ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Infineon's Robotic Car

Team #30

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1 Introduction

1.1 Challenge

Infineon's PSoC6 is a dual core, ultra-low-power MCU with 2MB flash, 1MB RAM, and up to 150MHz designed for IoT usage, according to the datasheet [1] but doesn't have a device that showcases the MCU's capabilities.

1.2 Background

Infineon has been developing microcontrollers for many years [2], with over eight families dedicated to different users. In 2016, Cypress (now under Infineon) had also asked a ECE 445 team to design a line following robot car before. However, Infineon had developed newer modules and hopes to have a robot that could demonstrate the machine learning capabilities of the new PSoC6 MCU.

1.3 Solution

We aim to build a two-wheeled robotic car with object detection capabilities that will be able to follow a taped line while recognizing voice commands to control its speed while not compromising the line following objective and also avoid obstacles placed on the line during real time using mostly Infineon products.

1.4 Visual Aid

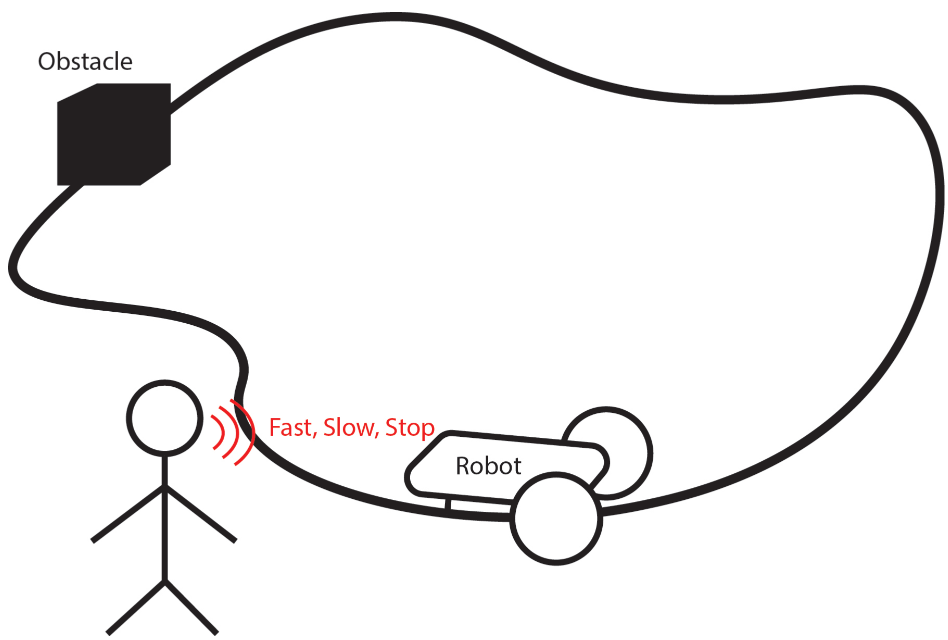

Figure 1: Prospective Demo

1.5 High Level Requirements

1. Voice Command: The robot should be able to register one word commands including "Foward", "Reverse", "Stop", "Speed up/down" and translate the commands into the robot's motion with a 90% success rate.
2. Obstacle Avoidance: The radar should recognize obstacles as small as a 5cm cube within 2-10cm to the radar, and turns the robotic car around with a 90% success rate.
3. Line Following: The robotic car should be able to follow a 5m taped track with a minimum radius of curvature of 25cm at up to 70% speed and less than 7.5cm off track with a 90% success rate
4. Speed Control: The control module should be able to control the motor speed continuously from 0-100% with less than 2 seconds of setting time.
5. Battery Life: The onboard rechargeable battery should be able to 15x30x5 cm car (estimated 500g) at 90% speed for at least 10 minutes.

