Robotic Car for Fire and Gas Leakage Detection

ECE 445 Design Document (Spring 2021)

Team 32

Quanrui Bai (quanrui2), Yufei Wang (yufeiw3), Yuqi Mao (yuqimao2)

TA: Dean Biskup

03/04/2021

Table of Contents

1. Introduction *2*

1.1 Objective 2

1.2 Background 2

1.3 Visual Aid 3

1.4 High-Level Requirements 3

2. Design *4*

2.1 Block Diagram 4

2.2 Functional Overview 4

2.3 Block-Level Requirements 6

2.4 Risk Analysis 11

2.5 Tolerance Analysis 11

3. Cost and Schedule *13*

3.1 Labor Cost 13

3.2 Parts Cost 13

3.3 Schedule 14

4. Ethics and Safety *15*

5. References *16*

1. Introduction

1.1 Objective

Stoves using natural gas or liquid propane are very common in homes and restaurants nowadays. Although the use of these gases is convenient, the poisoning and fire caused by their leakage have become deadly threats to our health and properties. As stated by the National Fire Protection Association, local fire departments responded to an estimated average of 4,200 U.S. home structure fires per year that started with natural gas ignition. These fires caused an average of 40 civilian deaths, 140 civilian injuries, and $54 million in direct property damage per year [1].

When rescuing people from gas leakage and fire, it is always dangerous for firefighters to enter the scenes directly. Because as the severity of the situation remains unknown, firefighters are susceptible to burns, smoke inhalation and crush injuries from collapsing structures [2]. Therefore, we decided to design a robotic car that can enter the sites of the accident first and help firefighters to assess the situation. This robotic car will carry a camera to take real-time images and several sensors to detect gas leakage and fire. It is designed to transmit data and operate remotely via Wi-Fi, so firefighters can operate the robot at a safe distance.

1.2 Background

Fire and gas leakage pose the risk of fatality for both civilians and firefighters. According to the U.S. Fire Administration, 18 firefighters experienced fatal injuries during fireground operations in 2019 [3]. Besides the threats from fire and toxic gas, potential dangers like falling and explosions can also cause casualties to the rescue team, as the situation at scenes remains unknown. The prevalent method of detecting fire and gas leakage is installing detectors on the ceiling, but these detectors cannot display the details of the environment. Therefore, a robot is needed to serve as the pioneer to take pictures of the scene, to detect the severity of fire and gas leakage, and to operate at a safe distance by firefighters.

