FIRE DETECTION AND SUPPRESSION SYSTEM FOR ELECTRIC RANGES

Design Document

Project #33

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1 Introduction

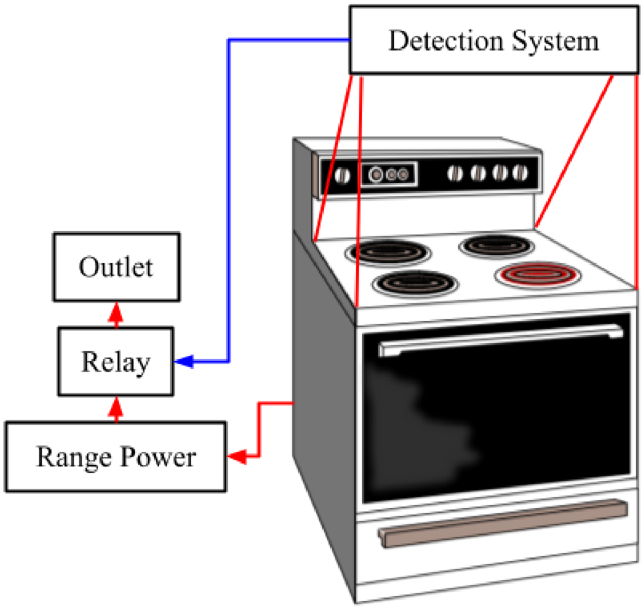
1.1 Problem

The problem that our project aims to address is the significant risk of fires associated with electric ranges in residential kitchens. According to statistics, electric ranges are responsible for 1,156 fires per million stoves in the United States, which is 2.5 times more than those caused by gas stoves (source: `https://www.prolinerangehoods.com/`). These fires can lead to property damage, injury, and even loss of life. While existing smoke detection systems can alert authorities, they often do so too late to prevent substantial damage or harm. With the increasing popularity of electric stoves, the incidence of fires caused by these appliances is likely to rise. Thus, there is a pressing need for an innovative solution that can both detect fires early and take immediate action to mitigate the risks associated with them.

1.2 Solution

The novelty of our solution lies in its comprehensive approach to fire detection and suppression in the context of electric ranges. Our two-part system, consisting of a main device attached to the stove hood and a peripheral shut-off device between the wall receptacle and the stove's power wire, allows for installation irrespective of the size or type of electric range being used. By integrating sensors capable of detecting key properties of combustion reactions (IR, and UV emissions), our system can detect fires quickly. Upon detection, our system will use an onboard fire suppression system to quickly mitigate the danger posed by a fire before it is allowed to grow and cause actual danger. This proactive approach, combined with the ability to shut off power to the stove, distinguishes our solution from traditional fire safety systems and promises to significantly improve the safety of residential kitchens, potentially saving lives and reducing property damage.

