ROBOTIC CAR FOR FIRE AND GAS LEAKAGE DETECTION

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Abstract

We designed a robotic car that can detect and assess the fire and gas leakage situation. The robotic car can enter the sites of the accident first and help firefighters assess the dangerous situation. The robotic car is equipped with sensors and a camera that can be used for sensing the environment. The sensor data and video streaming can be transmitted to users in real-time. Users will be able to control the robotic car remotely and change the camera's height on the robotic car. We have successfully implemented this project and designed two interfaces for users to get real-time information and control the robotic car wirelessly.

Contents

1. Introduction

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. 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 or videos of the scene, to detect the severity of fire and gas leakage, and to operate at a safe distance by firefighters.

2. Design

2.1 Design Procedures

The project has been designed to satisfy the following primary 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.
- The designed webpage can be used for controlling the robotic car and adjusting the height of the rod.
- The designed webpage can be used for presenting the video streaming from the camera, and multiple sensor data.

We used two ESP32-WROOM-32D [4] microcontrollers in this project. ESP32 was connected to all other subsystems and was programmed to receive data or transmit data. Other microcontrollers have been taken into consideration during the design phase, such as ATMega386. The reason to choose ESP32 was that ESP32 contains in-module Wi-Fi functionality, which makes it easier to program the module, connect different subsystems and perform the wireless transmission. For the camera, we chose the ArduCam Mini 2MP Camera. ArduCam Mini 2MP Camera has great compatibility and can be used in the microcontroller, Raspberry Pi, ARM, DSP, FPGA platforms. It is equipped with 2 megapixels image sensor OV2640, which can give clear visual images. Its SPI interface can be easily connected and programmed for camera commands and data stream. Other camera modules, such as ESP32Cam and ArduinoCam, are also available. However, the compatibility issue might occur as we need to connect the camera to our own microcontroller. For the gas sensors, we selected the MQ gas sensor series. MQ gas sensors have a high-quality dual-panel design with a power indicator and TTL signal output indication. MQ sensors are able to generate increasing analog output with increasing gas concentration. MQ gas sensors are low-cost, and library supported. For the robotic car, we selected the six-wheel Bogie Runt Rover. The Bogie Runt Rover is designed with a rocker-bogie suspension making it great for climbing over tough obstacles. With nearly 5 inches of ground clearance and 5 inches of flex, this little bot is easy to drive. Powerful motors driving six high-traction rubber tires give the bogie climbing capabilities.

