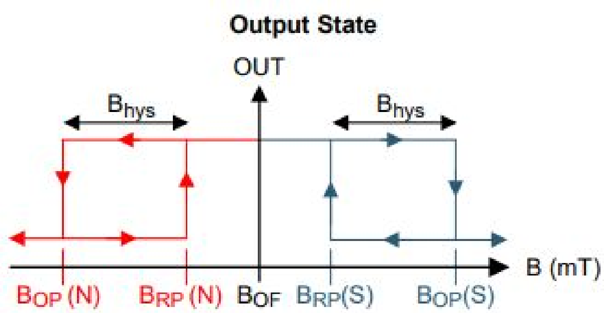

Figure 4.Output State of DRV5033-Q1

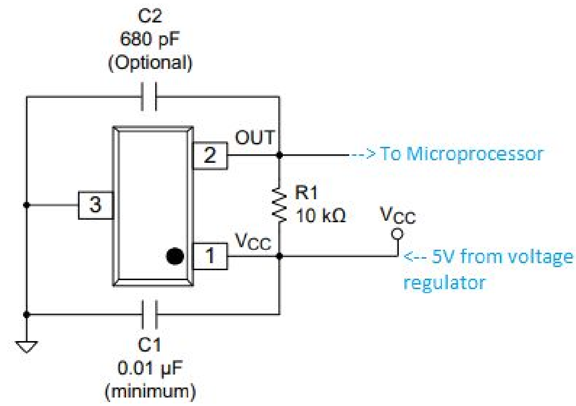

Figure 5. Circuit Diagram for Hall Effect Sensor

Requirement	Verification
1. Tracks speed of rotating wheel to within an accuracy of 5% 2. Can operate at any speed between 0 and 10mph (0 - 1681 rpm on a 2 inch diameter wheel)	1,2. A. Place wheel of RPM sensor on a treadmill and hold in place, while allowing it to spin freely B. Increase the speed of the treadmill from 0 to 10mph in increments of 1mph. C. Compare the sensor's speed calculation vs treadmill speed at each point.

2.2 User Interface

The UI will be implemented using a simple phone app and bluetooth receiver module. This will be the main way for the user to interact with the RC car. The user will be able to input their workout plan using the phone app, workout time and current speed will be displayed on the app and a emergency stop button will be available in case of need.

2.2.1 Bluetooth Module

The HC - 05 bluetooth receiver will be used as a gateway between the RC and an android phone. The receiver will communicate with the ATmega328P Microcontroller to allow a two way communication path. The workout plan is inputted through the UI and sent to the microcontroller while workout feedback is sent from the microcontroller to the UI. Figure 6 shows the pinout for the adapter we will be using.

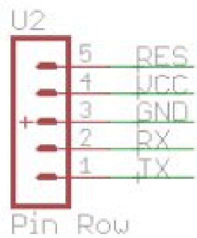

Fig 6. HC-05 pinout

Requirement	**Verification**
1. Can receive data sent through an android mobile app. 2. Can send data back to the app.	A. Setup a simple program that lights an LED when a button is pushed.

2.2.2 Phone User Interface

There are three main parts to the UI:

- Emergency stop: This is an important part of the project that focuses on an essential safety feature. It is one simple button. In the rare case that the RC car goes off track or is enroute to colliding with someone/something, this button can be used to cut power and force the car to stop.
- Speed settings: The user can set their desired speed using this feature. Using +/- buttons on the screen, the desired speed can be selected and increased/decreased during the workout.
- Workout time: The time elapsed since the start of the workout will be displayed here for the user to keep track of their progress.
- Current Speed: This is a feedback system that comes from the car's speed sensor. This information is used to keep track of the functionality of the RC car. It will be used to check whether the car is actually moving at the required speed.

Requirement	Verification
1. Sends a stop signal to the car when the button is pressed. 2. Accurately sends the required speed value. 3. Accurately displays time elapsed.	A. Measure time elapsed against a stopwatch.

2.3 Motor Controls

2.3.1 Motor Driver

We are implementing a single direction brushed motor control module in order to control the DC motor on the RC car. The motor driver controller will have a PWM signal from the microcontroller and amplify it to send to the motor. We will use MOSFET DMTH4008LFDFWQ which can handle up to 40V and 11.6A.

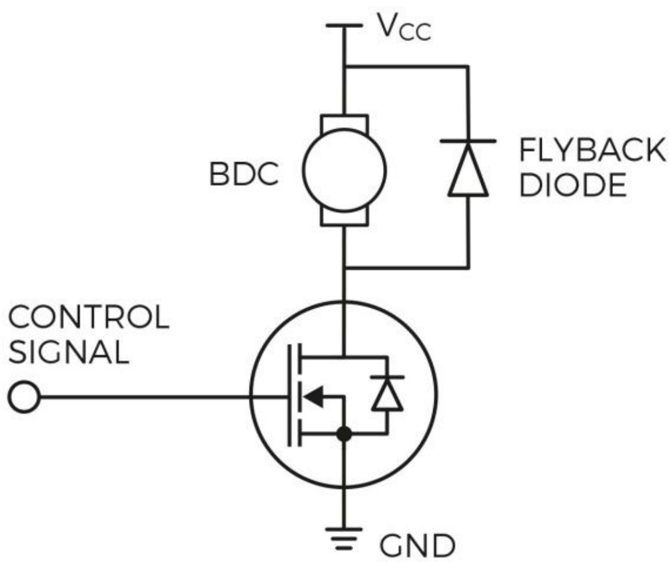

Figure 7. Circuit Diagram for motor driver module [6]