1.3 Visual Aid



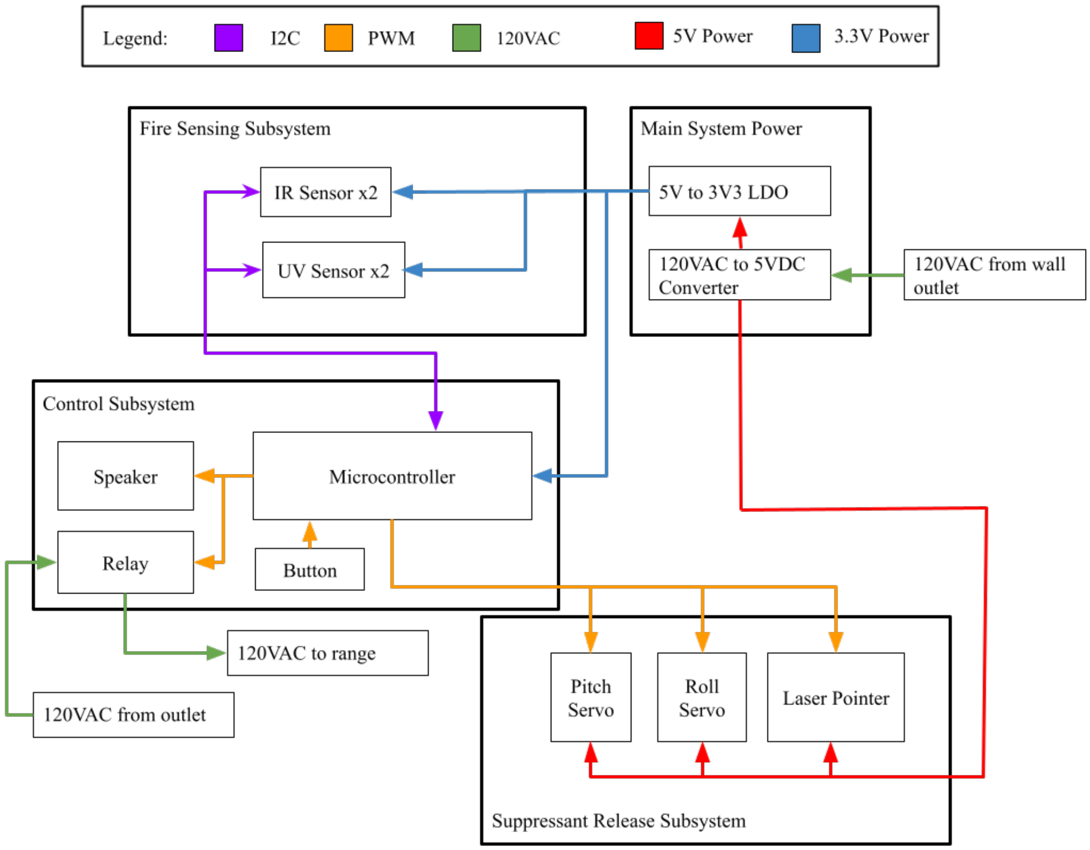
1.4 High-level Requirements

For our project to be successful the following three high-level requirements must be met:

1. Our device should be able to detect the number of burners that are one within 15 seconds of a change to the burners
2. Our device should be able to begin actuating the suppressant system and shut off power to the range within 3.5 seconds of an active fire
3. Our device should be able to actuate the suppressant mechanism, in our final demo this will be a laser pointer, within 4 seconds after the power to the range has been shut off

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 System Power Subsystem

The System Power Subsystem supplies power to the system, allowing components to properly work. There are 2 different methods for the system to power on: via USB (micro-b) or a 5V barrel jack. The primary usage of the USB is to program the micro-controller. The 5V barrel jack is for standard system usage. To convert 5 volt inputs to 3.3 volts, the system uses a linear regulator (LDO). The LDO is responsible for powering fire sensing subsystem as well as the micro-controller. All other components will be powered through the 5V line.

Requirements	Verification
IR, UV sensors and MCU receive $3.3V \pm 0.2V$	1. Prepare a digital multi-meter and measure the voltage across a ground point on the PCB and the part you are testing 2. Ensure the voltage is within the designated spec 3. Repeat until IR, UV and MCU have been tested
Speaker, Relay, Servo and Laser Pointer receive $5V \pm 0.5V$	1. Prepare a digital multi-meter and measure the voltage across a ground point on the PCB and the part you are testing 2. Ensure the voltage is within the designated spec 3. Repeat until all components have been tested
Linear regulator supplies a max of 300mA	1. Prepare a digital multi-meter and measure the voltage across the shunt resistor 2. Divide the voltage by the resistance of the shunt resistor to find the LDO supply current 3. Ensure this value is within spec

Table 1: Power Subsystem RV Table

2.2.2 Fire Sensing Subsystem

The Fire Sensing Subsystem is responsible for capturing the relevant data from the stove-top area and sending that data to the microcontroller. There are 2 types of sensors in this subsystem, IR sensors for measuring surface temperature, and UV sensors for measuring specific UV wavelengths given off by fires. An IR sensor and a UV sensor will be placed roughly above each burner to allow for the microcontroller to determine which one is on and which one is causing a fire. These sensors have an angle of incidence of roughly 30deg. This angle of incidence will allow for the detection of fires that may be offset from the burner, such as a newspaper that was too close to the burner. The IR and UV sensors will communicate with the microcontroller over I2C and will require 3.3V to be supplied from the LDO in the power subsystem. Both the IR and UV sensors have up to 4 selectable I2C addresses which will allow for the microcontroller to communicate with up to 4 of the same sensor.