2 Design

2.1 Block Diagram

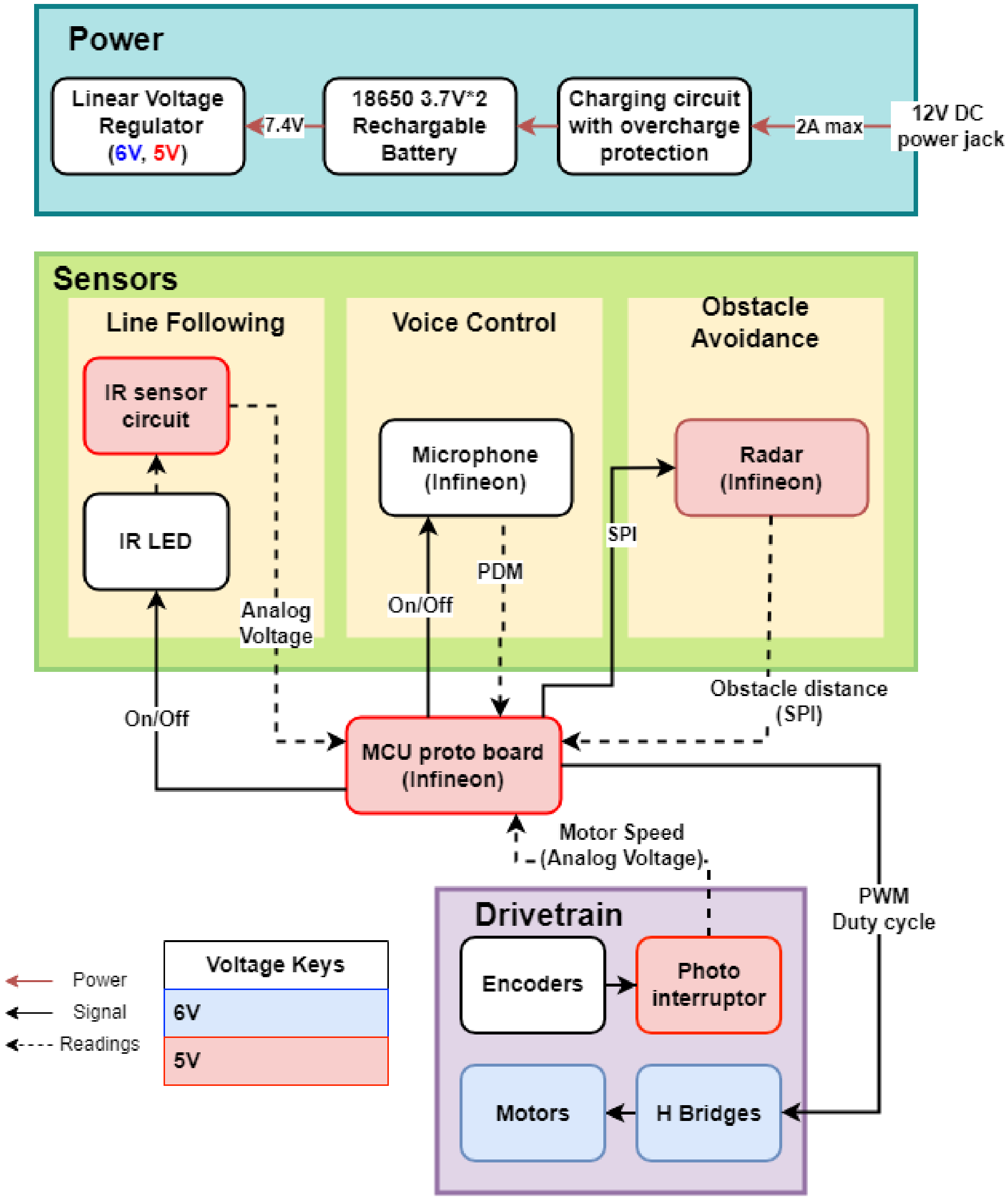

Figure 2: Block Diagram

2.2 Physical Design

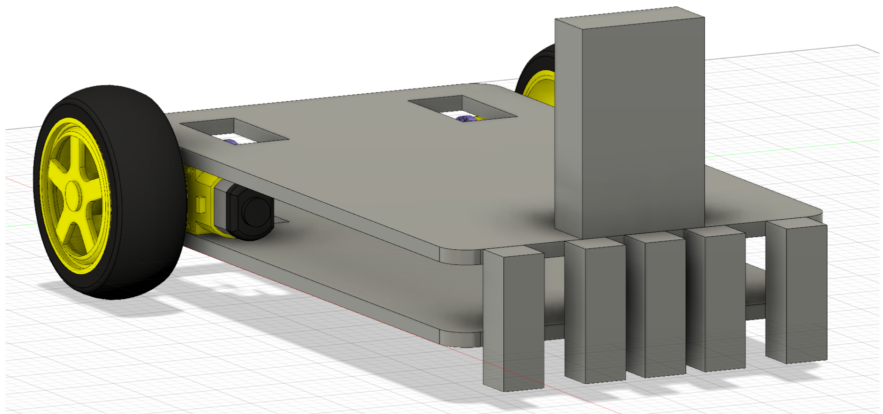

Figure 3: Physical Design of Robot Car

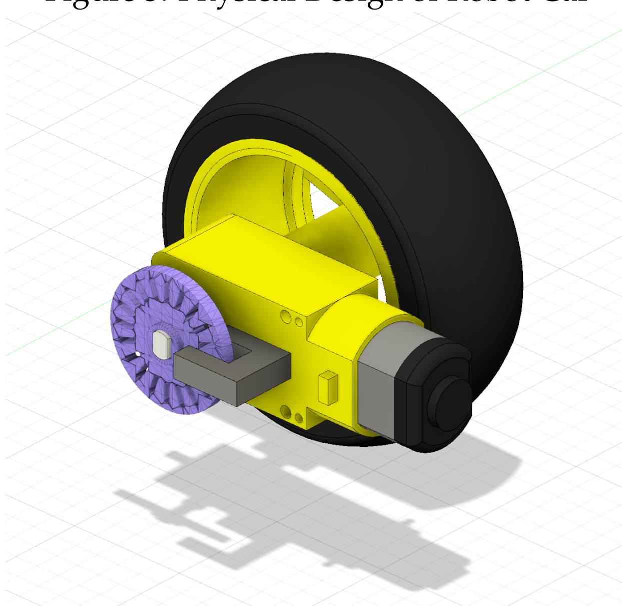

Figure 4: Motor with photo interrupter

2.3 Flow Chart

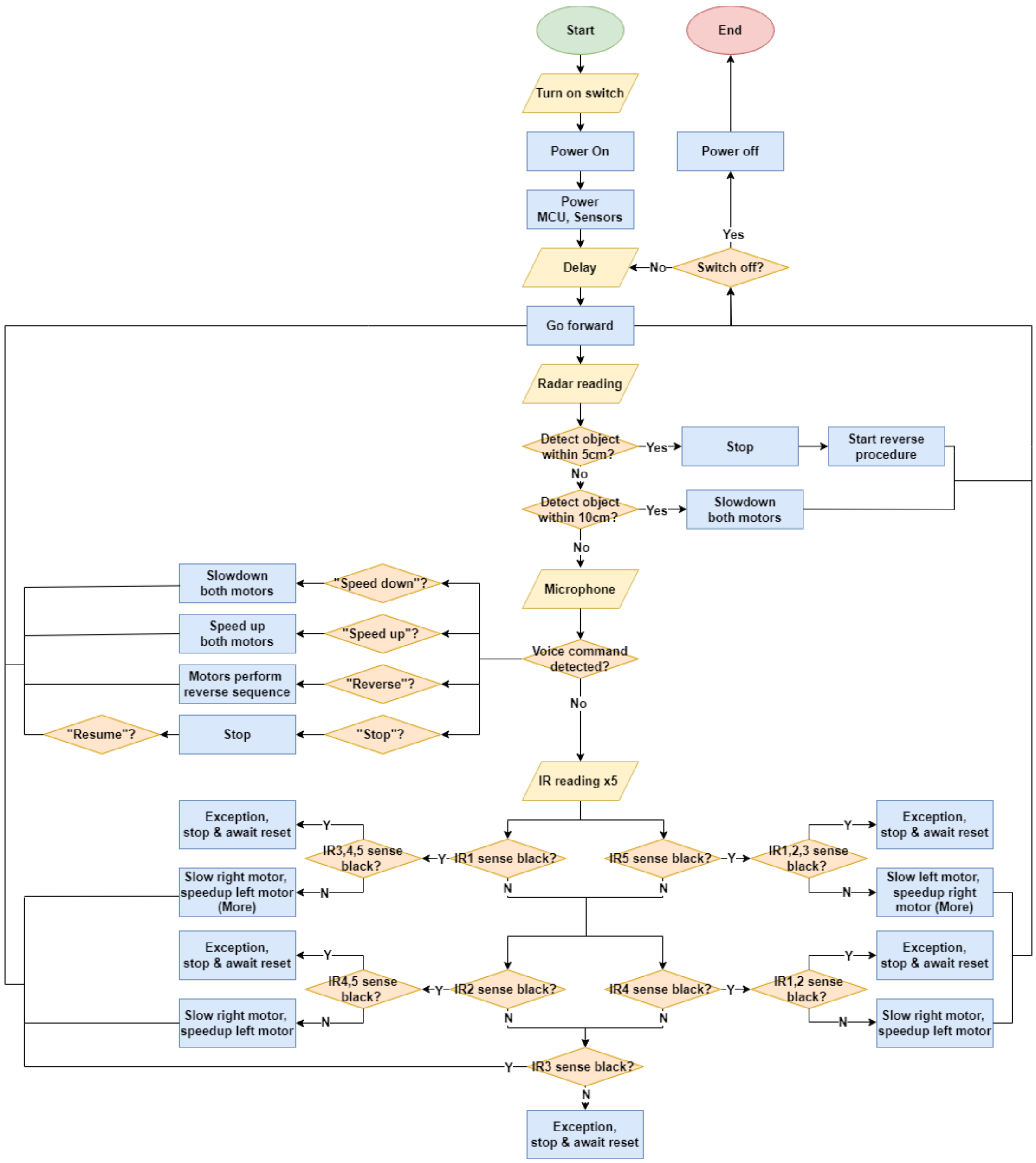

Figure 5: Flow Chart of System

2.4 Power Subsystem

Our power comes from two 3.7 V lithium ion rechargeable batteries connected in series to achieve a total voltage output of 7.4 V, which goes through a number of preset voltage regulators to output the required voltage and current for all the electronic components. The two batteries can be recharged with a typical USB charger.

2.4.1 Rechargeable Battery

To only use linear step down regulators, we require a battery capable of providing 6 V at at least 3 Amps for power to all the different components.

If we were to use a lower voltage battery, we would have to use step-up/boost converters that would add unnecessary complexity to our design.

To meet these requirements, we decided to use two 3.7 V lithium ion rechargeable batteries connected in series. In particular, the INR-18650-P28A perfectly suits our needs as it outputs 3.7 V at maximum 35 A with a total capacity of 2800 mAh according to the datasheet [3]. The rest of the characteristics can be found in Figure 6 below.

Capacity	Typical	2800 mAh 10.3 Wh
	Minimum	2600 mAh 9.56 Wh
Cell Voltage	Nominal	3.6 V
	Charge	4.2 V
	Discharge	2.5 V
Charge Current	Standard	2.8 A
	Maximum	6.0 A
Charge Time	Standard	1.5 hr
Discharge Current	Maximum	35 A
Internal Resistance	AC (1 KHz)	20 mΩ (Max)
	DC (10A/1s)	20 mΩ
Ambient Temperature	Charge	0°C to 60°C
	Discharge	-40°C to 60°C
Energy Density	Volumetric	610 Wh/l
	Gravimetric	220 Wh/kg

Figure 6: INR-18650-P28A Cell Characteristics
[3]

The dimensions of the battery is ideal for our purpose as it is cylindrical in shape, with a diameter of 18.6 mm and a height of 65.2 mm, weighing a total of 46 grams. Two batteries in series would increase the total height to 130.4 mm which would take up very little space on our PCB.

The charge time for the battery is extremely fast, being only 1 hour when supplying it with just 1.3 V at 2.8 Amps, and only half an hour when supplying it with 2.8 V at 5.6 Amps according to Figure 7 below.

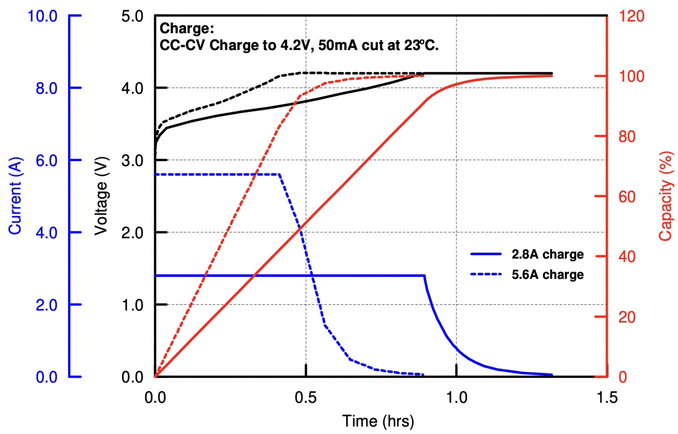

Figure 7: INR-18650-P28A Charge Rate Characteristics
[3]

Drawing a maximum voltage of 3.7 V at 3 Amps from the battery which has a total capacity of 2.8Ah, we can get approximately 55 minutes out of the battery before it is completely depleted and reaches its cut-off voltage of 2.5 V. This is quite impressive since we will not be running the DC motors at max power most of time. The discharge voltage of the battery also stays steady at around 3.7 V when 2.8 Amps is drawn from its entire capacity as shown in Figure 8 below.