1.3 Visual Aid

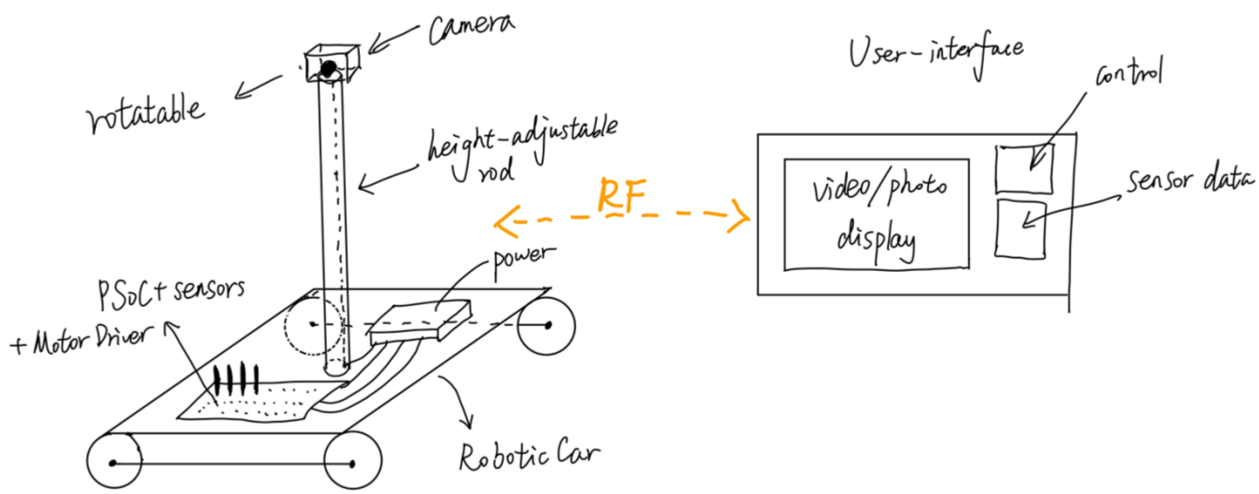

Figure 1. Pictorial Representation of the Overall Project

1.4 High-Level Requirements

- The robotic car can be remotely controlled via Wi-Fi at a distance over 200 ft.
- At most 500 ms delay, images recorded by the camera and data obtained from IR, temperature, and propane sensors can be sent back via Wi-Fi and displayed on the controlling computer.
- The camera on the robotic car can be raised for 15 inches and rotated in 360 degrees for better view.

2. Design

2.1 Block Diagram

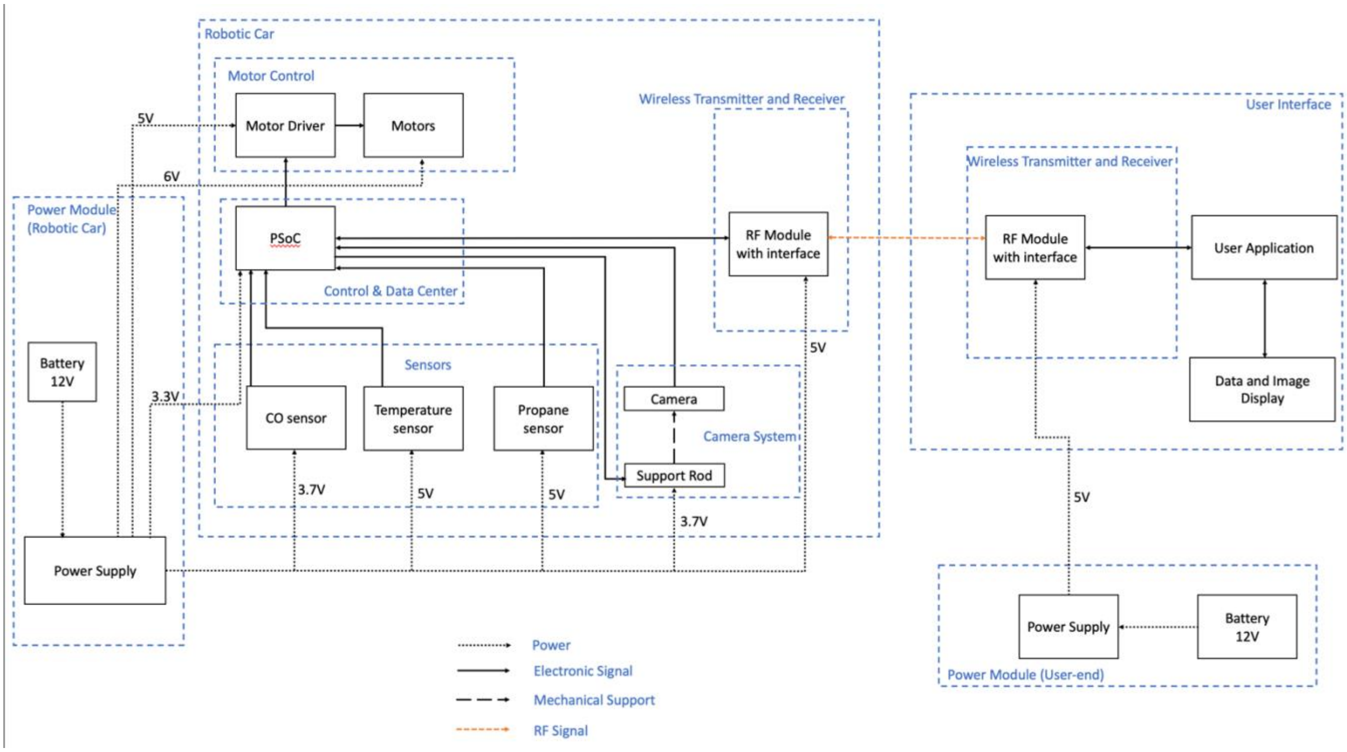

Figure 2. Block Diagram

2.2 Functional Overview

- **Motor Control:**

  The motor control subsystem is mainly used for controlling the speed and moving directions of the robotic car. We will build the motor driver circuit, and the microcontroller will send the designated outputs to H-Bridge as control instructions. The motor control subsystem relies on the power supply subsystem to deliver power that can drive the motors.