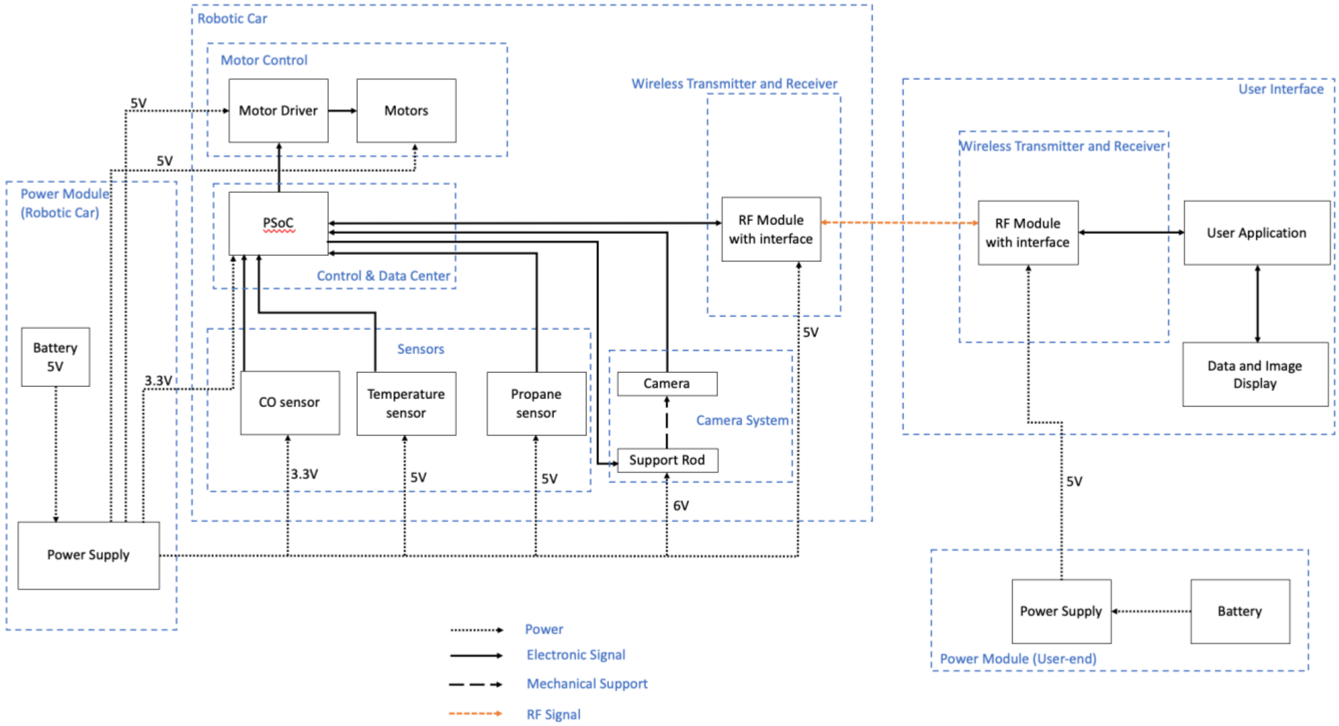

Figure 1. System Overview Block Diagram

2.2 Design Details

2.2.1 Sensors and Camera

The fire and gas leak detection subsystem include several sensors and one camera. Sensors are used to detect hazardous gas or fire conditions. The camera is helpful for users to monitor real-time situations. This subsystem is connected to PSoC, and PSoC processes the data according to different signals and data types. For the gas sensors, we noticed sensors could 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. The Height-adjustable Rod satisfies the requirement that the camera viewing heights and angles can be adjusted according to the user-end instructions. The rod is a linear actuator, and the camera is mounted on the top of the support rod.

Hardware: MQ-2 Sensor, MQ-5 Sensor, DHT-11 Temperature Sensor, ESP32-WROOM-32D Microcontroller, ArduCam 2MP Camera, Height-adjustable Linear Actuator.

Software: Webpage for presenting the video streaming from the camera and displaying multiple sensor data.