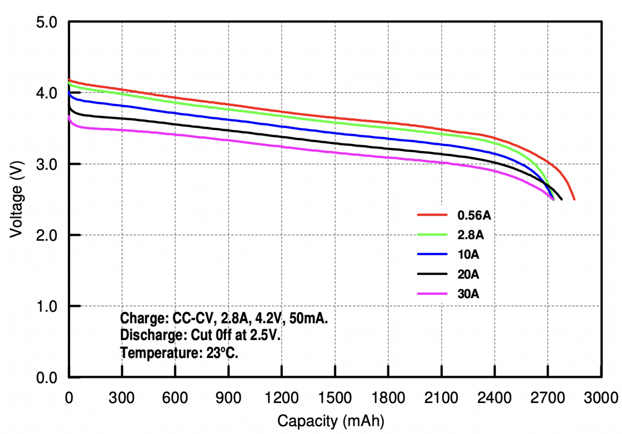

Figure 8: INR-18650-P28A Discharge Rate Characteristics
[3]

2.4.2 Battery Holder

To put our batteries on our PCB close to the components that draw power from it, we require mounts to place them on the PCB. To suit our needs, we chose the 1043P Battery holder module from Keystone Electronics, pictured in Figure 9 mainly because of two reasons. It is through hole mountable which is much easier to solder on to our PCB and uses THM Polarized contacts to ensure that the battery is placed in the correct orientation with its polarity matching every time. The holder can accommodate a battery with a diameter of up to 20.7 mm and height of up to 68.9 mm according to the datasheet [4] and hence, should not have any issues accommodating an INR-18650-P28A battery.

Figure 9: 1043P Battery Holder
[4]

2.4.3 Battery Management IC

To charge the batteries when they are depleted, a battery management system is required to allow safe charging and discharging of the two batteries. These safety concerns include over-voltage protection, over-current protection, over-temperature protection, under-voltage protection, and under-current protection among others. These concerns are valid because they could lead to a wide range of problems, from some that are minor inconveniences such as lowering the overall battery capacity, to others that pose major health risks such as a battery explosion.

To meet our safety requirements while also ensuring high capabilities in charging and discharging speeds, we chose the LTC4006EGN-6 for 2-Cell Series Lithium-Ion Battery since it meets our safety concerns while also including a number of additional features such as Built-In Charge Termination with Automatic Restart, High Conversion Efficiency: Up to 96%, A wide Input Voltage Range from 6V to 28V, Programmable Charge Current and Indicator Outputs for Charging among others as mentioned in the datasheet [5]. For our application, it would be in the standalone mode and we can easily configure the pins of the IC to charge the batteries at 8.4 V at 2 A which means that each battery would get 4.2 V and 2 A which would lead to a full charge very quickly. Since we will only be using the LTC4006 to charge the batteries, we will use the typical application circuit as seen in Figure 10 below.

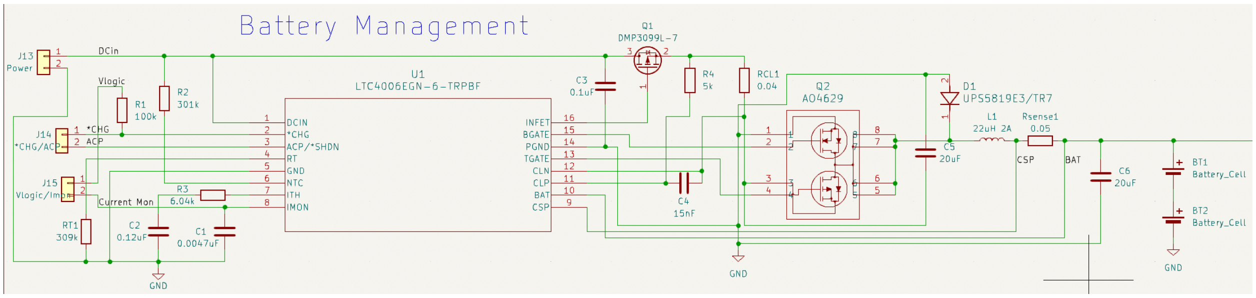

Figure 10: Schematic for Battery Charging

2.4.4 Voltage Regulator

For our different modules, we need to supply the correct voltages to the MCU and the motors. Our batteries can only supply a fixed 7.4 V at 3 Amps while the MCU requires 5 V at 3 Amps and each DC motor requires a maximum of 6 V at 1.5 Amps. To meet the power requirements of our two subsystems, voltage regulators are needed to convert the fixed input voltage to our varying output voltages.

For the MCU, we chose the MIC29300-5.0WU-TR linear voltage regulator as it is capable of converting a varying input voltage to a fixed 5 V at 3 Amps output voltage and current as per the datasheet [6] which fulfills the power requirements of our MCU.

For the motors, we chose the L7806ABV linear voltage regulator as it is capable of converting a varying input voltage to a fixed 6 V at 1.5 Amps output voltage and current as per the datasheet [7] which fulfills the power requirements of each DC motor.

We would use the typical application circuit for fixed voltage regulation pictured in Figure 11 below.

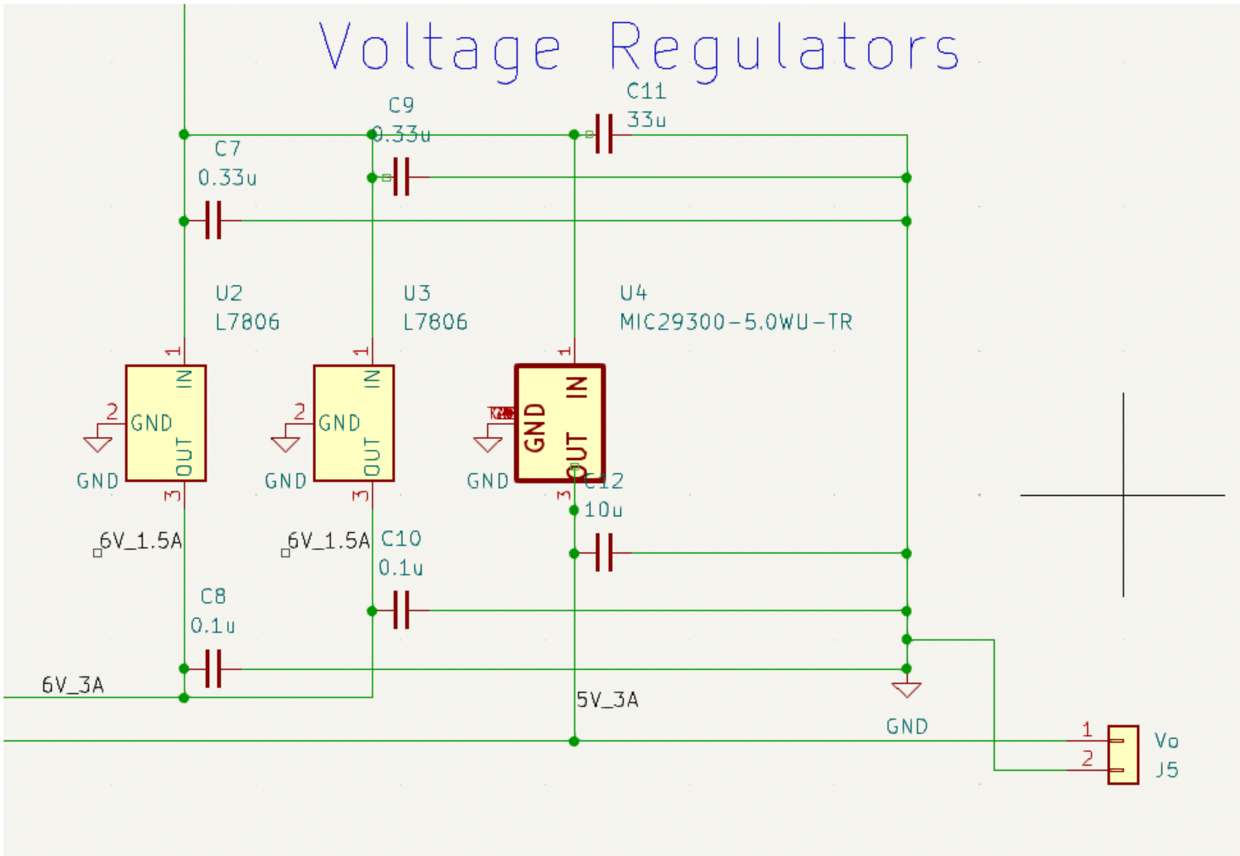

Figure 11: Schematic for Voltage Regulator

2.4.5 Requirements and Verification

Requirements	Verification
• The batteries must be able to reach full capacity when provided with a 5 V (USB) input through the battery management IC and must stop charging once it reaches full capacity. The battery must last at least 50 minutes when the maximum power is continuously drawn from it.	• Ensure that the battery is completely discharged before connecting the 5 V USB input to the battery management IC. • Monitor the input voltage and current being passed from the IC to the battery and ensure that is 8.4 V at 2 A by connecting the input of the battery to an Oscilloscope. • Once the charge is complete, verify that each battery is at 3.7 V and no current is being delivered to the battery with the USB input still connected. Record the time of charge cycle and verify that it is less than an hour. • Apply a 3 A load across the end of both batteries and record the time it takes for the output voltage to fall to 5 V.
• The two different types of voltage regulators should be able to provide the correct corresponding output voltage and current when a load of 3A is applied across each one.	• Connect the batteries to the voltage regulators according to Figure 11 and apply two separate 3 Amp loads across each voltage regulator. • Monitor the battery output voltage with an Oscilloscope and ensure that the voltage stays within the typical 3.6V +/- 0.1. • Monitor the voltage regulators' output voltage with an Oscilloscope and ensure that the voltage stays within the corresponding voltages of 5V +/- 0.1 and 6V +/- 0.1.