- **Wireless Receiver and Transmitter (RF module):**

  Two sets of wireless receiver and transmitter (RF modules) will be used in this design. One set of RF modules will be installed on the robotic car side. The other set of RF modules will be connected to the user-end system. The wireless transmitter can send control instructions from the user-end to the microcontroller installed on the robotic car. The user will also send control signals to operate the robotic arm. The wireless transmitter will be able to send sensor data and camera image to the user-end. The wireless receiver is essential for getting instructions and data.

- **Fire and Gas Leak Detection:**

  The fire and gas leak detection subsystem includes several sensors and one camera. Sensors will be used to detect hazardous gas or fire conditions. The camera is useful for users to monitor real-time situations. This subsystem will be connected to PSoc, and PSoC will process the data according to different signal and data types.

  For the gas sensors, we noticed that it can be categorized in two ways. Combustible gases (Hydrogen) are detected using infrared or catalytic sensors, while toxic gases (Carbon Monoxide) are detected by employing metal oxide or electrochemical technologies.

- **Support Rod with a Camera:**

  The lifting Rod subsystem satisfies the requirement that the camera viewing heights and angles can be adjusted according to the user-end instructions. The rod will be connected to the height adjustable motor and the camera will be mounted on another rotatable motor placed on top of the support rod.

- **User-End System and Interface:**

  The user-end system and application acts like a controller for users to control the robotic arm and robotic car remotely. This subsystem is important as it will be connected to an external display, and users can see and read real-time images and data transmitted back from the robotic car.

- **Power Supply:**

  Two separate power supply subsystems include batteries and voltage regulators. This subsystem acts like the power source for all the elements in this project, which will output the desired voltages to different modules.

2.3 Block-Level Requirements

- **Motor Control:** This is required to control the robotic car to move freely and avoid obstacles.

The speed and direction control is given by:

FWD	REV	V_{REF}	OUT1	OUT2	Operating mode
L	L	x	Open	Open	Standby mode – All switches are off
H	L	V_{DD}	H	L	Forward mode – Current flows from OUT1 to OUT2; 100% duty
L	H	V_{DD}	L	H	Reverse mode – Current flows from OUT2 to OUT1; 100% duty
H	H	x	L	L	Brake mode – Short circuit brake with low side switches on
PWM	L	V_{DD}	H	$\overline{\text{PWM}}$	Forward mode – Current flows from OUT1 to OUT2; PWM control mode
L	PWM	V_{DD}	$\overline{\text{PWM}}$	H	Reverse mode – Current flows from OUT2 to OUT1 PWM control mode
H	H	x	L	L	Brake mode – Short circuit brake with low side switches on

Figure 3: Motor Speed Control with a PWM Input Signal from ZXBM5210 datasheet [4]

Requirements	Verification
Requirement 1: H-bridge (an electronic circuit) can control motors to run forwards or backwards.	1. (a) Set up the microcontroller and prepare to send LOW/HIGH signals to the chip ZXBM5210 [4] (b) For all motors, output LOW (0V) to the REV pin and HIGH (5V) to the FWD pin. (c) Check and verify that all motors run in the forward direction. (d) For all motors, output LOW (0V) to the FWD pin and HIGH (5V) to the REV pin. (e) Check and verify that all motors run in the backward direction.
Requirement 2: Using H-bridge will be able to control the speed of the motors.	2. (a) Adjust the duty cycle of the PWM signal (0%, 25%, 50%, 75%, 100%) and output 5 levels of PWM signal to the FWD pin. (b) Check and verify that the motor should spin faster while increasing the duty cycle of PWM

	signal.
Requirement 3: The ultrasonic HC-SR04 [5] sensor will detect the obstacles within a range of 5 cm to 20 cm away from the car.	3. (a) Place a functional ultrasonic sensor on the table. (b) Place a notebook in the front of the ultrasonic sensor at the range of 5 cm. (c) Document the reading from the ultrasonic sensor and repeat the step (b) and (c) while increasing the distance further (5 cm per time).