Requirements	Verification
IR sensor must be capable of accurately measuring the temperature of the measured area within $\pm 1.5 \deg C$	1. Establish communication with the sensor and display the measured temperature value via log output 2. Using a heat-generating device with a known heat output such as a digital hotplate, position the sensor 16 inches above the device and start the heat-generating device 3. Allow the heat-generating device sufficient time to stabilize 4. Compare the output of the sensor in the log with the temperature that the heat generating device was set to and ensure it is within $\pm 1.5 \deg C$
UV sensor must be capable of detecting a change of ± 10 counts in UVa and UVb emissions within 1 second of said change	1. Establish communication with the sensor and display the measured values of UVa and UVb via serial logging output 2. Prepare a matchbox and a stopwatch 3. Start the stopwatch and light a match. Place the flame of the match 16 inches below the sensor as quickly as possible 4. Monitor the output of the sensor and stop the stopwatch when a change in the measured UVa/UVb emissions occurs. Repeat for the other UV spectrum to obtain 2 times

Table 2: Sensing Subsystem RV Table

2.2.3 Control Subsystem

The Control Subsystem is responsible for accumulating and processing the data given by the Fire Sensing Subsystem and subsequently using that data to determine an action for the Suppressant Release Subsystem and the kill-switch relay. The core of the Control Subsystem is the ESP32-S3 micro-controller that will be responsible for I2C communication to and from the sensors as well as the analog outputs needed to actuate the suppressant release subsystem. The other components are the Speaker and Relay which will be triggered when the micro-controller detects a fire and a button that allows the end user to override the micro-controller and stop the suppressant release in the case that the user knows there will be a fire. This subsystem will require 3.3V to be supplied by the power subsystem.

Requirements	Verification
Micro-controller must be able to determine which burner(s) are turned on within 10 $\pm$ 5 seconds of a change to the burners	1. Ensure the heating elements of the range are off and are at/near room temperature, with the IR and UV sensors placed 1 foot above both heating pads 2. Setup the micro-controller such that the detected burner is outputted to the log and prepare a stopwatch 3. Start the stopwatch and simultaneously switch on one of the heating pads of the range. 4. Stop the stopwatch when the correct burner is outputted by the micro-controller to the log and ensure the time is within spec 5. Repeat for all configurations of the 2 burners setup
Micro-controller must be able to determine the location of a fire within 2.5 $\pm$ 1 seconds of an active fire within the sensing area	1. Ensure the heating elements of the range are off and are at/near room temperature, with the IR and UV sensors placed 1 foot above both heating pads 2. Setup the micro-controller such that the detected fire and its location are outputted to the log and prepare a stopwatch and a matchbox 3. Start the stopwatch and simultaneously light a match next to one of the burners 4. Stop the stopwatch when the correct burner is outputted by the micro-controller to the log and ensure the time is within spec 5. Repeat for the other burner location
After fire detection a sound must play from the onboard speaker	1. Ensure the heating elements of the range are off and are at/near room temperature, with the IR and UV sensors placed 1 foot above both heating pads, and prepare a matchbox 2. Light a fire using a match and confirm that an audible sound is emitted

Requirements	Verification
After fire detection the micro-controller must trigger the relay within 2.5 $\pm$ 1 seconds	1. Ensure the heating elements of the range are off and are at/near room temperature, with the IR and UV sensors placed 1 foot above both heating pads, and prepare a matchbox and a stopwatch 2. Using a bench power supply, supply 5V on the input side of the relay and ensure that 5V is measured on the other side using a multi-meter 3. Start the stopwatch and light a fire using a match 4. Stop the stopwatch when the multi-meter measures 0V $\pm$0.05 and ensure that the time is within spec

Table 3: Control System RV Table

2.2.4 Suppressant Release Subsystem

The Suppressant Release Subsystem handles the aiming and the release of the fire suppressant at the area determined by the Control Subsystem. This subsystem contains 2 micro-servos arranged to allow for pan and tilt movement as well as a suppressant mechanism, which in our final demo will be represented by a laser pointer, but in a full deployment could be a small pressurized fire suppressant foam container that is actuated by a solenoid. All 3 of these parts require 5V to be supplied by the power subsystem and additionally, each servo will need at least 1A initially to surpass the locked rotor amperage and avoid stalling. The control subsystem will need to provide the PWM signal to the micro-servos for the angle after determining the location of the fire.