2.5 Micro controller Subsystem

The micro controller subsystem would include the PSoC6 MCU and other components on the development board. This is where all the sensor data is sent and control signal outputted. The dev board takes a 5V USB input, which we will be supplying through the batteries. The MCU development board already has built in voltage regulators for 1.8V, 3.3V and 3.6V, which are the voltages the on board components need.

2.5.1 Modus Toolbox

One of the requirements laid out by the pitcher was to use Modus toolbox, the environment Infineon developed to program the MCU. This software uses C, and other than the speed controller we will also need the MCU to be able to do voice recognition based on a trained model on edge. Another function the MCU has to implement would be the digital signal processing of the sensor readings from the radar module. The MCU would also take in analog voltage measurements from IR sensors on whether the car is on the line. In conclusion, the MCU takes the sensor readings and outputs the PWM to control how the car should move.

2.5.2 Requirements and Verification

Requirements	Verification
• The power bus should have a constant voltage without fluctuations more than 5%.	• The power bus should be probed when the motors are in full speed and the modules connected to verify
• As a complex IC chip, the MCU should have the input voltage steadily between 1.7 and 3.6V with +/- 0.1V. The temperature of the MCU should not rise to 85 degrees celsius.	• The power input to the MCU should be probed and the temperature sensors checked after running our program for 20 minutes.

2.6 Sensor Subsystem

2.6.1 Overview

The sensor subsystem includes IR sensors for line following, microphones for voice command, and radar sensors for obstacle avoidance. Output measurements of sensors provide MCU with its current configuration with respect to the environment, which is necessary for the MCU to control the of the robot car.

2.6.2 IR System

IR sensors are used for line following. Each IR sensor unit is composed of an IR LED as transmitter, a photo diode as receiver, and a differential amplifier used as a comparator to produce the analog voltage signal as pictured below in diagram 12.

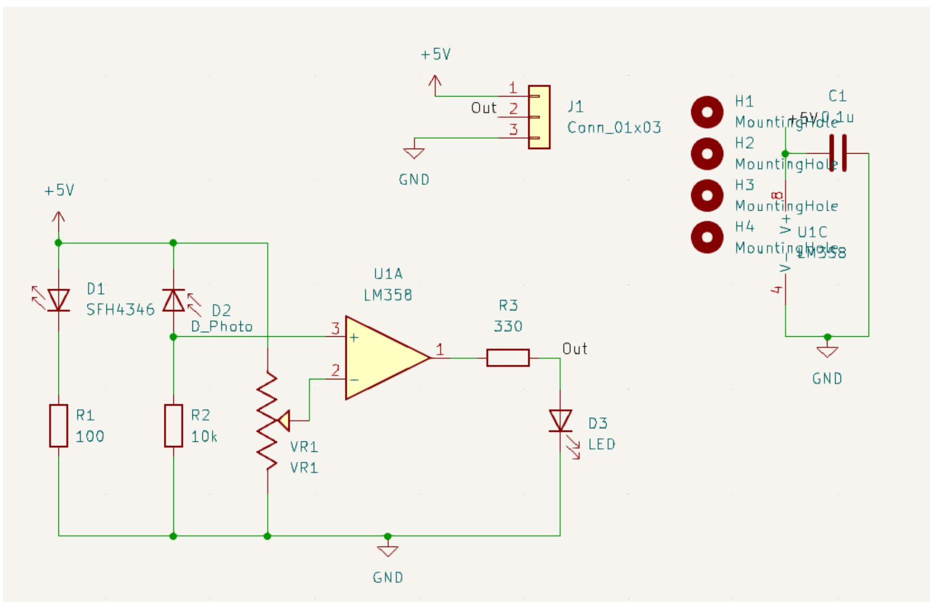

Figure 12: Schematic of IR Sensor Circuit

Output voltage level changes according to the intensity of light detected by photo diode with this equation:

$$V_{out} = A_{OL}(V_+ - V_-)$$

This helps us identify the surface color right below the sensor, since white surface will reflect much more light than black surface. We connect the circuit output to the MCU and set a voltage level threshold to decide whether the sensor is on the black tape or on the white background.

We will place 5 IR sensor units at the front end of our chassis (labeled 1-5 from left to right), with unit 3 at the center and two more on each side 1cm away from each other. For each unit, both the IR LED and receiver will be placed 0.5cm above the ground. Our tape will be 1.9cm in width. When the car is centered on the line, only unit 3 detects black surface while the other four detect white surface. When unit 4 detects black surface, this indicates the car is tilting left. Upon this information, MCU will send a command to the drive train to make a small right turn, in order to control the car back to the center. If unit 5 also detects black surface, this indicates the car is off the center to the left at a large degree. In this situation, MCU will command a large right turn. Vise versa for the car tilting right.

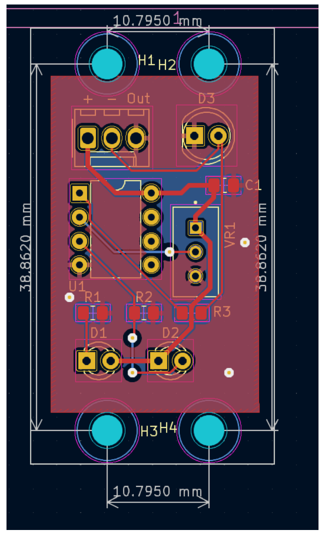

Figure 13: PCB Design of IR Sensor Circuit

2.6.3 Microphone System

The microphone is used for the voice command module. It takes in voice from the commander and outputs a PDM digital signal to the MCU for voice recognition. We are using the two built-in PDM microphones on the CY8CPROTO-062S2-43439 PSoC^{TM} 62S2 Wi-Fi Bluetooth® prototyping kit. It requires a supply voltage between 1.62V - 3.60V, which will be supplied internally by the development board.

The output PDM signal of microphone will be sent to our voice recognition system based on Cyberon Dspotter, a ML-solution to voice trigger and command. In order to achieve the optimize performance, the system has to extract the human voice command even when background noise is present. We identify motor noise as the primary source of noise, since the motors are mounted close to the microphones. If the noise has a significant impact on voice recognition, a digital low pass filter or other DSP methods such as recognizing the noise signal and cancelling it out will be used in the MCU to process the received signal before sending it for voice recognition.

2.6.4 Radar System

To perform obstacle avoidance, the most basic data we need will be the obstacle distance, but the angle of the obstacle might also be useful. Therefore, we chose the BGT60TR13C radar from Infineon, which has 1 TX antenna and 3 RX antennas and has frequency centered around 60 GHz. Figure 14 shows the block diagram for the radar module, which is already implemented in Infineon's radar shield and will be connected to the MCU through a SPI bus. We will power these to send frequency modulated continuous wave (FMCW) signals as shown in figure 15.

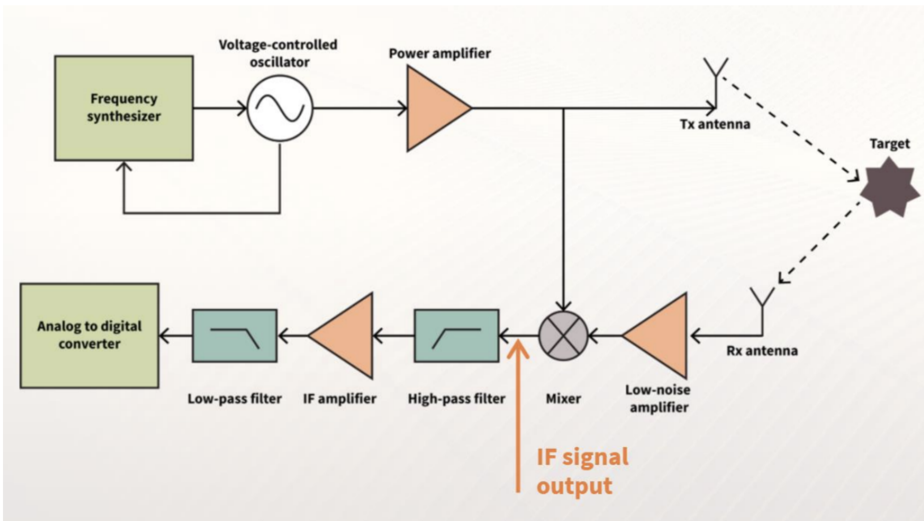

Figure 14: Block diagram of radar module
[8]

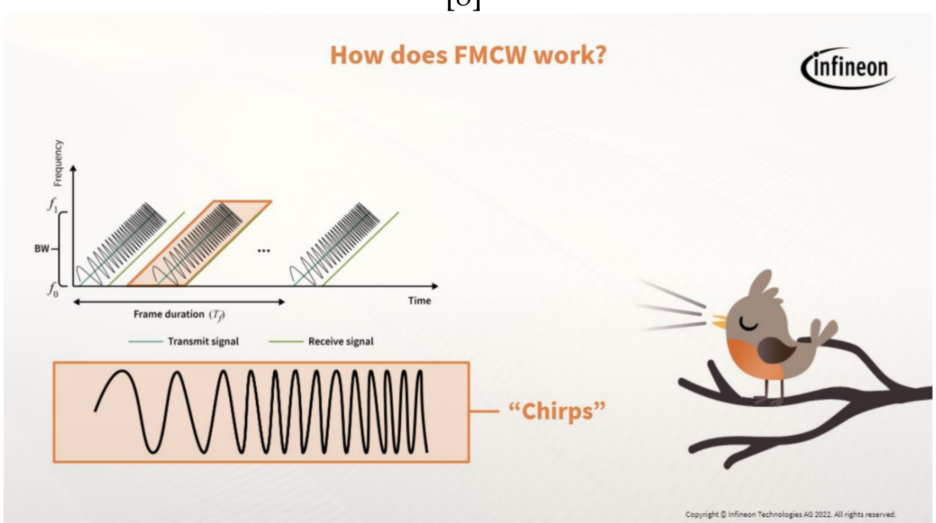

Figure 15: Diagram of FMCW chirps
[8]

By measuring the time delay τ between the transmitted and received signals, we can estimate the distance between the object and the sensor: $D = \frac{\tau}{2c}$. On the other hand, knowing the phase difference between two receiver antennas could tell us the angle as shown in figure 16. We would also be able to calculate the Doppler speed by the difference in frequency of the sent and received signal, but for now that wouldn't be too useful for a stationary target. Also, in most cases the radar would be mounted on a stationary object and detecting other objects, eg. presence sensor, and therefore could be a bit different when attaching it to a fast moving car.

