ECE 445
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Project #81: Fire and Gas Detection with Real-Time LED Navigation

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1. Introduction

1.1 Problem

Fires come unexpectedly at times and can pose a risk in many homes. Whether you have guests over who aren't very familiar with your home, or maybe you are staying at an Airbnb rental home so you are less familiar with exits. In the night, a fire could possibly happen in the middle of your sleep and panic will set in. Commercial smoke detectors in the market currently only give users the ability to call first-responders immediately and sound an alarm where there is a hazard detected in the home. The problem with these smoke detectors is that help isn't immediate, responders take a little while to reach home and smoke can blind your vision during your escape to an exit. A way to mitigate these hazards while also ensuring the best route to safety is what we have planned.

1.2 Solution

Our proposal is to create a smoke detector system with an advantage of giving families the most optimal route to safety given a hazard. For the basics of our system, we still plan to have our system be able to detect gasses such as carbon monoxide, and other flammable gases such as methane and propane. When any hazard such as these gasses or fire is detected, an alarm will sound and first responders will be notified of the hazard that is happening at the house. All of this is already done by modern smoke detectors, but our system will do even more. First, when a fire hazard is detected by our sensors, the HVAC system will shut off so as to not blow air through the vents and at the same time we will close all vents so as to help weaken the fire in its place. At the same time, LED's will be flashing which will indicate which route families should take to get to the safest exit that exists under the circumstances presented. An application will be provided where users will have to input their floor plan so that the system knows the basic layout of the house. From this, users will be able to tell the application where the sensors are located around the house, this is important as each sensor will have an LED indicator that will light up if the family should take that path that the sensor is located at. All of this will be governed by an algorithm which will relay all this information to the control unit so that all the proper indications work as intended and the family will be able to reach safety even if they aren't familiar with the house.