- **Wireless Receiver and Transmitter (Wi-Fi/RF module):** The data from the controller and images from the camera will be sent via Wi-Fi network, and there will be an antenna for receiving and transmitting. An interface for the RF module to plug-and-play with our primary robot will also be designed.

Requirements	Verification
Requirement 1: 2.4 GHz PCB trace antenna will be used to create the maximum transmitting range and throughput (about 200ft)	1. (a) Test the antenna match to the trace antenna with a network analyzer and a coaxial pigtail. Ensure that the impedance is within required range at IEEE 802.11 frequencies

Requirement 2: RF module interface, the RF module typically communicates with a microcontroller, and the speed is based on the RF protocol used. 315 or 433 MHz RF modules will be used to communicate with the 8051 microcontroller.	2. (a) We will connect 433 MHz RF (WRL-10534) [6] to our interface with a switching transistor and the PCB trace antenna. (b) When the input is logic HIGH, the 433 MHz Saw Resonator will produce a constant RF output carrier wave at 433MHz, and when the input is LOW, the oscillator will stop.
Requirement 3: Wi-Fi module (ESP8266) [7] should be able to communicate with UART and SPI proctor, which will have at most 500ms delay	3. (a) Connect our ESP8266's UART port with the UART bridge. (b) Programming a HTML page for a photo to SPI 4-Mb flash (c) Connect to the network with a computer or mobile device and open the HTML page to ensure the transmitting of photos is about 500ms.

- **Fire and Gas Leak Detection:** This part will use different sensors to detect fire or noxious gas leakage. It will include infrared sensor, CO sensor, temperature sensor, etc., based on the future development.

Requirements	Verification

Requirement 1: We will use MQ-series gas sensors [8] to detect the gas leakage, which can detect several dangerous gases.	1. (a) Connect Eiechip MQ-series gas detection sensor modules such as MQ-3, MQ-4 Propane, MQ-7 Carbon Monoxide to the microcontroller, and then we will check the outputs of our sensor, whether it is in normal range.
Requirement 2: We plan to use MLX90614 [9] infrared thermometer sensor as a fire sensor to detect the fire or temperature change in the working area.	2. (a) Connect MLX90614 Non-contact Infrared Temperature Sensor to the microcontroller. (b) Read the output of the sensor, comparing with the thermometer

- **Support Rod with a Camera:** There will be a camera that is fitted to the top of a height-adjustable support rod, to provide images or videos from different views and perspectives and fully examine the environment.

Requirements	Verification
Requirement 1: The camera should be focal length auto-adjustable, and it will be available to rotate 180 ° Left & Right, 180 ° Up & Down.	1. (a) Set up the microcontroller for the camera and connect it to Wi-Fi. (b) Open the HTML page or mobile device to show the picture the camera takes and check the focal length. (c) Check whether the remote controller can adjust the angle of the camera.

Requirement 2: The support rod can be extended up to 10 inches for the camera to examine the surrounding environment.	2. (a) Set up the microcontroller and prepare to send the signal to the motor. (b)Check whether the direction of the motor corresponds to the direction of the rod up/down.

- **User-End System and Interface:** We will design a User-End System and Interface to control the robotic car wirelessly and get image and sensor data from the robotic car.

Requirements	Verification
Requirement 1: Users will use web-application on PC or mobile device to control the robot car and provide the data and image within 500 ms delay.	1. (a) Connect both the remote controller and the microcontroller of the car to the Wi-Fi. (b) Start the timer while sending a random block of data from the controller to the car. (c)Echo the data back to the user-end system and stop the timer. (d)Divide the timer result by 2 to get the single direction transmission time, and make sure it's 500 ms.

- **Power Supply:** The power supply is required to support the robot movement, sensors, camera, Wi-Fi transmitter and receiver, and other elements functioning at all times.

Requirements	Verification
Requirement 1: Must be able to power the module between 3.3-12V, and we need the battery to have enough charge that could power the robotic car for at least 30 min.	1. (a) Connect terminals to a voltmeter and verify that the voltage will never exceed 2% of the limit. (b) After checking the voltage, start all the sensors and motors, and make sure the battery can power the car for at least 30 min.