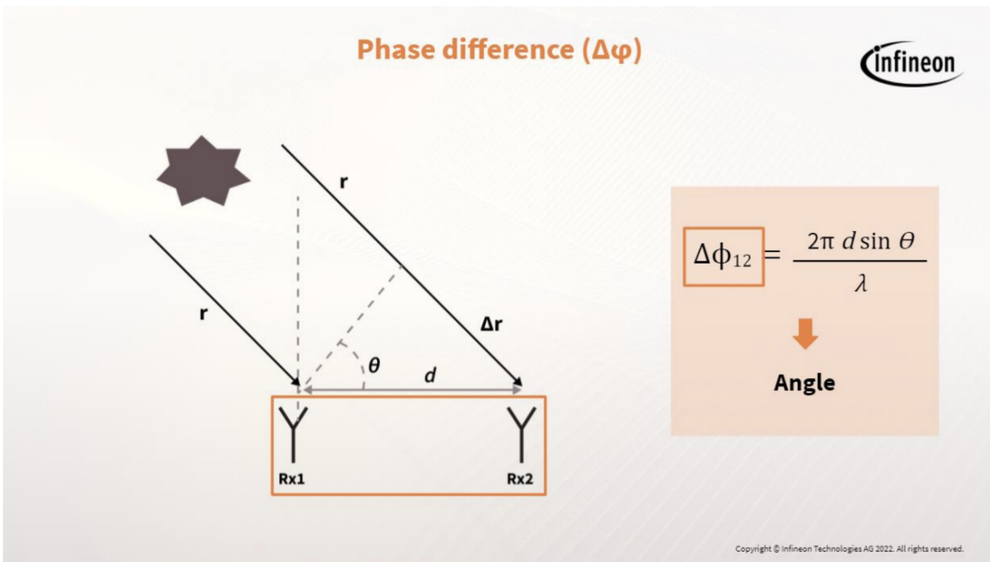

Figure 16: The relationship between phase and the angle
[8]

2.6.5 Requirements and Verification

Requirements	Verification
• Each IR Sensor unit must output voltage above the same threshold voltage of 2 V +/- 0.1 on white surface and output voltage below threshold voltage of 2 V +/- 0.1 on black surface.	• Connect the V_{cc} to 5V and GND to ground. Connect V_{out} to the voltmeter of the Oscilloscope. • Place the IR unit perpendicular and 0.5cm away from the white surface, and make sure the reading on voltmeter is below the threshold voltage. • Place the IR unit perpendicular and 0.5cm away from the black surface, and make sure the reading on voltmeter is above the threshold voltage. • Repeat step 1-3 for all 5 units on the same threshold voltage.
• Microphone able to detect voice command 2m away.	• Connect the Infineon development board to computer with a USB cable through the KitProg3 USB connector. • Program the development board with PSoC™ 6 MCU: PDM-to-PCM example provided in ModusToolbox. • Give voice commands ”Foward”, ”Stop”, ”Speed up”, ”Speed down”, ”Reverse” 2 meters away from the microphone. • Make sure the LED lights up every time a voice command is given, and does not light up when no voice command is given.

Requirements	Verification
• Voice command recognition should be able to recognize the 5 voice commands even when motor noise is present.	• Connect the Infineon development board to 5V power soucre via power cable. • Connect the two motors to 5v power source and place them right by development board. • Run our voice command recognition program and make sure it can identity the voice command with 90% accuracy.
• Radar sensor has to measure the distance of obstacle within 1 meter in the range of $\pm 40°$vertically and horizontally within 5% error rate.	• Connect the radar sensor to the SPI port on the development board. • Connect the development board to the computer. • Run the program for radar module on the development board. • Place obstacle in front of the radar and measure the distance from the obstacle to the radar. • Record the distance reading of the radar sensor and make sure it is within 5% error of the true distance.
• Radar sensor can perform accurate measurement while the sensor is moving.	• Connect the radar sensor to the SPI bus on the development board. • Move the radar toward the obstacle and away from the obstacle while keep track of the measurement reading. • Make sure the measured distance decreases as radar move closer to the obstacle at fixed velocity and check if the readings are roughly linear. • Fix distance to the obstacle (30cm) and walk in a circle with the radar facing the obstacle. Readings should not fluctuate more than 3cm.

2.7 Drive Train Subsystem

The two motors are bidirectional due to the addition of h bridges to allow current to flow in both directions through the motor. A photo interrupter will monitor motor speeds and provide feedback for use with speed modulation. Each individual motor should have variable continuous speed following capabilities from 0-100% based on the control signals from the MCU. It should also be able to rotate in both directions to enable turning.

2.7.1 H-bridge

The H-bridge is the heart of the Drive Train subsystem and is responsible for the behavior of the two DC motors. The H-bridge can configure the motors to achieve four different modes, to coast, to move forward, to reverse, and to brake. The H-bridge can also achieve speed control since it is provided with a Pulse Width Modulated signal from the MCU. The duty cycle of the PWM can be used to achieve varying analogous speed control.

The DC motors require a maximum of 6 V at 1.5 Amps each to run at maximum speed, and hence, when choosing our H-bridge, the maximum current the DC motor will draw, and the stall current, in which the motor needs to initially run, needs to be fulfilled. The H-Bridge that is chosen will need to be rated to handle that much current, otherwise the integrated circuit would burn out.

To meet our DC motor power requirements, we chose the DRV8833PWP Dual H-Bridge Motor Driver chip. The DRV8833PWP is ideal for our requirements because as mentioned in the datasheet [9] it can handle a wide power supply voltage from 2.7 to 10.8V while outputting an average current of 1.5Amps. Since the chip has two H-bridges inside, a single chip can be used to drive both of our DC motors as seen in Figure 17.

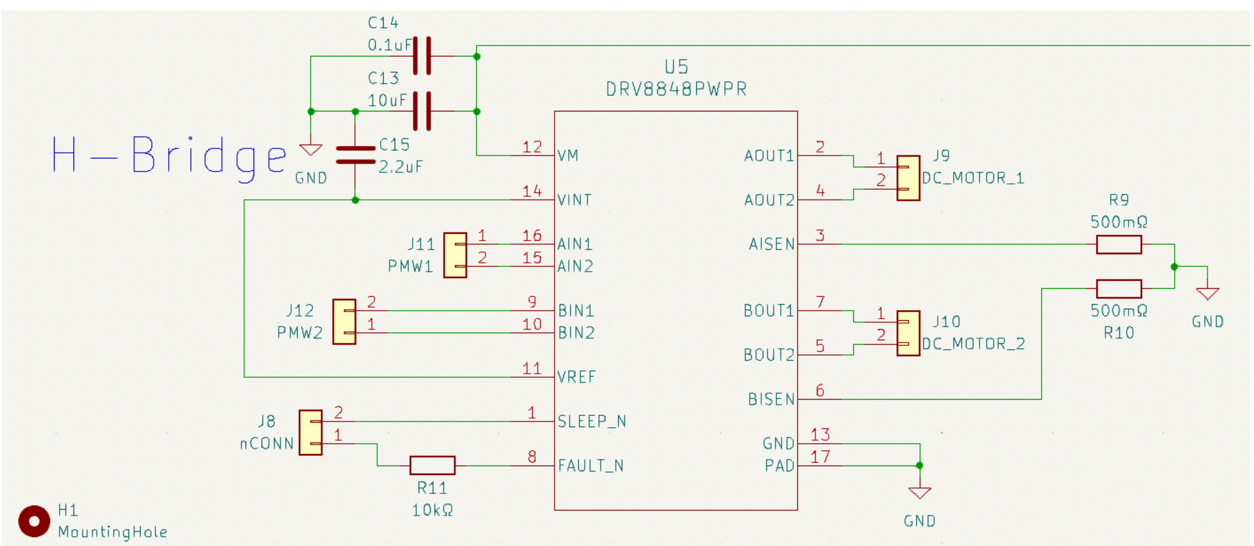

Figure 17: H-bridge Schematic

The AIN1/2 pins control the state of the AOUT1/2 pin which is connected to one DC motor while the BIN1/2 pins control the state of the BOUT1/2 pin which is connected to the other DC motor. The behavior of these xIN1/2 pins is described in Figure 18 below.

xIN1	xIN2	xOUT1	xOUT2	FUNCTION
0	0	Z	Z	Coast/fast decay
0	1	L	H	Reverse
1	0	H	L	Forward
1	1	L	L	Brake/slow decay

Figure 18: H-bridge Logic
[9]

Due to the inductive nature of the DC motors, the current must continue to flow through it even during the OFF time of the duty cycle, this current is known as recirculation current. In addition to the drive modes in Figure 18 the DRV8833PWP can also control the behavior of the recirculation current within the H-bridge to either decay quickly or slowly. A quicker decay mode results in the motor speed slowing down much quicker than that of the slower decay mode. The connections to control the decay modes are described in Figure 19 below.

xIN1	xIN2	FUNCTION
PWM	0	Forward PWM, fast decay
1	PWM	Forward PWM, slow decay
0	PWM	Reverse PWM, fast decay
PWM	1	Reverse PWM, slow decay

Figure 19: PWM Decay control
[9]

Additionally, the DRV8833PWP includes internal shutdown functions for over-current protection, short-circuit protection, under-voltage lockout, and over-temperature protection.