1.3 Visual Aid

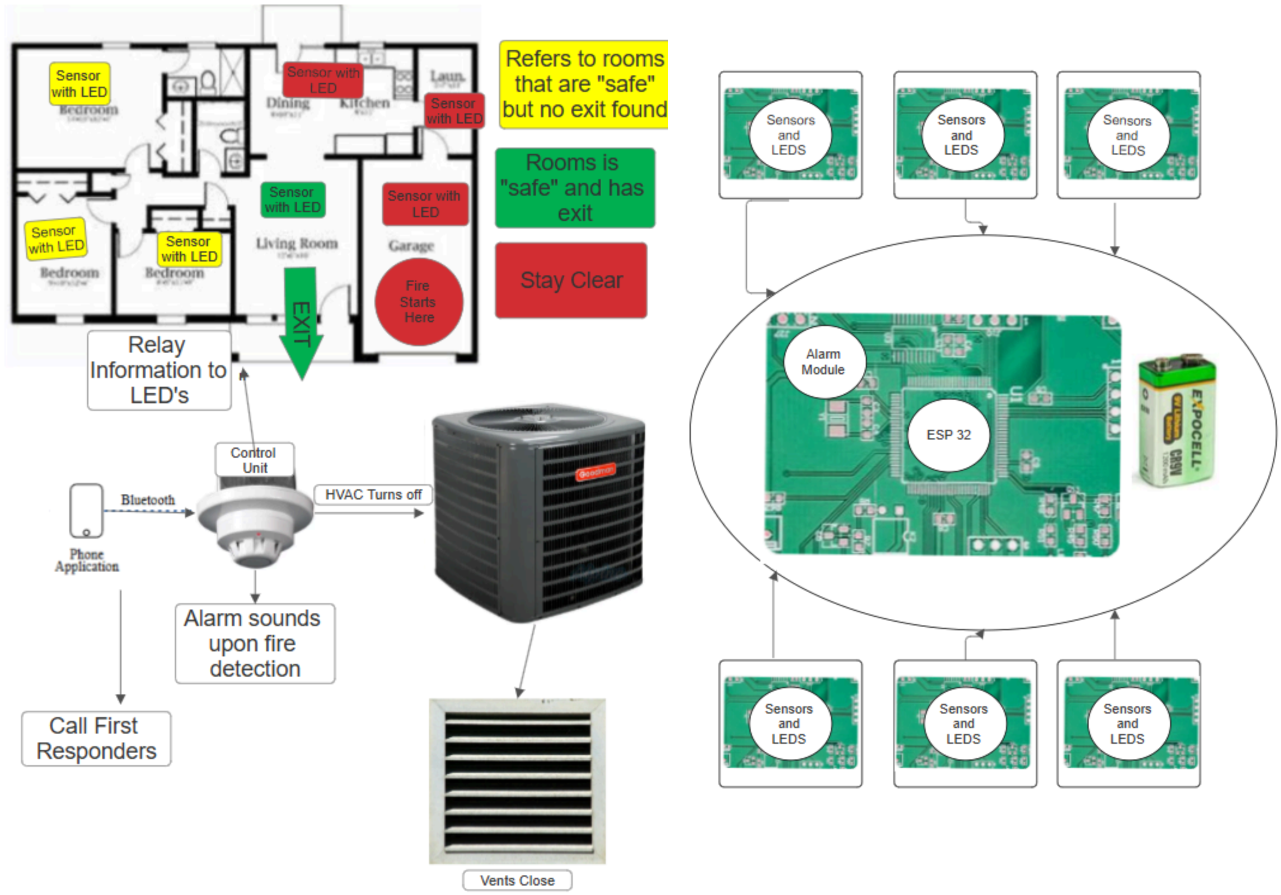

Figure 1: Visual Representation

1.4 High-level requirements list

- Application will consist of a place where you can layout your floor plan by designating rooms with connections such as doors that lead to other areas in the house along with the location of sensors and exits. The algorithm will isolate rooms that are affected and designates an exit that is furthest from the fire with 100% accuracy.
- Once a threshold of 90℃ is reached on the temperature sensors indicating a fire, a signal is sent to the control unit along with an alarm sounding and first responders being alerted to the hazard. The gas sensor will sound the alarm when a Carbon Monoxide (CO) level greater than 20 ppm is present.

- When a fire is detected the HVAC will turn off and the vents will close 100% of the time.