Requirements	Verification
Servos must be able to position the suppressant mechanism according to the location provided by the control subsystem within 5 deg	1. Connect the pan and tilt servos to the microcontroller 2. Determine angles to be tested for both pan and tilt 3. Supply the PWM signal corresponding to the determined angles to the servos and measure the resulting angles with a protractor 4. Ensure the angle is within spec and repeat with different angle tests within the sensing area
Servos must position the suppressant mechanism within 3 ± 1 seconds	1. Connect the pan and tilt servos to the microcontroller and prepare a stopwatch 2. Determine angles to be tested for both pan and tilt 3. Start the stopwatch and simultaneously supply the PWM signal corresponding to the determined angles to the servos and stop the stopwatch after servo movement has stopped 4. Ensure the recorded time is within spec 5. Repeat with more angles within the sensing area
Suppressant mechanism must be able to trigger within 3 ± 1 seconds	1. Connect the suppressant mechanism to the microcontroller and prepare a stopwatch 2. Start the stopwatch and simultaneously supply the necessary power to the mechanism 3. Stop the stopwatch when the mechanism has been actuated 4. Ensure the time measured is within spec

Table 4: Suppressant Release RV Table

2.3 Tolerance Analysis

2.3.1 Temperature Measurement of IR Sensor

One critical aspect of our system's design is the accuracy of temperature measurement of the IR sensor.

2.3.2 Feasibility Analysis for Temperature Measurement Accuracy:

Desired Temperature Measurement Range: 40°C min to 200°C max with tolerance of :
± 1.5°K = ± 1.5°C
The allowable error within the tolerance range can be calculated as follows:
Upper and lower limits of measured temperature = Desired Temperature ± Tolerance
Upper Limit = 200°C + 1.5°C = 201.5°C
Lower Limit = 40°C - 1.5°C = 38.5°C
Let's assume the temperature sensor has a linear response within its operational range. The IR sensor specifications list an accuracy of ± 1.5°K = ± 1.5°C at an ambient temperature of 25°C. Error is measured by the difference between the measured and actual temperature.
At the lower limit of 38.5°C:
Error = (38.5°C) - (40°C) = -1.5°C
At the upper limit of 201.5°C:
Error = (201.5°C) - (200°C) = 1.5°C

Both errors are acceptable, as they're within the specified ± 1.5°K tolerance. Based on the analysis, the temperature measurement accuracy within ± 1.5°K is feasible for our system. The sensor's accuracy remains within the specified tolerance even at the extremes of the temperature range.

2.4 LDO Voltage Regulator

2.4.1 LDO Voltage Regulator Specifications:

- Nominal Output Voltage: 3.3V
- Maximum Tolerance: ±10%

2.4.2 Objective:

We want to ensure that the LDO voltage regulator can maintain the output voltage within ±10% of the nominal value (i.e. 3.3V) under various conditions.

2.4.3 Tolerance Analysis:

The output voltage of an LDO regulator can be mathematically represented as:
Vout = Vin - Vdropout
Where:

- Vout is the output voltage (3.3V).

- Vin is the input voltage.
- Vdropout is the dropout voltage, which is the minimum voltage difference required between Vin and Vout for the LDO to regulate properly.

In our case, the LDO must regulate the output at 3.3V.
Therefore:
Vdropout = Vin - 3.3V
To ensure that the output voltage remains within ±10% of 3.3V, we can calculate the acceptable range for Vin as follows:
Lower Limit of Vin:
3.3V - (10% of 3.3V) = 3.3V - 0.33V = 2.97V
Upper Limit of Vin:
3.3V + (10% of 3.3V) = 3.3V + 0.33V = 3.63V
So, for the LDO to maintain the output voltage within ±10% tolerance, the input voltage (Vin) must be between 2.97V and 3.63V.

3 Cost and Schedule

3.1 Cost Analysis

The total cost for parts as seen below before shipping is \$78.34. 5% shipping cost adds another \$3.917 and 10% sales tax adds another \$7.834. We can expect a salary of \$40/hr$\times$2.5 hr$\times$60 = \$6000 per team member. We need to multiply this amount by the number of team members, \$6000$\times$ 3 = \$18,000 in labor cost. This comes out to be a total cost of \$18090.091

3.1.1 Parts List

Table 1: Itemized list of Components and Costs

Part Number	Manufacturer	Quantity	Unit Price	Link
ESP32-S3-WROOM-1-N4	Espressif Systems	1	\$2.95	Link
AS7331_T OLGA16 LF T&RDP	ams-OSRAM USA INC.	2	\$10.86	Link
TPIS 1S 1385/5029	Excelitas Technologies	2	\$13.63	Link
1967 (Servo)	Adafruit	1	\$18.95	Link
1054 (Laser Pointer)	Adafruit	1	\$5.95	Link
ALF1P05	Panasonic Electric Works	1	\$3.25	Link
AZ1117C-3.3TRG1	Diodes Incorporated	1	\$0.45	Link
AL-0540	Facmogu	1	\$9.99	Link
SPKM.15.8.A	Taoglas Limited	1	\$1.74	Link
500SSP1S2M2QEA	E-Switch	1	\$3.27	Link
PBH2UEESNPNAGX	E-Switch	1	\$0.80	Link