2.7.2 DC Motors

The biggest criteria for choosing the motors are the maximum rpm and maximum torque, as that would determine the car's maximum speed and maximum acceleration. To reduce costs, we wanted to stick with plastic DC TT motors. Out of the plastic TT motors, the highest rpm we could find was 250 without load, and that would be $V_{max} = \frac{250}{60} * \pi * D_{wheels} = 0.85m/s$. The relationship between the maximum torque and the maximum acceleration when the car is moving is as follows:

$$F_{max} = \frac{\tau_{max}}{D_{wheel}} = m_{car} * a_{max} + f_{kinetc}$$

The car would weigh around 500g, with the batteries roughly 100g, the motors another 100g, the chassis a 200g and another 100g for other PCB and modules. Thus, with estimating the kinetic friction coefficient at 0.15 and wanting an acceleration at least $1m/s^2$, the torque would have to be at least 80mNm. The Adafruit 3777 motors have 78 nNm, which is slightly under our expected value, but higher torque models would be a lot pricier and with smaller max rpm.

2.7.3 Photo Interrupter

To ensure that the motors are operating at the desired Revolutions per minute(RPM), speed control feedback is required. Since the DC motors are dual shafted, a Photo Interrupter can be mounted to the shaft that the wheel is not on to monitor the RPM. The Photo interrupter can be divided into three parts, the Encoder, the IR LED, and the IR sensor.

The Encoder is a plastic disc that can be snapped onto the opposite side of the wheel on the DC motor. It has a number of notches, as seen in Figure 20 below to allow light to pass through when it is rotating so as to count the ticks.

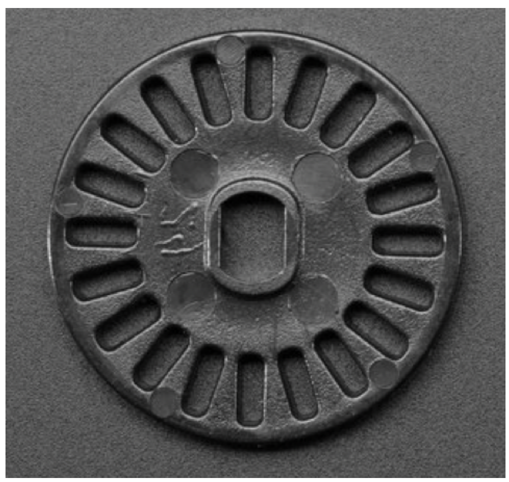

Figure 20: Plastic Encoder

A Photo Detector will be mounted to the encoder as shown in Figure 21 to calculate the rotation ticks. Its working principle is quite simple as it is essentially made up of an LED and a photo detector. Whenever the light from the LED passes through the slits of the encoder, the photo detector gets excited and passes a pulse to the MCU which calculates the actual RPM of the motor.

The photo detector must be able to detect a maximum of 250 RPM since that is the fastest speed that our motors can spin at, and it must also have a gap width of at least 2.55mm since the plastic encoder we use has a diameter of 25.75mm, a thickness of 2.55mm, and a weight of 1g as per the datasheet [11].

According to the above requirements, we chose the LTH-301-07 because as per the datasheet [12], it has a total response time of about 3.5 μs, while the minimum required response

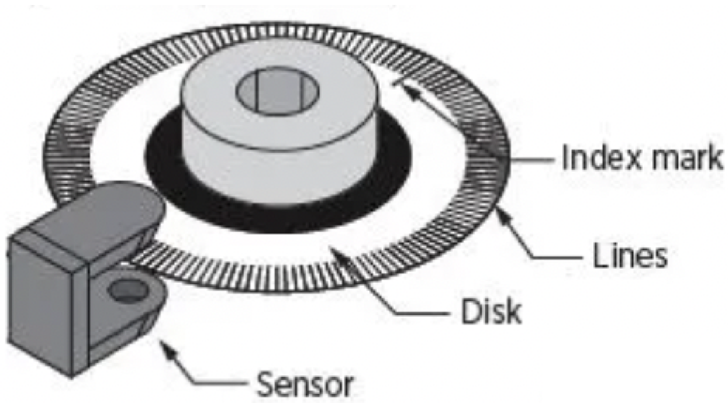

Figure 21: Photo Detector with Encoder
[10]

time would be around 6.25 ms as per the following calculation:

$$250\frac{rotations}{minute} = 4\frac{rotations}{sec}$$

The number of slits on the encoder is 20, and when we count the opaque parts between the slits of our encoder, we get a total of 40 possible ticks, and hence our total required measurement comes to:

$$4\frac{rotations}{sec} * 40 = 160\frac{rotations}{sec}$$

And hence, our response time per rotation is:

$$\frac{1}{160\frac{rotations}{sec}} = 6.25ms$$

The gap between the IR LED and the IR sensor according to the datasheet [12] is 5.08 mm which is more than the thickness of the encoder.

The schematic of the photo detector is quite trivial as per Figure 22 since it is only made up of two resistors, an LED, and a photo sensor and according to the datasheet [12], with the suggested LED current = 20 mA and LED voltage = 1.1 V, when Vcc = 5 V, we can choose R1 = 180 Ω and R2 = 2.2 kΩ and we will get safe operation. The total current will be 22 mA for our photo interrupter. Further tweaking the values of the resistors can further reduce the total current to as low as 0.4 mA [13].

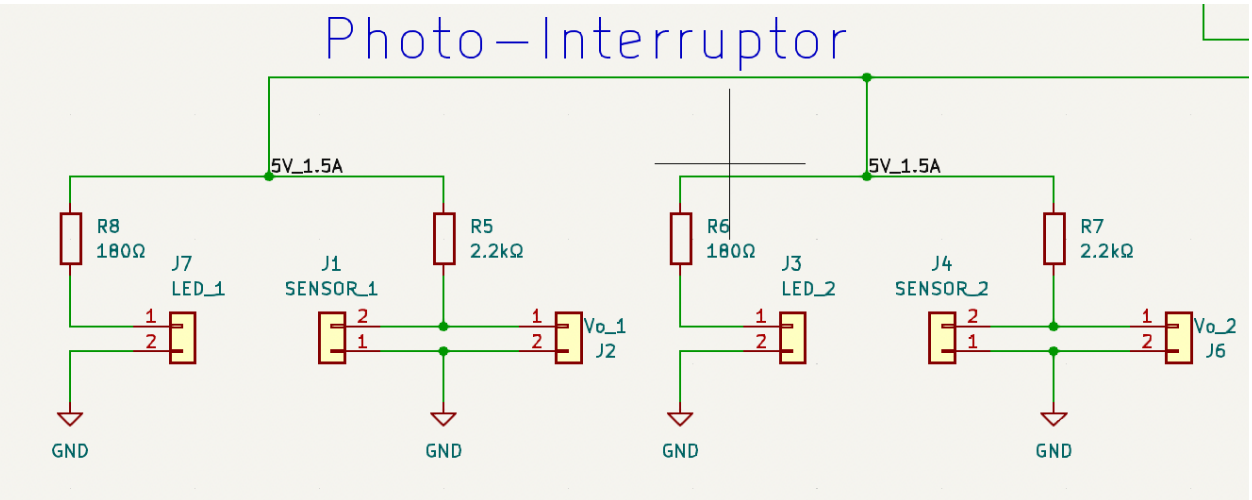

Figure 22: Photointerrupter Schematic

2.7.4 Speed Feedback Control

As there will be friction and a load on the motors, and we will also need speed that closely follows our reference speed for good line following performance, a feedback control loop would be needed. Figure 23 below shows the control diagram.