2. Design

2.1 Block Diagram

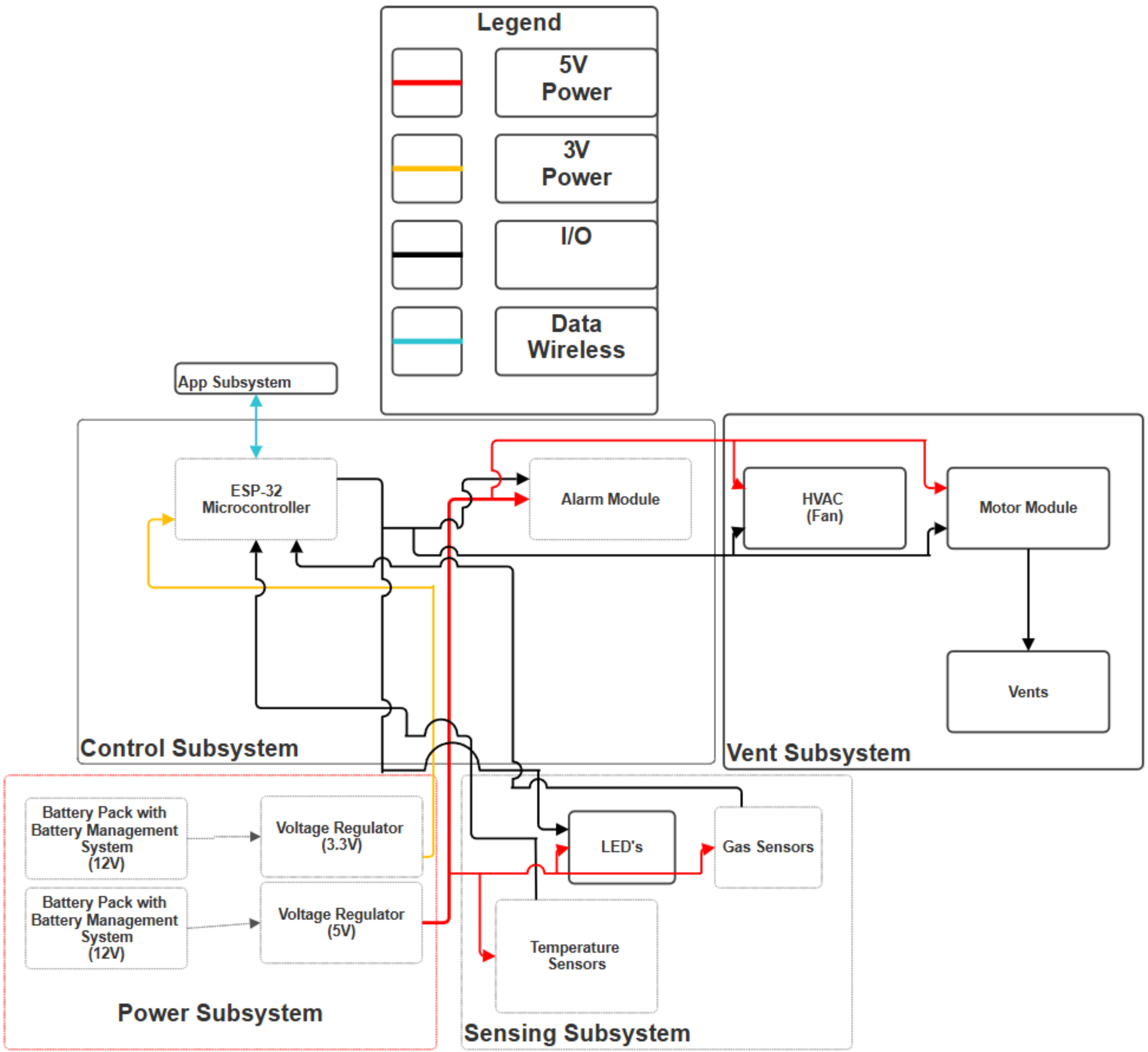

Figure 2: Block Diagram of System

2.2 Subsystem Overview

2.2.1 Subsystem 1: Temperature and Gas Sensors

Outside of the main smoke detection unit, we will have temperature sensors which will be placed in designated rooms in order to give our control unit relevant information about where the hazard has originated from. They will also contain the LEDs to lead inhabitants to the designated exit and alarms to notify them of any hazard detected. The temperature sensor will be the LM335AH which will be capable of measuring temperatures up to 100℃, and our gas sensor will be the MQ-9 which will be capable of measuring carbon monoxide between 20 ppm - 2000 ppm. Based on standard single family homes, we have concluded that there was an average of between 7-8 rooms per house. Therefore we decided on choosing 7 sensors overall that we will be using. The gas sensor will be exclusive to the main control unit while temperature sensors will be a part externally placed on each room. There will be 3 colors of LED's for distinction, Red for fire, yellow for safe room but no exit, and green for safety and exit. These LED's will also be powered by the 5v DC and will be found in each sensor board.

2.2.2 Subsystem 2: Vents

This will be a motorized controlled vent that will open and shut depending on whether a fire hazard is detected. The important feature about this is that we will need to be able to shut the HVAC unit first before the vents shut. This is due to the buildup of air pressure that will occur if the HVAC is left on as air will continue to flow through the vents that are now closed. In place of an HVAC unit, our plan will be to use a Fan that will turn off as soon as the fire is detected and the signal is sent to the control unit which will then be in charge of turning off the fan. For our motor, we will be utilizing a standard 5V Stepper Motor as it is a relatively cheap motor and simplest motor for our purposes of opening and closing a vent. In order to close we will need to incorporate an H-bridge that will give us the facility of moving the vent up and down. Now, due to us compensating for a weaker motor at 5V, we will be making a smaller sized vent to ensure our motor can handle the load.