Requirement 2: The voltage AC-DC converter must be able to convert 110 volts AC to desired DC voltage (3.3-12V).	2. (a) Connect terminals of the voltage regulator to a voltmeter and measure its output voltage. Verify the output voltage will never exceed 2% of the limit.

2.4 Risk Analysis

The most significant challenge in this design is to create the RF connection between the user and the robotic car. We need to consider a wide range of possible choices and our design purposes since the data and image require real-time transmission. We also consider designing an interface dedicated for RF modules since different aspects in this project might need different RF protocols for the best outcome. In order to achieve the optimal performance of remote controlling, transmitting and receiving, we need to choose an antenna for better communication purposes to create a transmitting range that is as far and stable as possible.

Another important aspect is the mechanical design and sensor fusion. We need to build a robotic car with about twelve components, such as the power supply, sensors, motors, a camera and a robotic arm. Combining those elements and letting them work together is also challenging.

2.5 Tolerance Analysis

Battery selection is important to keep the overall robotic car system working normally. Here, we analyzed the estimated power consumption (one hour):

Modules / Parts	Maximum Current
PSoC	15 mA
Car Motors	800 mA
Motor Driver	2.5 mA
CO Sensor	70 mA
Temperature Sensor	25 mA
Propane Sensor	100 mA

Camera	N/A
Support Rod	200 mA
RF Transmitter	8 mA
RF Receiver	8 mA
Ultrasonic Sensor	15 mA

$$\boldsymbol{Power = 15mAh + 800mAh \times 4 + 2.5mAh + 70mAh + 25mAh + 100mAh + 200mAh + 8mAh + 8mAh + 15mAh + 350mAh = 3993.5mAh}$$

We also need to consider the camera power consumption and energy transfer efficiency. That is the reason we decided to have a 12V, 3000mAh battery in order to maintain the functionality of the system for at least 30 minutes.

3. Cost and Schedule

3.1 Labor Cost

The labor cost for our three-person group is about $20/hour/person, 10 hours/week for every person. We consider spending about 10 weeks on our final design project, so the total labor cost is about 3·$20/hr·10hr/wk·10wks = $6,000.
The total cost for labor will be at $6,000.

3.2 Parts Cost

Our parts and manufacturing prototype costs are about below:

Description	Manufacturer	Part#	Quantity	Cost
ESP8266 Wi-Fi Module	SparkFun	WRL-17146	1	$6.95
Ultrasonic Sensor HC-SR04	SparkFun	SEN-15569	1	$3.95
Temperature Sensor MLX90614	HiLetgo	GY-906	1	$14.99
Gas Sensor MQ Series-3	Eiechip	MQ-3	1	$4.95
Gas Sensor MQ Series-4	Eiechip	MQ-4	1	$1.31
Gas Sensor MQ Series-7	Eiechip	MQ-7	1	$1.48
RF Transmitter	SparkFun	WRL-10534	2	$9.9
RF Receiver	SparkFun	WRL-10532	2	$12.00
Camera Board	Sony	Spresense 5MP Camera Board 4417	1	$35.00
RC Car with motors	To Be Determined	To Be Determined		

The total cost for parts and accessories will be at least $90.53.

3.3 Schedule

Week	Yuqi Mao	Yufei Wang	Quanrui Bai
2/15	Proposal discussion	Proposal discussion	Proposal discussion
2/22	Eagle Assignment and Pre-Design Document idea	Eagle Assignment and Pre-Design Document idea	Eagle Assignment and Pre-Design Document idea
3/1	Design document and parts list discussion	Design document and parts list discussion	Design document and parts list discussion
3/8	Design review and PCB design	Design review and Schematic design	Design review and PCB design
3/15	Configure and test sensors and order PCB	Design the User-End System	Program Microcontroller and Simulation
3/22	Communicate with Machine Shop and solder parts onto PCB	Test the User-End System	Configure and optimize the Wi-Fi module
3/29	Complete antenna match	Work on data transmission from camera to HTML page	Continue work on data transmission protocol
4/5	Integrate all the physical parts and prepare for testing	Software integration	Software integration
4/12	Test and debug	Test and debug	Test and debug
4/19	Mock Demo	Mock Demo	Mock Demo
4/26	Final demo, presentation and report	Final demo, presentation and report	Final demo, presentation and report