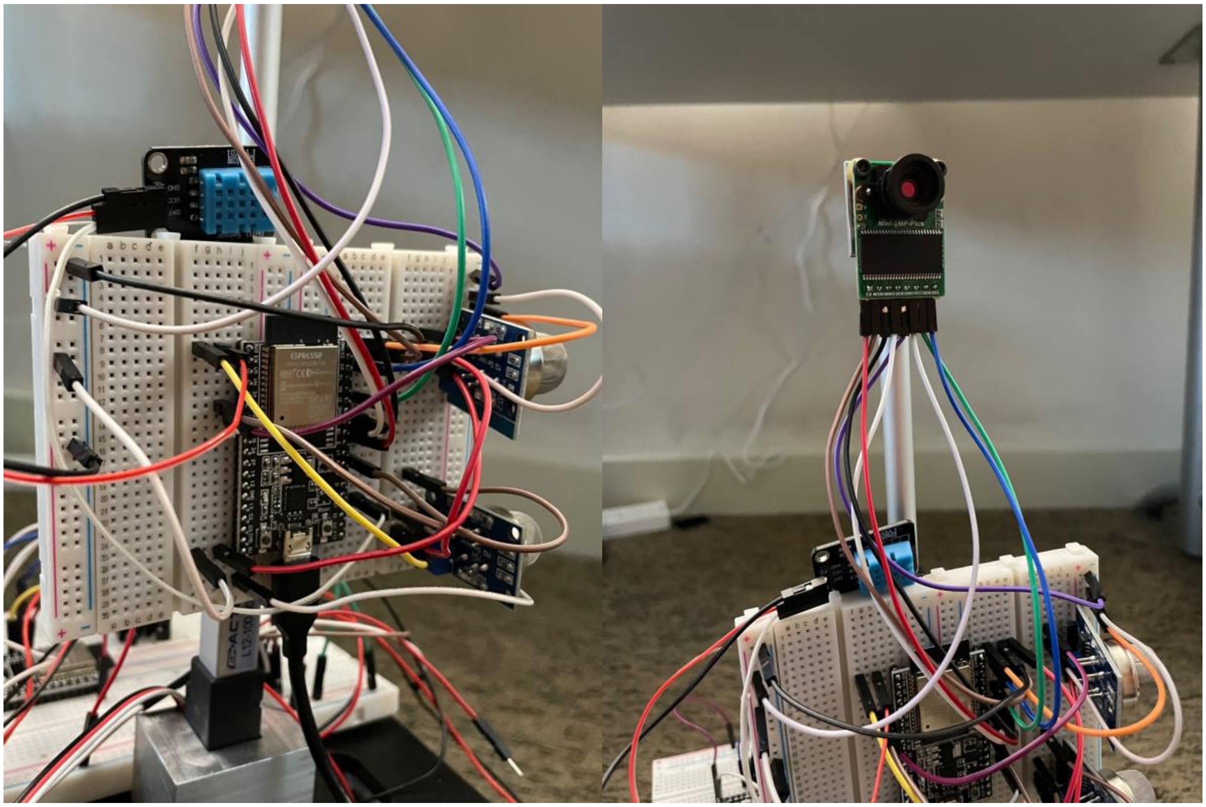

Figure 2. Sensors and Camera System Picture

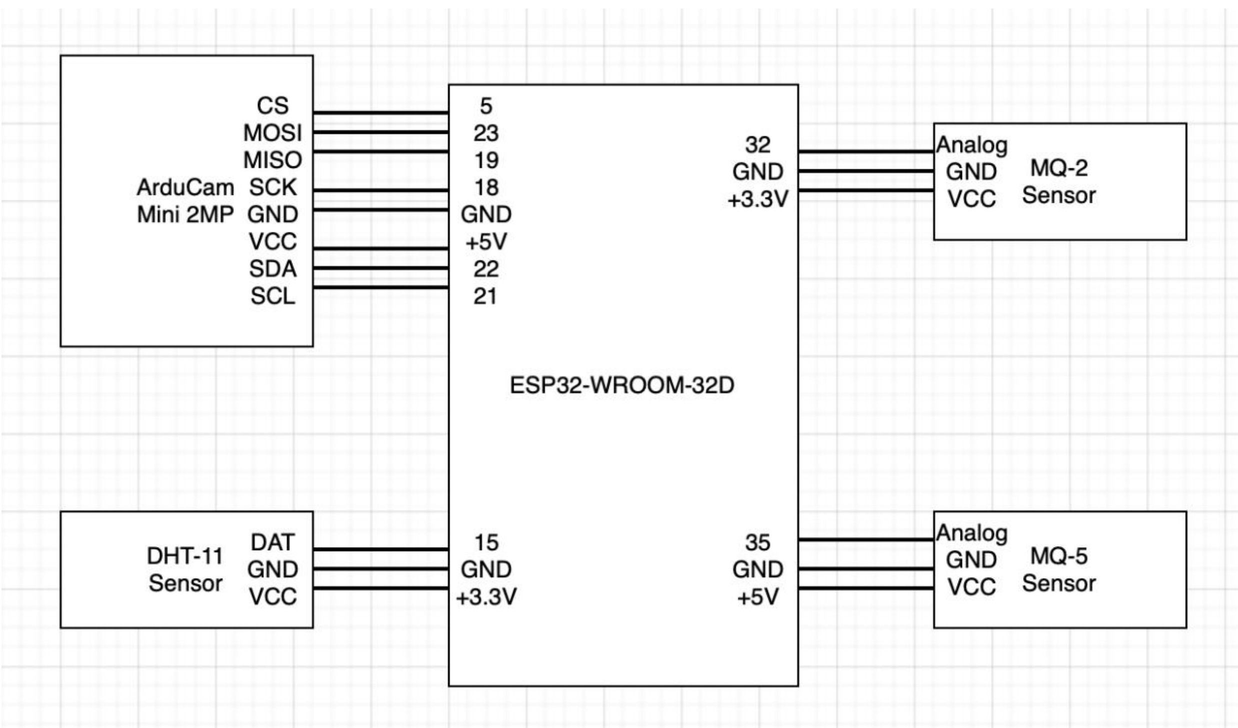

Figure 3. Pin Connection and Schematics

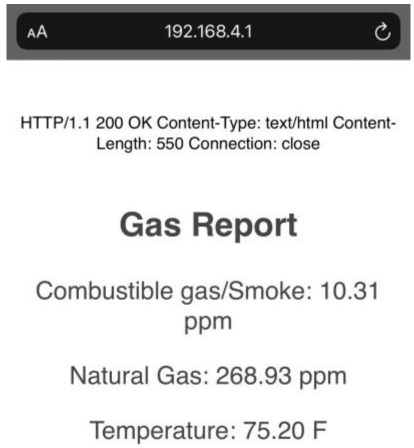

Figure 4. User Interface for Displaying Sensor Data

2.2.2 Robotic Car with Motors

The motor control subsystem is mainly used for controlling the speed and moving directions of the robotic car. We built the motor driver circuit using H-Bridge chips. Users can press the buttons on the web page to send instructions remotely to the ESP32 on the robotic car. Then, the microcontroller (ESP32) can send the designated outputs to the H-Bridge circuit as control instructions. The motor control subsystem relies on the power supply subsystem to deliver power that can drive the motors.

Hardware: ESP32-WROOM-32D Microcontroller, Robotic Car with six wheels, H-Bridge Chips.

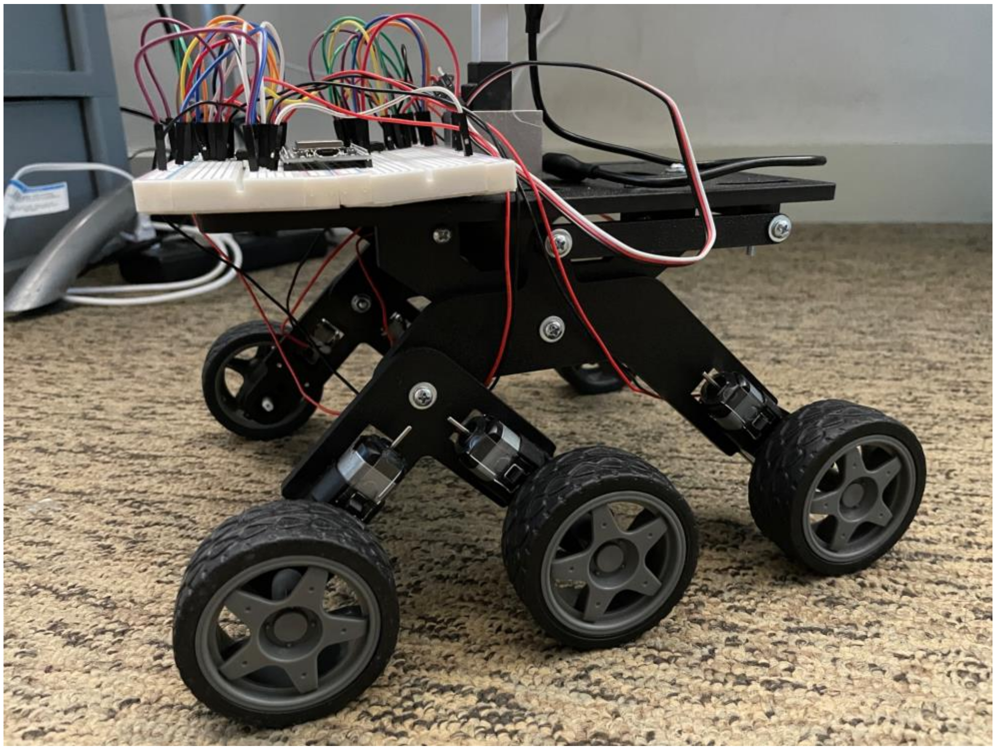

Figure 5. Robotic Car with six wheels

2.2.3 User Interface

The user-end system 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. We designed two web pages using HTML for the user interface. One webpage is used for presenting the video streaming from the camera and displaying multiple sensor data. The other webpage is used for controlling the robotic car and adjusting the height of the rod.

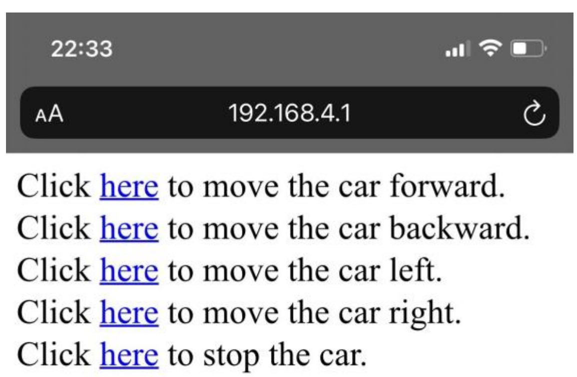

Figure 6. Screenshot of user interface for controlling

3. Design Verification

- **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 7. Motor Speed Control with a PWM Input Signal from ZXBM5210 datasheet [5]

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 [5] (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. (There are 5 speed levels)	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 [6] 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).