2.2.3 Subsystem 3: Control

The control system will be in control of receiving data from the sensors which will then be stored in the application. Our ESP32 will be in control of making this communication happen between our hardware and software. The ESP32 has a Wi-fi & Bluetooth module which makes it possible for us to give and receive information from the application. Our ESP32 will be in charge of also relaying output information to our alarm and LED and making sure that these systems only sound or light when a hazard is detected. The alarm will be a CMI-9605IC-0580T magnetic buzzer indicator capable of producing a sound of up to 80dB which would be enough to alert everyone of a hazard that is detected. The device is rated for 5V and has minimum current consumption at 30mA.

2.2.4 Subsystem 4: Application

The application subsystem will be the primary user interface where the homeowner can configure their floor plan, sensor placement, and exit locations. It will be built using React and allow the user to drag and drop elements to define rooms and their connections. The application will communicate with the control unit using Firebase, utilizing Firestore for real-time sensor data updates. Upon detecting a hazard, the app will run a pathfinding algorithm to determine the optimal escape route and relay the information to the control unit for activating the LED and HVAC systems.

2.2.5 Subsystem 5: Power Supply

We will be using 1200mAh, 9V high-capacity lithium-ion batteries. The batteries, with the battery management system along with the voltage regulators will then power everything including the sensor system, the control system, and the motorized vents. A sensor will also be connected to check the remaining charge of the batteries, which will be sent to the app for the user to see when the batteries need to be changed. The voltage regulator used will be a LM317T 3-Terminal Adjustable Regulator which will allow us to convert the 12V to our desired voltages of 3.3V and 5V.

2.3 Subsystem Requirements

2.3.1 Subsystem 1 Requirements:

- At room temperature (25℃) the accuracy of our temperature sensor will be ±1℃. For temperatures on the extreme side (~100℃) we will operate with a ±2.7℃ accuracy.
- The gas sensor will update the value of carbon monoxide concentration every 90 seconds with a ±1 second difference.
- The gas sensor will update the value of flammable gas concentration every 60 seconds with a ±1 second difference.
- The gas sensor will operate at 5V with a ±0.1 threshold.
- LED’s will provide a minimum of 3000mcd to ensure proper visibility.

2.3.2 Subsystem 2 Requirements:

- The fan will always shut off when a fire is detected to prevent the flow of air.
- Vents will always close when a fire is detected to help weaken the spread of fire.
- The Stepper Motor must provide enough torque at 200g cm min to ensure that the vent will close and open properly.

2.3.3 Subsystem 3 Requirements:

- ESP32 must be able to provide sufficient interfaces and GPIO pins to support simultaneous connections of:
    1. Temperature Sensors
    2. Gas Sensors
    3. Alarm Module
    4. LED's
    5. Application
- ESP32 will have a Xtensa dual-core 32-bit LX6 Microprocessor operating at a clock speed of 240MHz and will be able to perform at up to 600 DMIPS (Dhrystone MIPS).
- ESP32 will have 520KB of SRAM and consist of a flash memory of 4-16MB, 512 Bytes of which are used to store data.
- At 5V and in the presence of a hazard, the alarm must play a sound of 80dB capable of being heard throughout the house.

2.3.4 Subsystem 4 Requirements:

- The application will communicate with the control unit via Wi-Fi with at least 98% reliability.
- The pathfinding algorithm must determine the safest exit route within 2 seconds of hazard detection.
- The app must communicate the escape route to the control unit within 5 seconds of hazard detection.
- The app must consistently receive sensor data while connected in real time.

2.3.5 Subsystem 5 Requirements:

- Voltage Regulators will be able to maintain a steady output of 3.3V and 5V with a maximum load regulation accuracy of ±1.5%.
- The Ion-Lithium battery pack must be used with a battery management system.