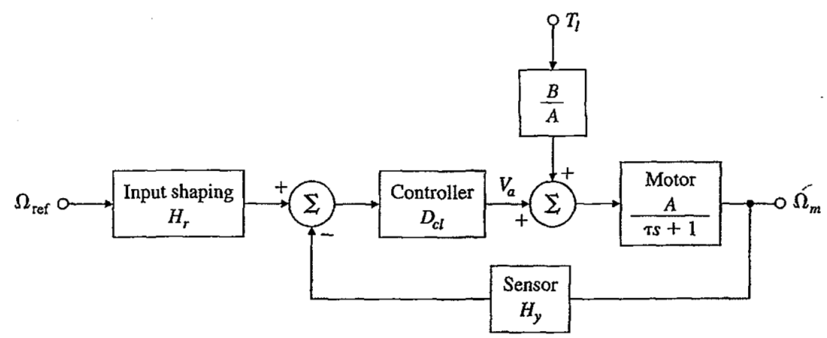

Figure 23: Feedback control diagram with load
[14]

For our controller, we will most likely use a PID controller, which would allow us to reject disturbances and improve the time response. The controller will be implemented by the MCU, which would be in the following form:

$$k_P * e(t) + k_I * \int_0 te(t) + k_D * \dot{e}(t)$$

The proportional term is rather easily implemented, the integral part would be the accumulation of previous errors which can be done using +=, while also putting upper and lower caps on the error that is added to prevent integral windup from significant errors. The integral part just requires the error from the previous time step to subtract from the current error. We then add the calculated efforts to the current PWM duty cycle, keeping in mind the the PWM duty cycle should be capped both at a max around 100% and a low that would be determined through experiment. To actually find the gain constants k_P, k_I, k_D, we would use Simulink in MATLAB to simulate the unit step response and tune the gain until we have a satisfactory rise time, overshoot, and settling time. Rise time describes the time it takes for the unit step response to reach 90% of the reference, which would be related to how fast the car can actually turn. The overshoot would describe the the maximum output reached in terms of the reference, which other than having the potential of damaging the motors, would also cause the car to make too big turns and could become difficult to stay on the center of the line. The settling time describes how much time it takes for the response to become steady, which would also be important when following a straight line. To have a set of gains that fits all three criteria could be challenging, thus we could implement two separate controllers, one for making turns and the other for going straight and staying on the center. However, to do so, we would need to obtain the model for the motors and the constant load. This can be done through experiment, characterizing the motor and also the friction coefficient of the wheel and the surface. Upon finding a satisfactory gain, we can then put those into the MCU and test the performance physically.

2.7.5 Requirements and Verification

Requirements	Verification
• The H bridge must be able to switch between the 4 modes, coast, reverse, forward and brake.	• Connect the Vcc to 5V and GND pins. Connect the xIN1/2 pins to the voltage supply of the Oscilloscope and pass in a constant 3.3 V. Connect the xOUT1/2 pins to the voltmeter of the Oscilloscope. • Ensure that for the 4 variations of input according to Figure 18, the output matches as well on the Oscilloscope.
• The H bridge must be able to handle the rated 1.5 Amps and 6V required by both motors when they run at full speed.	• Connect the h-bridge to a supply of 6V and 3 Amps and connect both motors to it according to Figure 17 • Monitor the supply voltage to the H bridge and the output voltages to both motors, pins xOUT1/2. • Ensure that the H bridge does not overheat during operation and that the entirety of supply voltage is transmitted to the outputs when a PWM cycle of 100% is passed to the H bridge.

Requirements	Verification
• The decay within the H-bridges should be controllable and distinct between the two modes of fast decay and slow decay.	• Connect the Vcc to 5V and GND pins. Connect the xIN1/2 pin to the voltage supply of the Oscilloscope and pass in a constant/50% duty cycle of 3.3 V or GND. Connect the xOUT1/2 pins to the voltmeter of the Oscilloscope. • Ensure that for the 4 variations of input according to Figure 19, the output matches as well on the Oscilloscope.
• The speed sensors' response time should be continuously outputting and updating the tick signal at least fast enough to capture 250 RPM.	• At steady motor speed, the speed sensors should output the ticks corresponding to the correct speed which is RPM*40 ticks per rotation (+/- 5 RPM)
• The DC motor should go up to 180 RPM with load at max power to reach a speed of 0.6m/s	• Power the motor at 6V and 100% duty cycle. Check the max current drawn on an oscilloscopes. • With the chassis assembled, let the wheels run at full speed for 5 seconds and measure the distance travelled.
• The photo interrupter should be able to detect when an object is placed between the gap.	• Connect the pins of the photo interrupter according to Figure 22, and the output pin to the voltmeter of the Oscilloscope. • Ensure that there is LOW output when nothing is placed in the gap and a HIGH output on the Oscilloscope.

Requirements	Verification
• The photo interrupter's response time should be smaller than 6.25ms to be able to update fast enough to capture 250 RPM.	• Connect the pins of the photo interrupter according to Figure 22, and the output pin to the voltmeter of the Oscilloscope. • Connect the motor with Encoder to a 6 V voltage supply to get maximum rotation of 250 RPM and place the encoder between the sensor. • Ensure that the oscilloscope gets a signal with a frequency of 160 Hz (+/- 5 Hz).
• The controller should ensure that the motors have a rise time <0.7s, overshoot <25%, and settling time of <2s. Steady state speed should be within +- 5 RPM.	• The controller gains would be first determined through simulation • Once a acceptable controller is found, we test it on the physical car and checking the speed through the MCU.

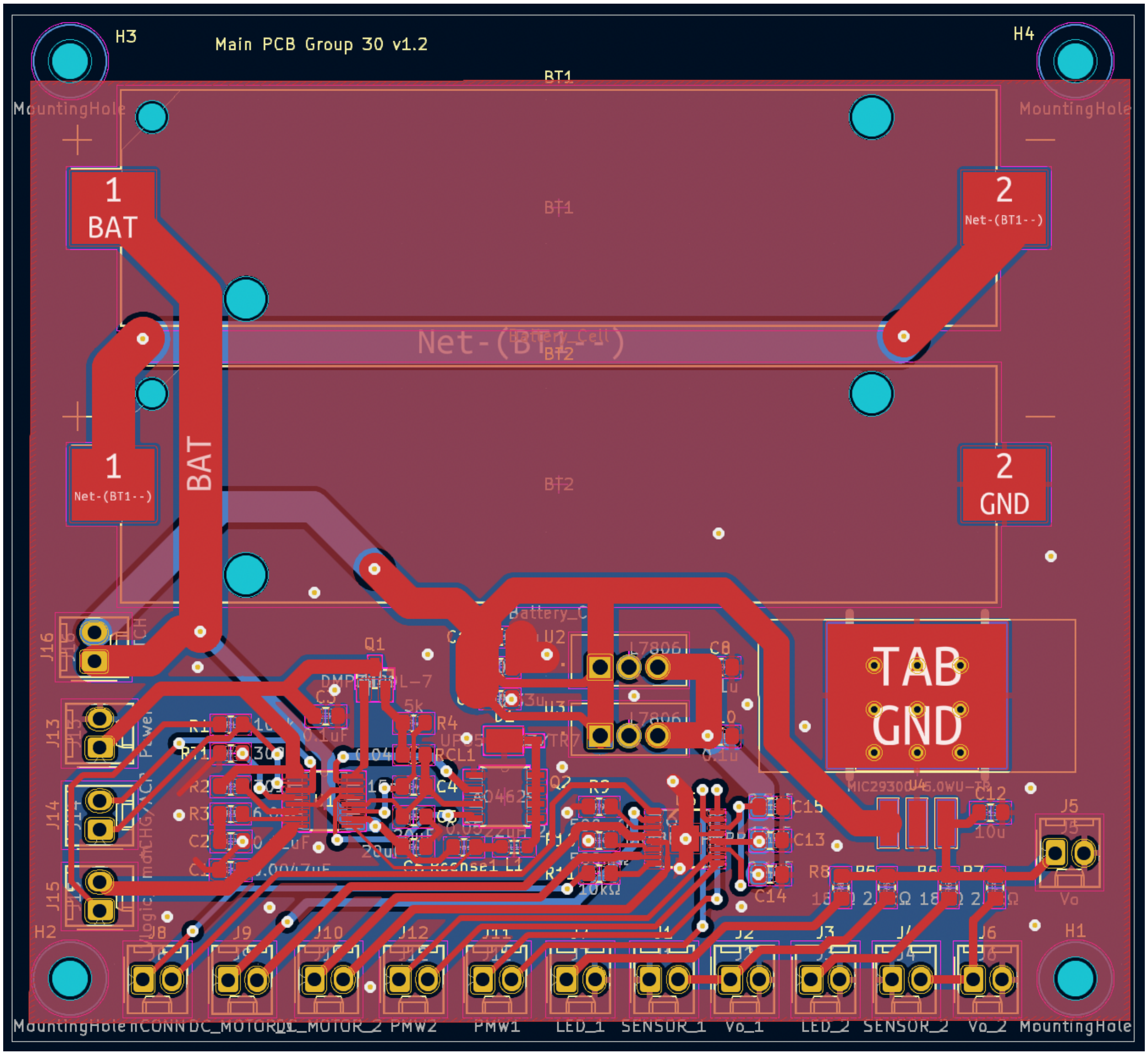

Figure 24: PCB Design of Main Board which Includes the Power and Drive Train Subsystems