Table 1. Verification Table for Motor Control

- **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.

Requirements	Verification
Requirement 1: Wi-Fi module should be able to communicate with UART and SPI proctor, which will have at most 500ms delay. We will use two servers for sensor data and video streaming. And our ESP 32 [4] microcontroller has an internal Wi-Fi module.	1. (a) Connect our ESP32 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 videos and sensor data is about 500ms.

Table 2. Verification Table for Wi-Fi

- **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 [7] to detect the gas leakage, which can detect several dangerous gases.	1. (a) Connect Eiechip MQ-series gas detection sensor modules such as MQ-2, MQ-5, MQ-7 to the microcontroller. (b) Program the sensors using the sensor library, and then we check the outputs of our sensors, whether the output is in normal range.
Requirement 2: We plan to use DHT-11 [8] infrared thermometer sensor as a fire sensor to detect the temperature change in the working area.	2. (a) Connect DHT-11 Temperature Sensor to the microcontroller. (b) Read the output from the sensor, compared with the thermometer reading to check the accuracy.

Table 3. Verification Table for Fire and Gas Leakage Detection

- **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, which is the linear actuator made by the machine shop, can	2. (a) Set up the microcontroller and prepare to

be extended up to 10 inches for the camera to examine the surrounding environment.	send the signal to the motor. (b) Check whether the direction of the motor corresponds to the direction of the rod up/down.

Table 4. Verification Table for Camera and Rod

- **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. We will have two web pages: one is for movement of the car, and another is for video streaming.	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.

Table 5. Verification Table for User Interface

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

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.

Table 6. Verification Table for Power Supply

4. Costs

4.1 Parts

Our parts and manufacturing prototype costs are the following:

Description	Manufacturer	Part#	Quantity	Cost
ESP32-WROOM-32D Board	ACEIRMC	ESP-WROOM-32D	4	$26.15
Temperature Sensor	HiLetgo	DHT-11	1	$2.10
Gas Sensor MQ Series Set	Eiechip	MQ Series 9 Pcs	1	$18.99
Robotic Car with Motors	ServoCity	N/A	1	$76.99
ArduCam Mini 2MP Camera	Arducam	OV2640	1	$25.99
Linear Actuators	Actuonix	L12-100-50-6-R	1	$49.99
ZXBM5210 H-Bridge Chip	Diodes Incorporated	ZXBM5210-SP-13	2	$12.00
Battery / Power Bank	Insignia	NS-MB10MK21	1	$35.00

Table 7. Parts Cost

The total parts parts and manufacturing prototype cost is $247.21.

4.2 Labor

The labor cost for our three-person group is about $20/hour/person, 10 hours/week for every person. We spent about ten weeks on our final design project, so the total labor cost is about 3 x $20/hr x 10hr/week x 10weeks = $6,000. The total cost for labor is $6,000.

5. Conclusion

5.1 Accomplishments

In our project, we successfully actualized the functionalities of the robotic car, including the remote controlling of the car and the height-adjustable rod, the data display of gas and temperature sensors, and the streaming display of the camera. The sensor can accurately detect the change of combustible gas concentration. Therefore, we can conclude that we have achieved all the main features we have proposed in the project design, and we believe that this robotic car can help firefighters in the real situation with a few improvements.

5.2 Uncertainties

Even though we have actualized all our proposed functionalities, we encountered some problems in our design that need further improvements. First, the turning radius of our car is too large. This is because our overall system is too heavy, and our power supply is too weak for six motors. We control the speed of the motors using the AnalogWrite function, which ranges from 0 to 255. But we can only adjust its value within 200-255 because the motors don't respond to power values below that. Secondly, we can't power the motors and the extendable rod using the same board. Our height-adjustable rod requires 6V input voltage, but we use a 5V power bank for the board, and the six motors consume a large amount of power from the board. Therefore, when we plug in both the motors and the rod, the height-adjustable rod couldn't respond to the user's instructions. So, one significant improvement we need to make is the power supply.

