ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Infineon's Robotic Car

Team #30

KAI-CHIEH LIANG
(kcliang2@illinois.edu)
WEI-JUI CHEN
(wjchen2@illinois.edu)
SAHARSH BALLAE
(sballae2@illinois.edu)

TA: David Null

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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, but doesn't have a device that showcases the MCU's capabilities.

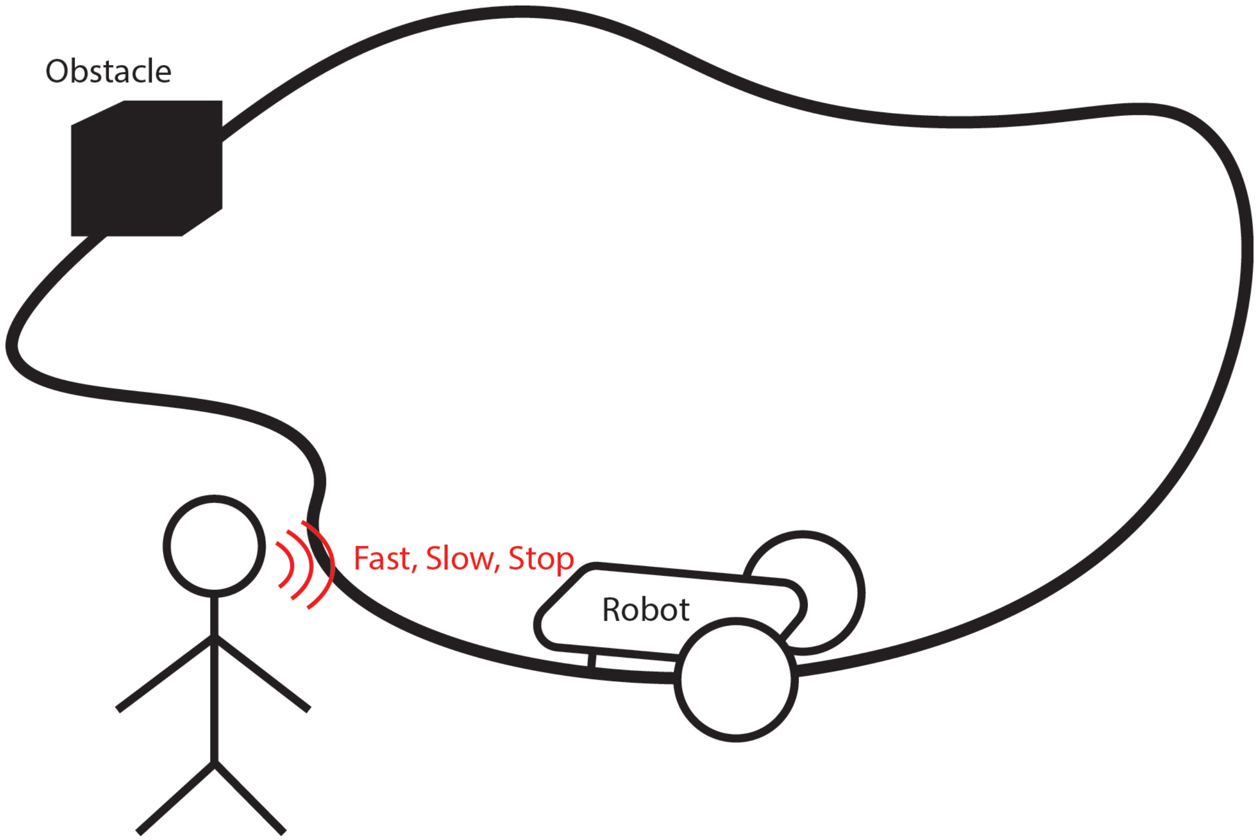
1.2 Background

Infineon has been developing microcontrollers for many years, 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 that will be able to follow a taped line while recognizing voice commands and avoid obstacles using mostly Infineon products.

