Robotic Car for Fire and Gas Leakage Detection

ECE 445 Design Document

Team 32

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1. Introduction

1.1 Objective

Stoves using natural gas or liquid propane are very common at home and restaurants nowadays. Although the usage of these gases brings us convenience, 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's 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 check the situation. This robotic car will carry a camera to take real-time images and several sensors to detect gas leakage and fire. It will be able to transmit data and be remotely controlled via Wi-Fi, so firefighters can operate the robot at a safe distance.

1.2 Background

Fire and gas leakage can be fatal 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 for being the pioneer to take pictures of the scene, detect the severity of fire and gas leakage, and being controlled by firefighters at a safe distance.

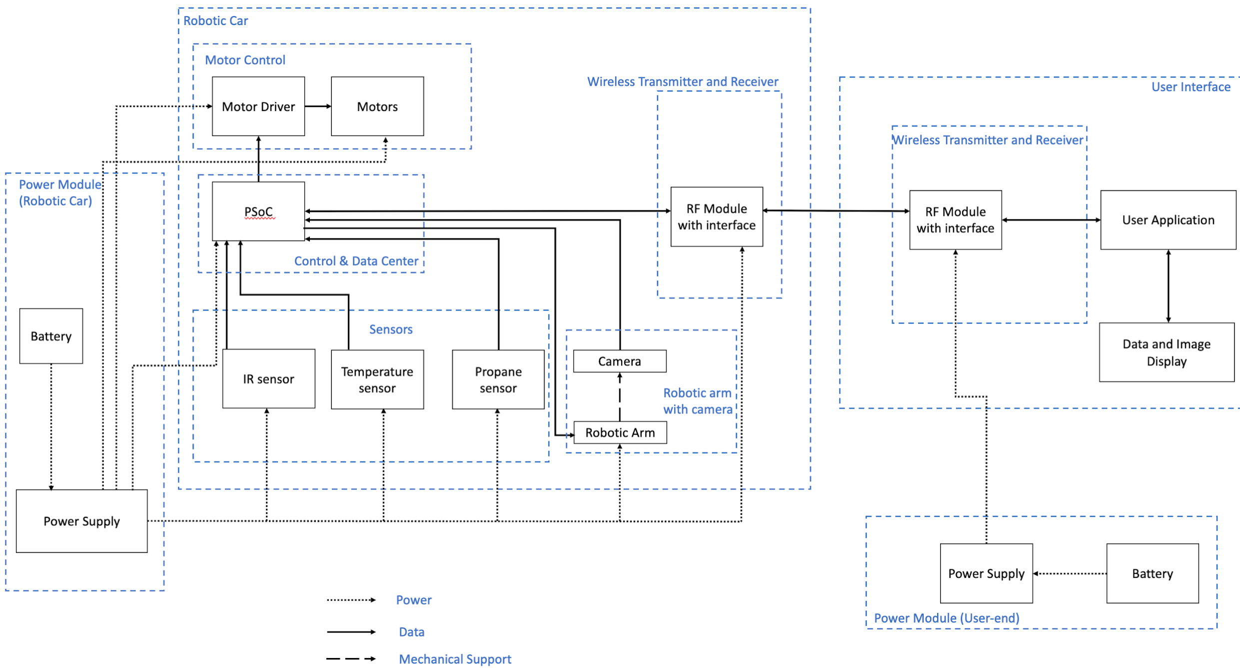
1.3 High-Level Requirements

- The robotic car can be remotely controlled via Wi-Fi at a distance over 200ft.
- At most 500ms 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.

1. Design

2.1 Block Diagram



2.2 Functional Overview

- **Motor Control:**

  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 control 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.

- **Robotic Arm:**

  Robotic arm subsystem satisfies the requirement that the camera viewing heights and angles can be adjusted according to the user-end instructions. The robotic arm can help the camera rotate and move through flexible heights.

- **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

2.3.1 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	$\overline{PWM}$	Forward mode – Current flows from OUT1 to OUT2; PWM control mode
L	PWM	V_{DD}	$\overline{PWM}$	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 2: Motor Speed Control with a PWM Input Signal from ZXBM5210 datasheet [1]

- Requirement 1: H-bridge (an electronic circuit) can control motors to run forwards or backwards.
- Requirement 2: Using H-bridge will be able to control the speed of the motors.
- Requirement 3: The ultrasonic SEN-15569 sensor will detect the obstacles about 4 inches away from the car, and then turn around to avoid crashing.

Requirements	Verification
Requirement 1: H-bridge (an electronic circuit) can control motors to run forwards or backwards.	1. (a) Set up the microcontroller and papare to send LOW/HIGH signals to the chip ZXBM5210 (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 [2] sensor will detect the obstacles within a range of 5 cm to 20 cm 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).

2.3.2 Wireless receiver and transmitter (RF module): The data from the controller and images from the camera will be sent via WIFI 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.

- Requirement 1: 2.4 GHz PCB trace antenna will be used to create the maximum transmitting range and throughput.
- 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.
- Requirement 3: WiFi module should be able to communicate with USB proctol, which will have a high-speed serial interface.

  Verification Table Here

2.3.3 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.

- Requirement 1: We will use MQ-series gas sensors to detect the gas leakage, which can detect several dangerous gases.
- Requirement 2: We plan to use MLX90614 infrared thermometer sensor as fire sensor to detect the fire in the working area.

2.3.4 Robotic Arm with Camera: There will be a camera that is fitted to a robotic arm, so we can get images or videos from different views and perspectives and fully examine the environment.

- Requirement 1: The camera should be focal length auto-adjustable, and it will be available to rotate 180 ° Left & Right, 180 ° Up & Down.
- Requirement 2: The robot arm can extend up to 20 inches for the camera to examine the surrounding environment.

2.3.5 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.

- Requirement: The system will be compiled by C and Python language, and users will use web-application on PC to control the robot car, and get the data and image within 500 ms delay.

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

- Requirement: Must be able to power the module between 3.3 - 12 volts, and we need the battery to have enough charge that could power the robotic car for at least 30 min.
- Requirement: The voltage regulator must be able to convert 110 volts AC to desired DC voltage.

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 need to be transmitted in real-time. 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 since we want the transmitting range to be as far and stable as possible.

Another important aspect is the mechanical design and sensor fusion. We need to build a robotic car with a lot of 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. Cost and schedule

3. Ethics and Safety

According to IEEE Code of Ethics [4], 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 should 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.

The project work should be honest and realistic. All the errors and findings should 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.

All project participants should 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.

References

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

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

[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] 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.acm.org/code-of-ethics [Accessed: Fed. 18, 2021]