2.4 Tolerance Analysis

In our project, we are using an adjustable voltage regulator, this means that the output voltage will not always be guaranteed to give us the desired voltage that we want as resistors have tolerances that will cause some difference in what we calculated vs what we expect to see. The voltage regulator output can be expressed as Vo = V_ref(1+R1/R2) + (Iadj * R1). Here Iadj is the current that will flow from the middle pin of the regulator and this current is generally very small so the effects can be neglected at times. R2 is typically set at 240 ohms for these devices and V_ref is set to be 1.25V, the minimum voltage allowed by the device. So, ignoring the Iadj*R1 term, we can then come up with a value of R1 that should give us an output voltage of 5V, in this case we would select R1 = 720 ohms. Upon simulating, you would see the following results:

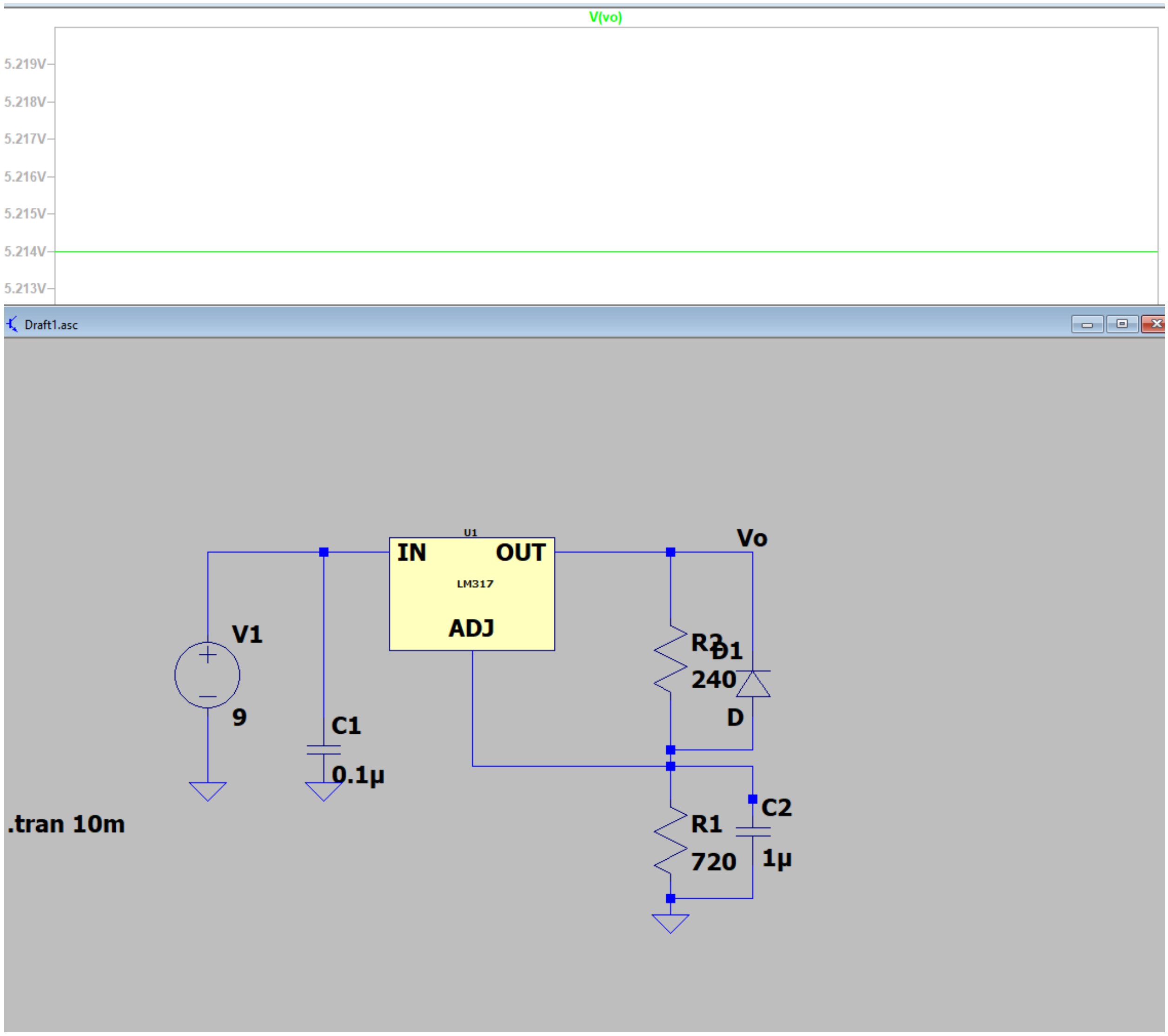

Figure 3: Simulation of LM317 Voltage Regulator

We see here that the value we see isn't exactly 5V, and the reason for this is because we are neglecting the current that we assumed to be small coming out from the ADJ pin. Also, while the reference voltage is typical 1.25V, this value could range from 1.2V - 1.35V depending on the condition, so, with this we can find the current coming out of the pin ADJ by using ohm's law across R2. In doing so, we get that I2 min = 1.2/240 = 5mA, and I2 max = 1.3/240 = 5.625mA. This value is pretty significant and would be enough to cause our voltage to vary from what we expect to see, the voltage produced across R1 would be 720*5mA = 3.6V minimum and 4.05V maximum. And when we add this values to our references voltages across R1, we can see that the output can actually range from 4.8V-5.4V. Fortunately, most of our sensors that we have connected to can maintain these ranges of values as well as our ESP32 which will be connected to a 3.3V regulator. One thing that may still need to be taken into consideration would be the tolerances of real resistors, this could inflate these numbers a bit higher, so making sure that our devices can handle these changes is important.

3. Ethics and Safety