Requirement	Verification
1. Drives the robot at a speed setting defined by the user within an accuracy of 5% 2. Can operate at any speed between 0 and 10mph (0 - 1681 rpm on a 2 inch diameter wheel) 3. The robot's wheels will be able to turn in order to correct it's path	1,2,3. A. Set the speed of a robot and put it on a treadmill with matching speed B. Compare the speed of the robot with the treadmill, and ensure that the robot is neither too fast nor too slow C. A sample line will be setup that the car can follow in order to ensure that the motor servos can turn and follow the line

2.3.1 Motor Servo

The servo motor that came with the RC car originally will be used in order to turn the wheels so that the robot itself is able to turn and follow a track. This servo will need to be disconnected from the original wiring and wired onto our control circuit instead. The details of the servo are not listed on the page for the RC car itself, so the maximum PWM and circuit will be tested by wiring it up to an oscilloscope and looking at the waves when different inputs are put into the original RC controller.

Requirement	Verification
1. The robot's wheels will be able to turn in order to correct it's path	1. Set up a trial race track with a white line for the robot to follow to ensure that the servos are correctly turning the vehicle in the desired direction

2.4 Power Distribution

Our power distribution system consists of a rechargeable battery and a step down converter. The 5V source from the step down converter will be sent to power the arduino, IR sensors, speed sensor, etc.

2.4.1 LiPo Battery

A 7.4V 850mah LiPo battery will power our robot. The battery will be connected directly to the voltage regulator. The voltage on the battery will vary between 8.4 and 7.0 volts depending on the charge the battery is holding. We will utilize the existing voltage sensor on the RC car to power the car off when the battery is discharged. The battery is removable and rechargeable via an external USB charger. We will prototype the robot with this battery and upgrade to a larger battery later in order to meet our design requirements.

Requirement	**Verification**
1. Powers the robot for 20 minutes at 6mph	A. Fully charge the battery via external charger B. Set the speed to 6mph in the user interface C. Place the car on the track and let it run until it runs out of battery. Record the amount of time it runs for.

2.4.1 Voltage Regulator

The AMS1117 LDO will be used to step down the voltage from the battery to 5V used by our microprocessor.

Requirement	**Verification**
1. Produces 5V on the output for the entire voltage range of the battery (7.0 - 8.4 V) 2. Able to draw 500 mA without issues	A. Connect a test circuit that draws 500mA and adjust the voltage from 7 to 8.4 V

2.5 IR Sensors

The sensor used here will be the SEN-11769 ROHS. It has the ability to detect lines and nearby objects. The sensor has an IR LED and uses the light reflected from this LED to detect lines or objects . It will mainly be used to detect changes from white to a darker color. This sensor will communicate well with the microcontroller to send data to the motor controls to determine the RC car's path. A circuit diagram of the sensor is shown in Figure 8.

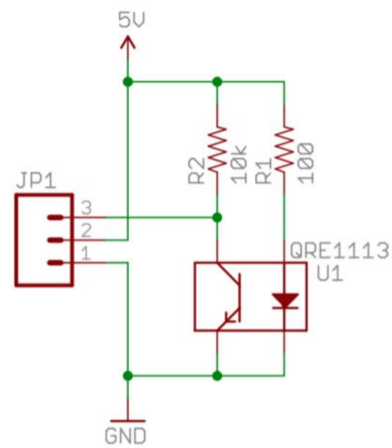

Fig 8. SEN-11769 IR Sensor Circuit Schematic

Requirement	Verification
1. Can differentiate between white and a darker color within a 5mm range.	A. Setup a white tape track to test the sensor by moving it similarly to the RC car.

2.6 Tolerance Analysis

One tolerance that will be critical to maintain is the speed calculated by the hall effect sensor. It is critical that this measured speed be very accurate in order to ensure the user is running very close to their target pace. Our target percent error on the speed is five percent as stated in High Level Requirement 3. This means that when the car is travelling at its maximum speed of 10mph, the sensor should read between 9.5 and 10.5 mph at all times. Likewise, when traveling at the minimum speed of 1mph, the sensor should read between 0.95 and 1.05 mph at all times. In order to achieve the requirement listed above, we will calculate the accuracy required by the hall effect sensor. We will assume the hall effect sensor is placed adjacent to a 2 inch diameter wheel with a magnet passing the sensor exactly once for each rotation of the wheel. This means that we will see a pulse from the sensor every time the car travels 6.283 inches (Eq 1.).