1.4 Visual Aid



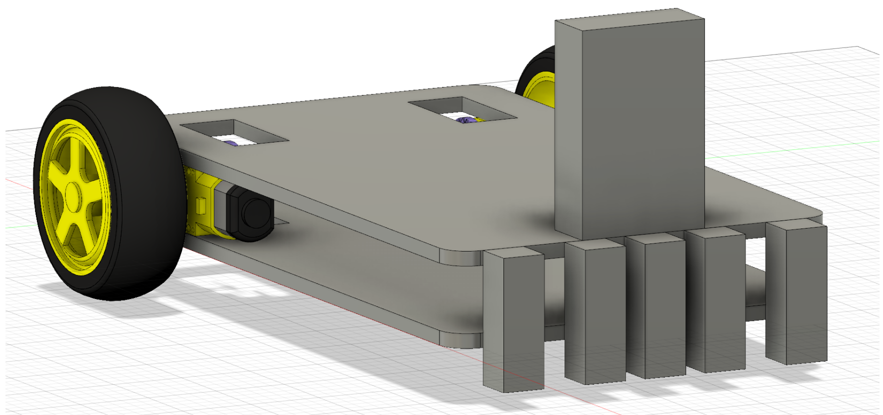


Figure 1: Physical Design of Robot Car

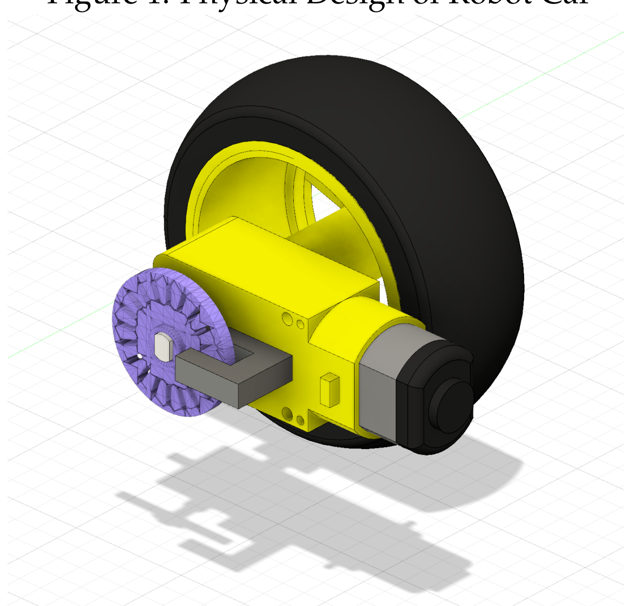


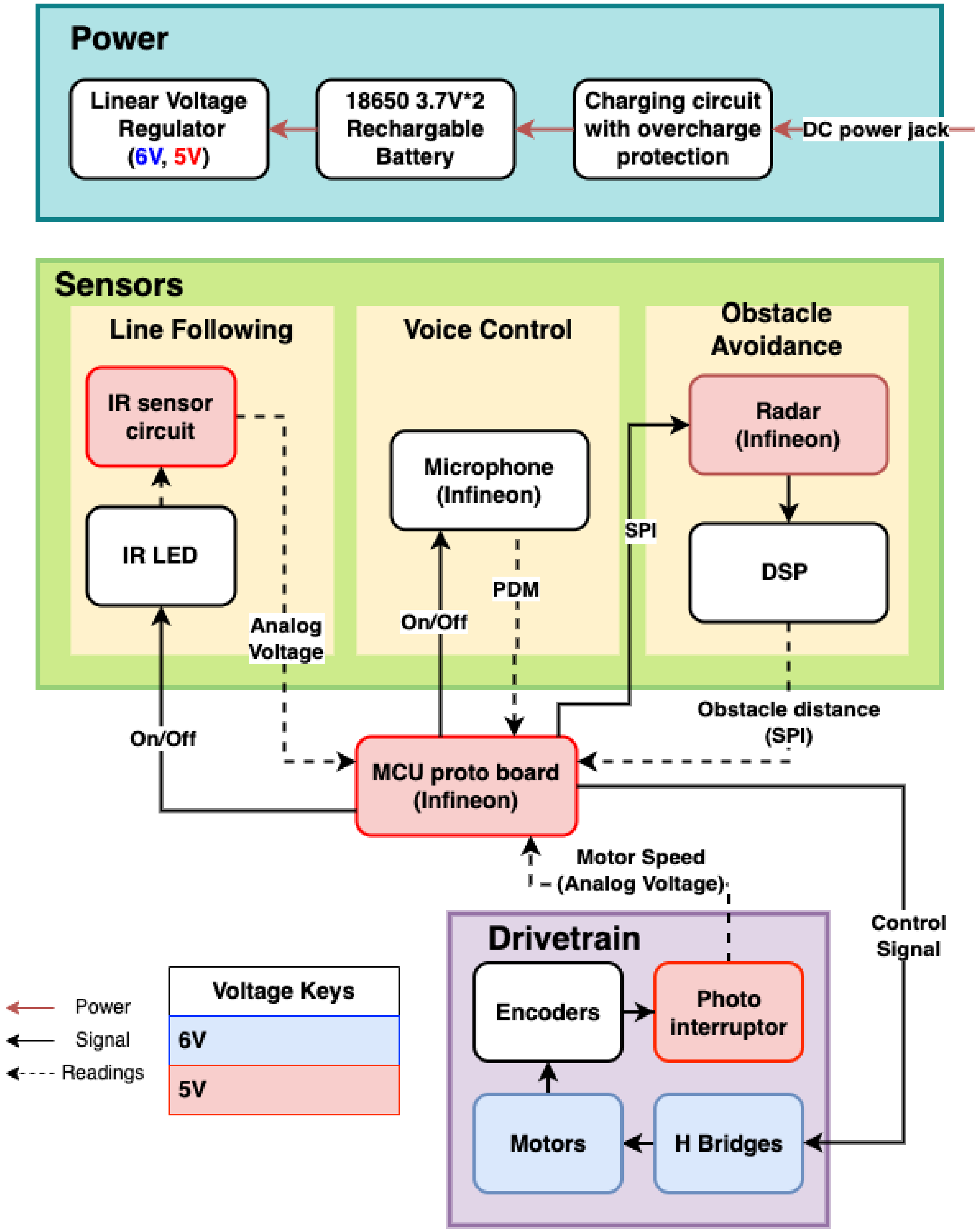
Figure 2: Motor with photo interrupter

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



2.2 Subsystem Overview

2.2.1 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 DC power jack.

2.2.2 Microcontroller 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. The MCU would take in analog voltage, PDM and SPI signals. The software would be developed in C using the Modus toolbox environment.

2.2.3 Sensor Subsystem

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.

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 circuit to produce the analog voltage signal. 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. 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.

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 PSoCT M 62S2 Wi-Fi Bluetooth® prototyping kit. 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.

The Radar system is used for obstacle avoidance. 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. The radar module 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.

2.2.4 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.

2.3 Subsystem Requirements

2.3.1 Power Subsystem

Per the overview, the power will be supplied from two 3.7 V lithium ion rechargeable batteries connected in series. The batteries must be able to reach full capacity when provided with DC power 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. The batteries must also be able to provide a stable voltage to the components during its entire discharge cycle and automatically stop providing power when it reaches the cut off voltage.

2.3.2 Microcontroller Subsystem

As the MCU is a quite sophisticated component, we would want the input voltage to the dev board to be stable, ideally within +/- 5%. The actual voltage input the PSoC6 gets should be within +/- 0.1V and the temperature of the MCU should not rise to above 85 degrees Celsius.

2.3.3 Sensor Subsystem