Total = \$91.34

3.2 Proposed Schedule

Week of	Task	Member
9/18	Component Research Order prototype parts Machine Shop Discussion	John Arjun Arjun
9/25	PCB Design Begin breadboarding Fire Detection algo brainstorm	John Arjun Prathamesh
10/2	Finalize PCB Design Continue breadboarding, finalize machine shop plans Continue algo research	John Arjun Prathamesh
10/9	PCB revisions Finalize communications with sensors and actuators Finalize algo and begin implementation	John Arjun Prathamesh
10/16	Integration of burners onto machine shop range Algo implementation Algo implementation	John Arjun Prathamesh
10/23	Work on fire detection accuracy and speed of suppression system	Everyone
10/30	Continue working on system accuracy and precision, managing any bugs	Everyone
11/6	Mostly final product, begin working on demo and presentation	Everyone

4 Ethics and Safety

4.1 Ethics

- Accuracy and False Positives/Negatives (IEEE Code of Ethics 1.2): Ensuring the system's accuracy in detecting fires without generating false alarms is important to unnecessary disruptions and costs for users. To avoid ethical breaches we must conduct rigorous testing of our sensors to avoid false breaches.

- Privacy (IEEE Code of Ethics 1.3): The system should not compromise the privacy of its users/customers. Any data collected, such as sensor readings or user information, must be handled with strict confidentiality and comply with relevant data privacy regulations.

- Safety of End-Users (IEEE Code of Ethics 3.7): The system's primary purpose is to enhance safety. We should ensure that the system does not introduce new risks or vulnerabilities and that it reliably performs its safety functions without endangering users.

- Transparency (IEEE Code of Ethics 2.6): Transparency in system operation and functionality is crucial. Users should be informed about how the system works and what data it collects. Clear documentation and user interfaces will help achieve this transparency.

4.2 Safety

- Electrical Safety Standards: Ensure that the electrical components and connections within the system meet safety standards, such as those specified by UL (Underwriters Laboratories). Proper isolation and protection of electrical components to prevent electrical shocks or fires within the system itself is a must.
- Fire Suppressant: Ensuring that the release of fire suppressant is controlled and safe is a priority. It should not cause harm to occupants or damage to property. We plan on conducting safety tests to determine the impact of the suppressant release. The fire suppressant used in the system should meet industry standards for fire control and safety.
- Fire Safety Regulations: We plan on abiding by the local, state, and federal fire safety regulations that apply to our system. We will take steps to ensure that the installation and operation of your system do not violate these regulations.

References

[1] IEEE Code of Ethics, "1.2. To avoid deceptive acts, we must strive for the highest accuracy in all scientific and technical communications." Available online: `https://www.ieee.org/about/corporate/governance/p7-8.html`

[2] Johnson, A., "Ensuring Accuracy in Fire Detection Systems," IEEE Fire Safety Journal, vol. 25, no. 3, pp. 45-52, 2020.

[3] IEEE Code of Ethics, "1.3. To respect the privacy of others, we must protect sensitive personal and business information as confidential." Available online: `https://www.ieee.org/about/corporate/governance/p7-8.html`

[4] IEEE Code of Ethics, "3.7. To avoid injury to others, we must ensure the safety of our products and systems." Available online: `https://www.ieee.org/about/corporate/governance/p7-8.html`

[5] IEEE Code of Ethics, "2.6. To be honest and realistic in stating claims or estimates based on available data." Available online: `https://www.ieee.org/about/corporate/governance/p7-8.html`

[6] Underwriters Laboratories (UL), "Safety Standards." Available online: `https://www.ul.com/`

[7] National Fire Protection Association (NFPA), "NFPA Standards for Fire Suppressants." Available online: `https://www.nfpa.org/`

[8] U.S. Fire Administration, "Fire Safety Regulations and Standards." Available online: `https://www.usfa.fema.gov/prevention/outreach/regulations.html`

Power Supply: https://www.amazon.com/Facmogu-Switching-Transformer-Compatible-5-5x2-1mm/dp/B087LY41PV/ref=sr$_{13}$?$keywords = 5v$
Stove: https://www.amazon.com/GAU-80306-Electric-Double-Burner-1500-Watts/dp/B0056H4FPI
https://illinois.zoom.us/j/87312571231?pwd=MXkxWVA3dEpHOVpCVCthdFByRjMyUT09