In our project, we strive to meet the requirements laid out in the IEEE Code of Ethics to ensure that our fire and gas detection system will help to improve the lives of its users by keeping them safe in dangerous situations. Our main emphasis is on the health and wellbeing of our project's users, so we intend to strictly adhere to Section I.1 of the IEEE Code of Ethics which instructs us to keep the safety and health of the public as our highest priority, which includes the disclosure of any problems our project may face that would jeopardize the safety of its users. [1]

Another ethical concern that arises from our project is the collection of personal data as we will be using an app to send the floorplan of the users home to the control unit. According to the ACM Code of Ethics Section 1.6, we will ensure our users' right to personal privacy by only using the data relevant to the operation of our project and making sure that data is secure and only accessed by the control unit of our system. [2]

One safety concern of our project is the use of 9V batteries to power our project. We will make sure that our batteries are protected from any accidental faults in our project in order to protect against any damage that may be done to our other systems or to the batteries themselves.

Another safety concern is with the testing and operation of our project in the labs. We will be testing our sensor's response to fires and carbon monoxide so it is important to follow lab safety guidelines and make sure that all tests are done in a controlled and well ventilated environment for everyone's protection. Extra precautions will also be taken when transporting dangerous materials we may be testing.

The operation of the automatic vent system also poses a safety concern as it may be dangerous for the user to handle it while it is in operation. To ensure the safe handling of the automatic vent closure, considerations will be made to encapsulate as many moving parts as possible in order to minimize the risk of an accident happening if the vent closure system activates while handling. In addition to ensuring safe handling of the vent closure, we must also ensure the deactivation of the HVAC system for not only the protection of the HVAC system itself, but for the protection of the user from any issues that may arise if it doesn't turn off.

4. References

[1] IEEE, "IEEE Code of Ethics," ieee.org, Jun. 2020.
https://www.ieee.org/about/corporate/governance/p7-8.html

[2] ACM, "ACM Code of Ethics," ACM, [Online]. Available:
https://www.acm.org/code-of-ethics