Each IR Sensor unit must output voltage above the same threshold voltage on white surface and output voltage below threshold voltage on black surface. Microphone should be able to detect voice command 2m away. Voice command recognition should be able to recognize the 5 voice commands even when motor noise is present. 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. And radar sensor can perform accurate measurement while the sensor is moving.

2.3.4 Drive Train Subsystem

For ease of control, the H bridge must be able to switch between the 4 modes, coast, reverse, forward and brake. The PWM signal passed to the H-bridge should have approximately the same duty cycle PWM at the output and the decay within the H-bridges should be controllable and distinct between the two modes of fast decay and slow decay. Additionally, for speed feedback control, the speed sensors should be continuously outputting and updating the tick signal at least fast enough to capture 250 RPM and at this maximum RPM, the DC motors should draw less than 2 A and on average, the DC motor should reach a steady speed of 200 RPM. The photo interrupter should be able to detect when an object is placed between the gap. Finally, for smooth acceleration and deceleration, the controller should ensure that the motors have a rise time less than 0.7s, overshoot less than 25%, and settling time of less than 2s and the steady state speed should be within +- 5 RPM.

2.4 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:

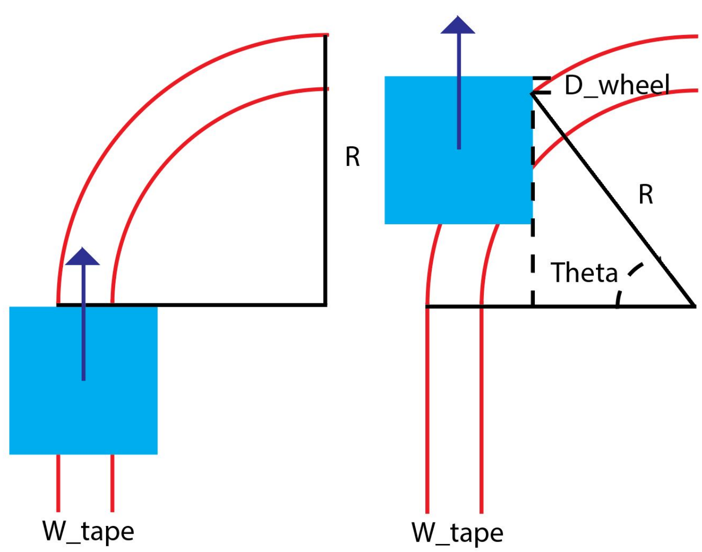


Figure 3: Off-track diagram

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

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 Ethics and Safety

3.1 Ethics

As per the IEEE Code of Ethics [1], 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.

3.2 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 [2]. 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.

References

[1] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/08/2020).

[2] M. P. Systems. “”MP2672 Datasheet”.” (2020), [Online]. Available: https://www.monolithicpower.com/en/documentview/productdocument/index/version/2/document_type/Datasheet/lang/en/sku/MP2672/document_id/6229/ (visited on 09/28/2023).