5.3 Ethical considerations

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

According to the IEEE Code of Ethics 5 [9], the project work was honest and realistic. All the errors and findings have been documented accordingly. Since the project involved a lot of data processing and experimental check, the behavior of the robotic car and the data from sensors have been tracked and documented for further examination and project improvement.

According to the University of Illinois Student Code, Article 1 Part 4 [10], all project participants followed the student code and avoided stealing, cheating and plagiarism. Using any resources or previous work conducted by others has been referenced, cited, and credited.

According to Occupational Safety and Health Administration [11], lithium batteries may cause danger and injuries if there exist design defects or being used or recharged improperly. Project participants always followed the protocols and practiced danger prevention methods set by Occupational Safety and Health Administration while dealing with lithium batteries.

5.4 Future work

Firstly, we need to ensure the safety of our robotic car and whole circuit system, especially under hazardous fire conditions. We have researched the thermal insulation material, and we found that fiberglass or extruded polyurethane is the ideal material. Fiberglass will protect our system working at most 760 Celsius. If the product is intended for short-term use, the operating temperature can reach as high as 1093 Celsius degrees.

Components	Lowest Operating Temperature (℃)	Highest Operating Temperature (℃)
ESP 32 [4]	-40	125
ArduCam OVA2640 [12]	-10	55
Ultrasonic Sensor [6]	-15	70
Raspberry PI [13]	-30	70

Table 8. Operating Temperature for Different Components

We found that using chips that can operate at high temperatures is a more convenient way. It is more reliable than fiberglass, so we have to research high-temperature tolerance chips in the future.

Secondly, we want to redesign the wheels (like the image below), which are enabled to climb the stairs. Our robotic car must adapt to various surroundings, so firefighters can avoid fire and dangerous gas exposure. We have designed the climbing part for our products, which has a caterpillar band. Also, there is an axis to rotate for climbing stairs.

Next, we need to increase the output voltage of our robotic car, which can support our linear actuator to lift the camera. We make mistakes about communications with machine shop, and voltage verification. The linear actuator working voltage is 6, but our esp32 microcontroller is 5 output voltage. On the other hand, our car is very heavy, so we have to increase the power to make the turning radius small.

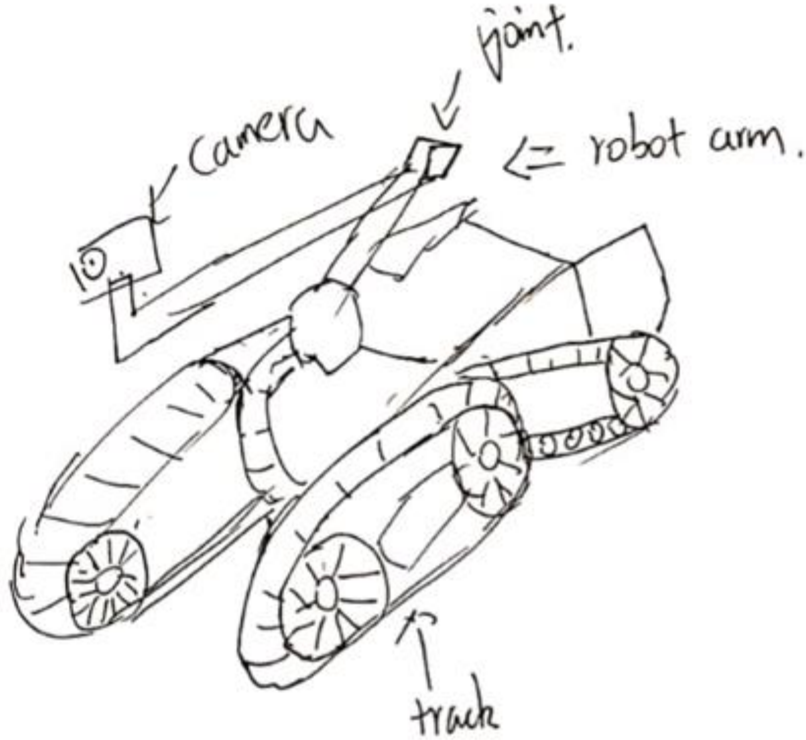

Figure 7. The Improved Version of Robotic Car with Robotic Arm

At last, we should redesign the user interface because, in the demo, we must use two phones or devices to control the robotic car. One is for movement, and another is for video. We should combine the two interfaces into one. Users can use only one server to control the car and watch the video streaming simultaneously.

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