4. Ethics and Safety

According to IEEE Code of Ethics 9 [10], while implementing the project and doing the testing, the safety of people and the environment must be ensured. Since this project involves dangerous gas leakage and fire situations, the testing and validation of this project will be difficult. All teammates will follow safety instructions and requirements when conducting the functionality check, and contingency plans must be made before testing. The project will use battery and power sources, lab members must follow lab safety rules to handle power-related devices and prevent electric shock.

According to IEEE Code of Ethics 5 [10], the project work will be honest and realistic. All the errors and findings will be documented accordingly. Since the project involves a lot of data processing and experimental check, the behavior of the robotic car and the data from sensors must be tracked and documented for further examination and project improvement.

According to University of Illinois Student Code, Article 1 Part 4 [11], all project participants will follow the student code, and avoid stealing, cheating and plagiarism. Using any resources or previous work conducted by others must be referenced, cited and credited.

According to Occupational Safety and Health Administration [12], lithium batteries may cause danger and injuries if there exist design defects or being used or recharged improperly. Project participants will always follow the protocols and practice danger prevention methods set by Occupational Safety and Health Administration while dealing with lithium batteries.

5. References

[1] M. Ahrens and B. Evarts, “Natural Gas and Propane Fires, Explosions and Leaks Estimates and Incident Descriptions”, 2018. [Online] Available: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/osNaturalGasPropaneFires.ashx. [Accessed: Feb. 17, 2021].

[2] L.McQuerrey, “The Risks of Being a Fireman”, 2018. [Online] Available: https://work.chron.com/risks-being-fireman-8600.html. [Accessed: Mar. 2, 2021].

[3] U.S. Fire Administration, “Annual Report on Firefighter Fatalities in the United States”, 2019. [Online] Available: https://www.usfa.fema.gov/data/statistics/ff_fatality_reports.html. [Accessed: Feb. 17, 2021].

[4] Diodes Incorporated. REVERSIBLE DC MOTOR DRIVE WITH SPEED CONTROL, ZXBM5210 Datasheet. Retrieved from http://www.diodes.com/ files/datasheets/ZXBM5210.pdf.

[5] Ultrasonic Ranging Module HC - SR04 Datasheet. Retrieved from https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf.

[6] RF Transmitter Data Sheet for WRL-10534. Retrieved from http://cdn.sparkfun.com/datasheets/Wireless/General/TWS-BS-3_433.92MHz_ASK_RF_Transmitter_Module_Data_Sheet.pdf

[7] ESP 8266 Wi-Fi Module Graphical Data Sheet. Retrieved from https://cdn.sparkfun.com/assets/f/e/5/6/f/ESP8266ModuleV2.pdf.

[8] MQ-Series Gas Sensor Data Sheet (MQ-3 as Example). Retrieved from https://www.sparkfun.com/datasheets/Sensors/MQ-3.pdf.

[9] The MLX90614 Temperature Sensor Data Sheet. Retrieved from https://www.melexis.com/-/media/files/documents/datasheets/mlx90614-datasheet-melexis.pdf.

[10] Institute of Electrical and Electronics Engineers, “IEEE Code of Ethics”, *IEEE Policies, Section 7 - Professional Activities (Part A - IEEE Policies)*, 2020. [Online] Available: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: Fed. 18, 2021].

[11] University of Illinois at Urbana-Champaign, “Article 1, Part 4 - Academic Integrity Policy and Procedure,” University of Illinois at Urbana-Champaign. [Online]. Available: https://studentcode.illinois.edu/article1/part4/1-401/. [Accessed: Mar. 04, 2021].

[12] Occupational Safety and Health Administration, United States Department of Labor, “Preventing Fire and/or Explosion Injury from Small and Wearable Lithium Battery Powered

Devices", 2019. [Online] Available: https://www.osha.gov/dts/shib/shib011819.html. [Accessed: Mar. 4, 2021].