2.8 Tolerance Analysis

In order for our car to look cool, it would have to be able to run at high speeds around the taped track without drifting off. We define off track as the moment when the tape is not between the two wheels. The biggest challenge in doing so, would be how fast the car could turn. We saw this as two parts: how much time does it take for the car to start make a observable difference in heading. Assuming the car heads straight without a change in speed before the car starts to turn, this time constraint t_{max} can be determined from how much distance the car can travel straight without being determined as off track. From the figure shown below, we first find the condition where the car is just about to be off track:

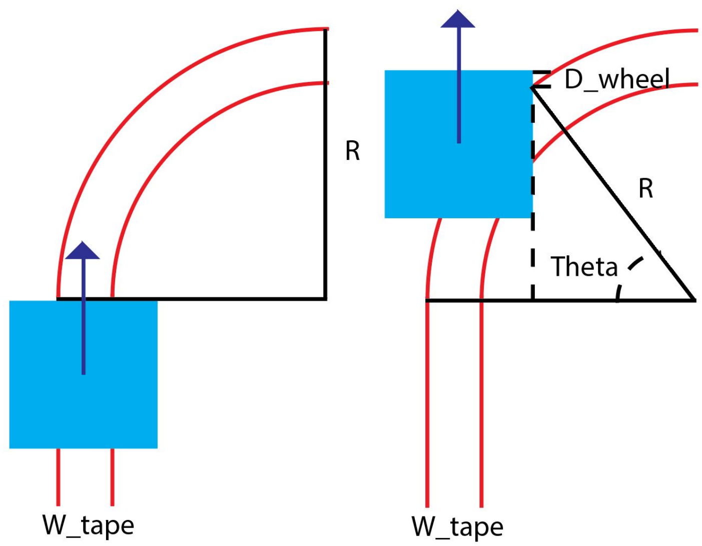

Figure 25: Off-track diagram

$$Rcos(\theta) = R - \frac{w_{tape}}{2} - \frac{w_{car}}{2}$$

We can express θ in terms of the other constants:

$$\theta = arccos(1 - \frac{w_{tape}}{2R} - \frac{w_{car}}{2R})$$

Then looking at the vertical distance, we can express the distance the car can travel before having to make a observable change in heading as $D_{max} = Rsin(\theta) + D_{wheel}$. We divide by the velocity of the car to get the maximum time before the car's heading has to change: $\frac{Rsin(\theta)+D_{wheel}}{V_{car}}$. Assuming the car motors have a angular frequency of 100rpm in a straight line, we find the velocity $V_{car} = \frac{100}{60} * \pi * 2 * R_{wheel} = 35cm/s$. For calculations, we set our goal as making a $R = 25cm$ turn, we can finally arrive that $D_{max} = 23.7cm/s$ and $t_{max} \approx 0.7s$.

Let's discuss what takes up this time. The time between the track starting to turn and the center-right IR sensor entering the area of the tape would be in milliseconds, which is negligible. The time between the photo-resistor entering the area of the tape and the photo-resistor picking up a change in current would also be negligible as the sensor would be a few cm above the tape and the light travels in light speed. The time it takes for the MCU to register the change would also be negligible as the ADC has a 2Msps. The MCU would also output an updated reference speed to the speed control almost instantaneous. Therefore, the majority of the time would be used for the motors to actually follow the reference speed change. Therefore, in this scenario we would want our controller and motor to have a rise time of around 0.7 sec. As compensation for the rather small rise time, we could tolerate a 25% overshoot, as the motors should be well under their max rpm rated at 250. In a scenario where the motor runs on 150rpm on straight lines, we find that $V_{car} = 51cm/s$ and $t_{max} \approx 0.47s$

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Each group member will be expected to work around 2.5 hours per day over a 50 day period on the project with a salary of $42/hr.

$$\$42/hr * 2.5 * 50 = \$4,200$$

For 3 group members, the total labor cost will come up to $12,600.

3.1.2 Parts

Description	Manufacturer	Part Number	Quantity	Extended Price
PSoC 62S2 Wi-Fi Bluetooth Prototyping Kit	Infineon	CY8CPROTO-062S2-43439	1	$56.25
P28A 18650 2800mAh 35A Battery	Molicel	INR-18650-P28A	2	$9.98
BATT HOLDER 18650 1 CELL PC PIN	Keystone Electronics	36-1043P-ND	2	$6.52
IC BATT CHG LI-ION 2CELL 18QFN	Monolithic Power Systems Inc.	1589-MP2672GD-0000-ZCT-ND	1	$2.71
CAP CER 1UF 6.3V X7R 0402	Murata Electronics	490-13339-1-ND	1	$0.10
CAP CER 10UF 16V X5R 0805	Murata Electronics	490-6473-1-ND	2	$0.32
CAP CER 22UF 4V X5R 0603	Murata Electronics	490-5526-1-ND	4	$0.64
CAP CER 0.1UF 6.3V X5R 0201	Murata Electronics	490-3167-1-ND	7	$0.70
RES SMD 30K OHM 0.1% 1/16W 0402	Susumu	RG10P30KBCT-ND	1	$0.48
MP6K000 0.05%	VPG Foil Resistors	MP6K000-ND	1	$0.44
FIXED IND 1.5UH 2.6A 0.06OHM SMD	Murata Electronics	490-10648-1-ND	1	$0.27
IC REG LINEAR 5V 3A TO263-3	Microchip Technology	MIC29300-5.0WU-CT-ND	1	$4.68
IC REG LINEAR 6V 1.5A TO220AB	STMicroelectronics	497-1444-5-ND	2	$1.48
IC MOTOR DRIVER PAR 16HTSSOP	Texas Instruments	296-29394-5-ND	1	$2.96
CAP CER 2.2UF 6.3V X6S 0402	Murata Electronics	490-10012-1-ND	6	$0.60
CAP CER 10000PF 10V X7R 0201	Murata Electronics	490-3194-1-ND	1	$0.10
GEARMOTOR 200 RPM 3-6V DC	Adafruit Industries LLC	1528-2589-ND	2	$5.90
TT MOTOR ENCODER (PACK OF 2)	Adafruit Industries LLC	1528-2615-ND	1	$0.95
SENSOR OPT SLOT PHOTOTRANS MOD	Lite-On Inc.	160-2210-ND	2	$2.36
INFRARED LED	N/A	ILED-8	10	$9.30
Photo Resistor	N/A	PID 161	10	$11.70
LM358N LOW POWER OPERATIONAL AMPLIFIER	N/A	LM358N	7	$6.51
10K SINGLE TURN 1/2WATT TRIMPOT	N/A	3352W-1-103	5	$7.50

Figure 26: List of parts and cost

The total cost for the parts is $132.45. 5% shipping cost adds $6.63 and 10% sales tax adds $13.25 for a total parts cost of $152.33.

3.1.3 Grand Total

Adding the cost of labor and the cost of the various parts, we have a grand total cost of $12752.33.

3.2 Schedule

Week	Task	Person
10/1 - 10/7	Order parts for prototype	Everyone
	Power system prototyping	Wei-Jui
	IR sensor prototyping	Kai-Chieh
	Drive train prototyping	Saharsh
10/8 - 10/14	1st PCB design and order	Everyone
	Radar module testing	Kai-Chieh
	Cyberon ML model testing	Wei-Jui
	Start motor control	Saharsh
10/15 - 10/21	Car assembly and module integration	Everyone
	Finalize motor control	Saharsh
	Voice control implementation	Wei-Jui
	Line following implementation	Kai-Chieh
10/22 - 10/28	Obstacle avoidance implementation	Kai-Chieh
	2nd PCB design and order	Everyone
	Chassis design and 3D print	Wei-Jui
	Advance feature research	Saharsh
10/29 - 11/4	Advance feature design and implementation	Everyone
11/5 - 11/11	Advance feature implementation and testing	Everyone
11/12 - 11/18	Minor bugs fixing and fine tuning	Everyone
11/26 - 12/2	Demo	Everyone

Table 1: Planned schedule

4 Ethics and Safety

4.1 Ethics

As per the IEEE Code of Ethics [15], our design must be developed sustainably and comply with ethical designs while ensuring the privacy of others and to disclose any potential factors that might risk the safety of the public and environment. Our project fits the IEEE Code of Ethics 1.2 as we are creating a demo-able project to teach the public about the electronics and machine learning, while promoting interest in STEM among children. Any criticisms of our technical design, our claims stated based on our best estimates of the available data or our proper credit of others' contribution will be sought, accepted and acted upon to ensure lawful conduct in our professional activities. Any actions that undermine the ethical and moral integrity of the team will be circumvented. All members will work in an environment of acceptance and non-discrimination.

4.2 Safety

The most possible potential safety hazards we identify are the physical safety of people and surroundings if the robotic car goes out of control and safety related to power and battery. To mitigate the potential hazards, we should test the robotic car in an open field or an enclosed area. A stop button easily accessible should also be installed on the robotic car. For power related hazards, we will follow the battery safety guidelines as listed on the course website. Our battery charger chip has built in overvoltage, overcurrent, overtemperature, short circuit and reveresed polarity protection **MP2672**. When charging the batteries, at least one team member would be next to it. The batteries would be stored in fire proof bags when not used and ideally stored away not fully charged.

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