$$\text{Circumference} = \pi * D = 2\pi = 6.283 \text{ inches} \quad \text{Eq. 1}$$

To make our calculations easier, we can convert mph to inches per second using the conversion below.

$$1mph = \left(\frac{1\ mile}{hour}\right)\left(\frac{63360\ inch}{mile}\right)\left(\frac{hour}{3600\ sec}\right) = 17.6\ inches/second \quad \text{Eq. 2}$$

Examining the two edge case where the car is traveling 1mph and 10mph, we want the sensor to read a value of 176±8.8 in/sec and 17.6±0.88 in/sec respectively. Now to calculate how often the magnet passes the hall effect sensor, we can divide the circumference of the wheel by the speed of the car.

$$\left(\frac{6.283\ inches}{rotation}\right)\left(\frac{sec}{176\pm8.8\ inch}\right) = 0.0357\pm0.00170\ seconds\ per\ rotation \quad \text{Eq. 3}$$

$$\left(\frac{6.283\ inches}{rotation}\right)\left(\frac{sec}{17.6\pm0.88\ inch}\right) = 0.357\pm0.0170\ seconds\ per\ rotation$$

This means that when the car is travelling at 10mph, the magnet will pass the hall effect sensor every 0.0357 seconds, and the sensor needs to be accurate within 0.00170 seconds. Using Eq. 4, we can see, our system will be running at 29.4 Hz at the max.

$$\left(\frac{1}{0.0357-0.0017\ seconds}\right) = 29.4\ Hz \quad \text{Eq. 4}$$

The DRV5033-Q1 sensor claims it can operate up to 10,000Hz, and our system is well within that range so we are very confident that the sensor will meet our accuracy requirements.

3 Costs

Our labor costs are estimated to be $40/hr and 10 hours/week for 3 people. Since the semester is 16 weeks long, the total labor cost is as follows

$$(\frac{3\ people}{})(\frac{16\ weeks}{})(\frac{\$40}{hour})(\frac{10\ hours}{week})(2.5)\ = \$48,000 \qquad \text{Eq. 5}$$

The cost of parts is shown in the table below

Part	Cost
DEERC RC Cars 9300 High Speed Remote Control Car	$ 79.99
HC - 05 Bluetooth module	$ 7.99
SparkFun RedBot Sensor - Line Follower	$ 2.80 x 10
DRV5033-Q1 Hall Effect Sensor	$ 0.73
ATmega328P Microcontroller	$ 2.29
DMTH4008LFDFWQ Mosfet	$ 0.64
Total	$119.64

Adding up the parts cost along with the labor costs brings our total project cost to $48,000 + $119.64 = $48,119.64

4 Schedule

Week	David	Ben	Gaurav
3/8/21	Write speed sensor code, finalize prototype with machine shop	Learn basic android studio	Learn basic android studio
3/15/21	Prototype PCB	prototype PCB for Motor Controller	Create basic UI for app
3/22/21	Finalize PCB, create and test speed sensor	Interface bluetooth with android app	Work on interfacing app and bluetooth module
3/29/21	Develop PID control system	Develop PID control system	Create modules for emergency stop and speed input
4/5/21	Test control system	Test communication between app and control system	Test interface in controlled environment
4/12/21	Debug and test car on track	Debug and test car on track	Debug and test car on track
4/19/21	Final debugging and testing	Final debugging and testing	Final testing for Demo
4/26/21	Prepare for final presentation	Prepare for final presentation	Prepare for final presentation
5/3/21	Finish final paper, final presentation	Finish final paper, final presentation	Finish final paper, final presentation

5 Safety and Ethics

There are inherent risks to having a project which utilizes its own power system. The biggest is the method we store power for the operation of our robot. We chose to use a Lithium-Ion battery, however, these batteries come with inherent risks if precautions are not taken [7]. Lithium-ion batteries may explode if handled improperly. In order to reduce risks, we will test our charging circuit to ensure that the battery does not achieve voltages above manufacturer specifications. The battery will be placed in such a way that padding will reduce impact if the robot were to run into objects or people, in order to prevent damages due to physical impact. Other problems may arise if the battery reaches extreme temperatures which may lead to battery failure or fire. In order to mitigate this risk, we will monitor the temperature of the battery to ensure that the temperature does not exceed 45°C. Charging the battery at very low temperatures may also lead to battery damage. A warning will be posted telling customers not to charge the batteries at low temperatures.

Although the design is autonomous, it will not utilize machine learning or artificial intelligence, instead it will solely rely on predefined use cases. However, this is still an autonomous vehicle and we must mitigate harm [8]. The biggest consideration is to prevent the vehicle from running into other people that are also running on the track. To do this, we implement ultrasonic sensors to signal the robot to stop if it detects anything within 2 meters in front of it. Other measures that we took were to add a stop function to the phone app

We will follow IEEE's code of ethics #1: "To uphold the highest standards of integrity, responsible behavior …" [9]. In doing so we must try to mitigate inherent risks of autonomous vehicles and reduce the chance of injury as much as possible.

Citations

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