FIRE DETECTION AND SUPPRESSION SYSTEM FOR ELECTRIC RANGES

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Objective and Background:

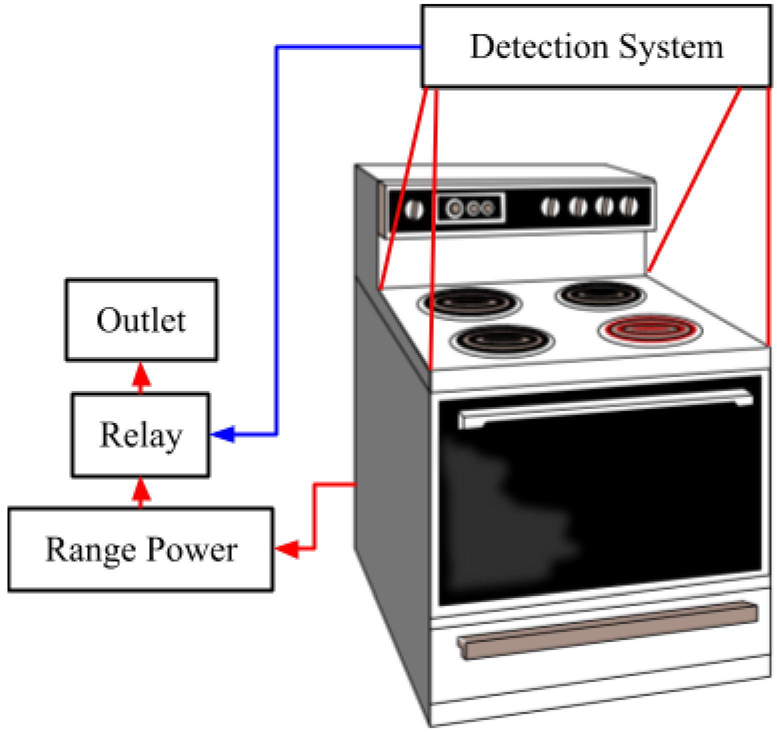

Figure 1: General System Connections

Problem:

Electric ranges are responsible for 1,156 fires per million stoves in the US, which is 2.5x more than those caused by gas stoves. While smoke detection systems are able to alert authorities, they are often too late to prevent property damage and in some cases, lead to a loss of life. With electric stoves becoming more and more popular, the amount of fires that these stoves cause will only increase.

Solution:

The best way to prevent major fire damage is to notify the user if the stove catches fire as well as shutting off power to the stove before any additional fires occur. The user will be notified with a loudspeaker and the stove will be shut-off. This will be a 2-part system with minimal wiring, due to the intended proximity to the stove. The main device will be attached to the hood of the stove and the peripheral shut-off device will be attached between the wall receptacle and the stove power wire.

This device provides another level of security for the user in fire prevention. Should the user need to step away from the stove at any time, the device will be able to shut off the stove and notify the user if any fires occur.

High-Level Requirements List:

1. The device should be able to detect the number of burners that are on within **15** seconds.
2. It should start aiming the suppression system and cut power to the range within **2.5** seconds of an active fire.

3. The system will actuate the suppression system within **5** seconds after the power has been cut.

Design

System Block Diagram:

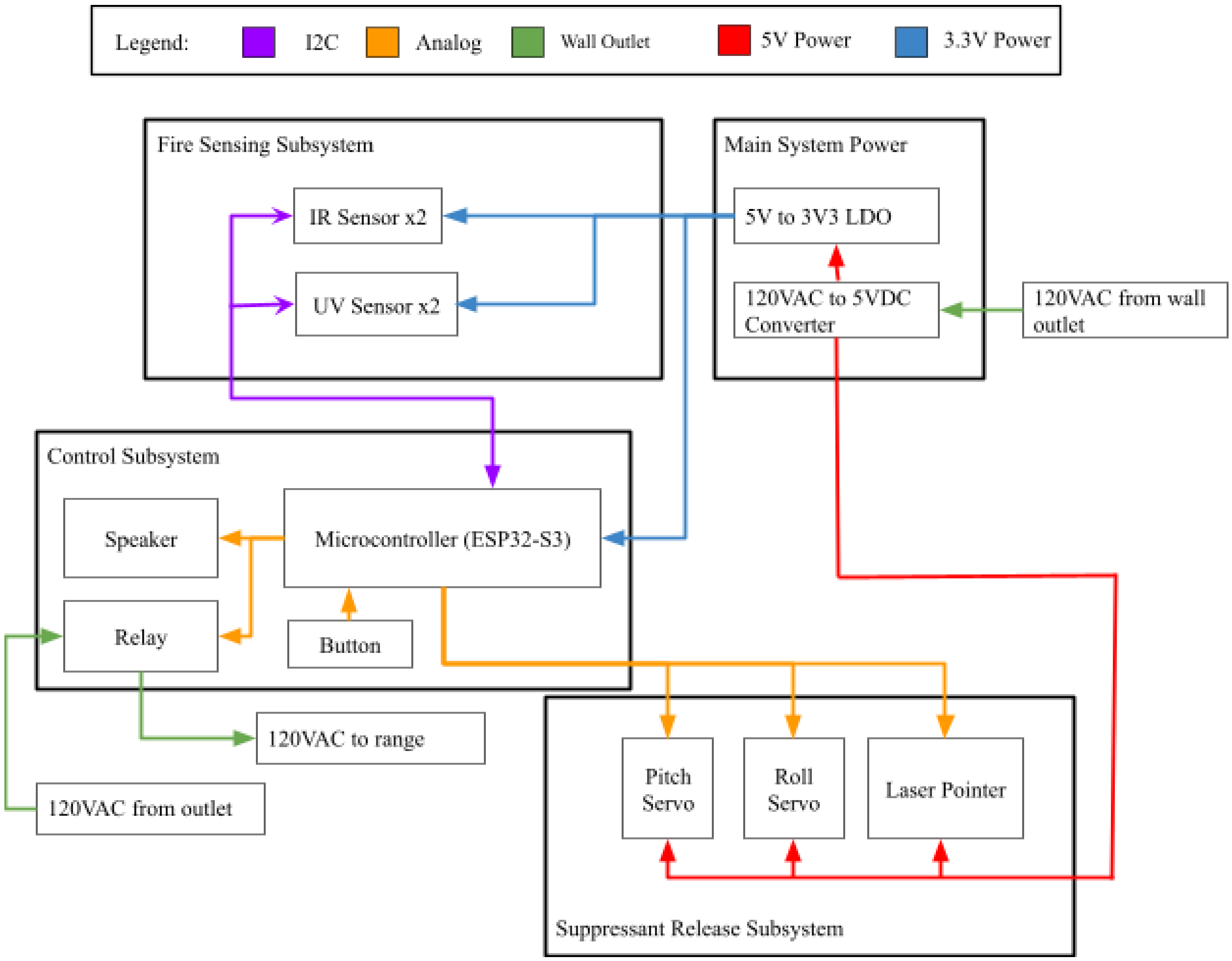

Figure 2: System block diagram with detailed subsystem blocks

Subsystem Descriptions:

- Main System Power
    - This block handles the system power regulation required for each component on the device. Without the linear voltage regulator or the buck-boost converter, the system would have to be powered by 5V and other system components would be limited to a 5V supply.
    - Our requirement for this subsystem block is to be able to detect 3.3V +/- 0.1V at the devices that require it like our sensors. We will verify this by using a digital multimeter and measure the voltage across the Vcc and ground pins of the devices that need 3.3V
    - Components:
        - 120VAC/5VDC Converter: Standard 5V USB block used to power the device from a US-standard wall outlet.
        - 5V to 3V3 LDO: Converts 5V to 3.3V required for the IR and UV sensors
        - Buck-Boost Converter: Converts 5V to 6V for components in the suppressant release subsystem

- Fire Sensing Subsystem
    - This subsystem is responsible for detecting key properties of a combustion reaction which are IR emission and UV emission. This data is sent to the microcontroller for processing and will be powered from the main system power subsystem.This subsystem will succeed if each of the sensors is capable of reading their respective measurements at the rated accuracy and precision.
    - Components:
        - IR Sensor: Sensor to measure temperature. It communicates to the microcontroller using I2C communication protocols. It needs 2.6-3.6V for operation, which is supplied from the LDO. It can measure up to 200℃. This sensor must be capable of measuring the temperature of the measured area within ±1.5 deg C. We can verify this by using a heat source with a known temperature and measuring against that.
        - UV Sensor: Sensor for detecting ultraviolet electromagnetic frequencies in the 260-360 nm range. It communicates with the microcontroller using I2C communication protocols. It needs 2.7-3.6V for operation, which is supplied by the LDO. We needs this sensor to be capable of be capable of detecting changes(+- 10 counts) of UVa and UVb emis-sions within 1 second of a change
- Control Subsystem
    - This subsystem handles communication and data from the sensors. Depending on the data will make a decision to activate the suppressant release subsystem and trigger the speaker and relay. The subsystem will succeed if it can successfully detect a fire using the data from the sensors with a false-negative rate of <1% and a false-positive rate of <10%.
    - Components:
        - Microcontroller (ESP32-53): The MCU processes data from the sensors and determines whether or not a fire is present. It also determines the location of an

active fire (or heat signature) and engages the suppressant release subsystem, speaker, and the 240VAC relay. The microcontroller must be capable of determining the location of a fire within 3 seconds of a fire. We can measure this by starting a controlled fire in the range of the sensor and seeing the output of the microcontroller

    - Speaker: The speaker will play a pitch at around 1kHz to send an audible alert to the end-user. The microcontroller must be able to actuate the speaker after the detection of a fire. We can verify this audibly
    - Relay: The relay passes power through from the wall outlet to the range, allowing the microcontroller to control power to the range. The microcontroller must be able to trigger the relay and stop the flow of power. We can verify this by hooking up a simple LED circuit and verifying that the LED does go off when the relay is triggered by the mcu.

- Suppressant Release Subsystem
  - This subsystem controls the position and the actuation of the fire suppressant onto the detected fire. This subsystem will also contain the fire suppressant itself and a downward-facing valve, whose pitch and roll can be adjusted using servos. A solenoid will manage the release of the sealed suppressant. The control subsystem will manage the position of the servos and the state of the solenoid.
  - Our pan-tilt servos must be capable of positioning themselves according to the PWM signals sent by the mcu. We can verify this by sending a predetermined PWM signal to the servos and using a protractor, measure the resulting angle in the servos.
  - Finally we need the solenoid to be able to actuate given a signal from the mcu. This is something we can visually verify upon a signal from the mcu.
  - Components
    - Pitch Servo: Closed-loop servo for adjusting the pitch of the valve. It is controlled by the MCU.
    - Roll Servo: Closed-loop servo for adjusting the roll of the valve. It is controlled by the MCU.
    - Solenoid: Limits the flow of the suppressant.

Tolerance Analysis

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

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.\\

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.

Ethics and Safety

Ethics:

- Accuracy and False Positives/Negatives (IEEE Code of Ethics 1.2): Ensuring the systems accuracy in detecting fires without generating false alarms is important to unnecessary disruptions and cost 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.

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.

https://www.prolinerangehoods.com/blog/cooking-fire-statistics-safety-tips/