Real-Time Fire Escape Plan

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1 Introduction

1.1 Objective

Current fire escape routes are rigid and do not adapt to quickly changing situations during a fire. Fire alarms will tell you only that there is a fire, but not where that fire is located. If a fire has engulfed the escape route, already frightened people can panic and be trapped in a building without knowledge of where to go.

Our goal is to create a system which will adapt to a fire based on temperature and smoke density and direct occupants within the building toward the nearest safe exit using LED arrows and a building map phone application.

1.2 Background

The ideal application for our system is a large building with many exits, hallways, and rooms with an asymmetrical layout. For example, a hospital has many patient rooms and escape routes, and occupants who are often unaware of the fire escape route. When the fire alarm is triggered, this can cause mass confusion and panic as patients frantically find an exit based on posted signs which convey no information regarding the status of the danger. According to the National Fire Protection Agency, there were an estimated 5,750 fires with an average of 2 civilian deaths in health care facilities between 2011-2015 [1]. Since the leading death toll in these fires is with ill residents who are presumably unfamiliar with the building, our goal is to reduce the number of deaths by directing them out of the building automatically.

In addition, a minor flame can quickly turn into a major fire within 30 seconds [2]. When this happens, a raging fire can produce thick black smoke that fills nearby areas. This smoke can develop within just one minute [3] inhalation of this smoke can cause permanent lung damage. Carbon Monoxide alone is dangerous at concentrations as low as 50 parts per million [4]. This problem is especially relevant to potentially panicked building occupants as they might run directly into a smoke filled room/hallway. Asphyxiation is the leading cause of fire deaths, exceeding burns by a three-to-one ratio, so knowing where to run to escape is extremely important.

Currently, the focus of innovation has primarily been in residential homes, whether that is aiding the action of leaving the building, or installing smarter home fire alarms. There is little to no discussion on how to improve fire escape plans for commercial and industrial buildings. Additionally, while some projects such as Google Nest [5] have created networks that provide more information regarding the location of danger, no solution on the market gives visual indication of the safest escape route. Although knowing only the location of a fire may be helpful for a small building with which occupants are very familiarized, such as a home, having real-time exits signs will aid in the escape for occupants unfamiliar with the layout of the burning building.

1.3 High-Level Requirements List

- The smoke detectors and thermocouples should relay measured data back to the master logger.

- The LED display system should light up arrows based on sensor data, showing the direction of escape.

- The phone application should display a map of the building and show changing heat and smoke data in real time.

2 Design

The “Master Logging” block will be the main controller of the system. The microprocessor will be loaded with a maze solving algorithm that determines safe paths to exit the building. The maze in this scenario will be a blueprint of the building that marks all possible exits.These safe paths will be updated in real time using feedback from the sensor modules. The “Sensor Module(s)” are comprised of a smoke and temperature sensor. They will be placed strategically around the building. They communicate air quality and heat data wirelessly using WiFi back to the master logging board. Once the logging board has determined the optimal path, it will use WiFi to communicate to the “KED” block. This block will be LEDs placed on the floor at an intersection of hallways and at exits. This block receives data from the master logging board and lights up an LED indicating the correct direction to move. An example of this floor sign system at an intersection is seen in Figure 2.

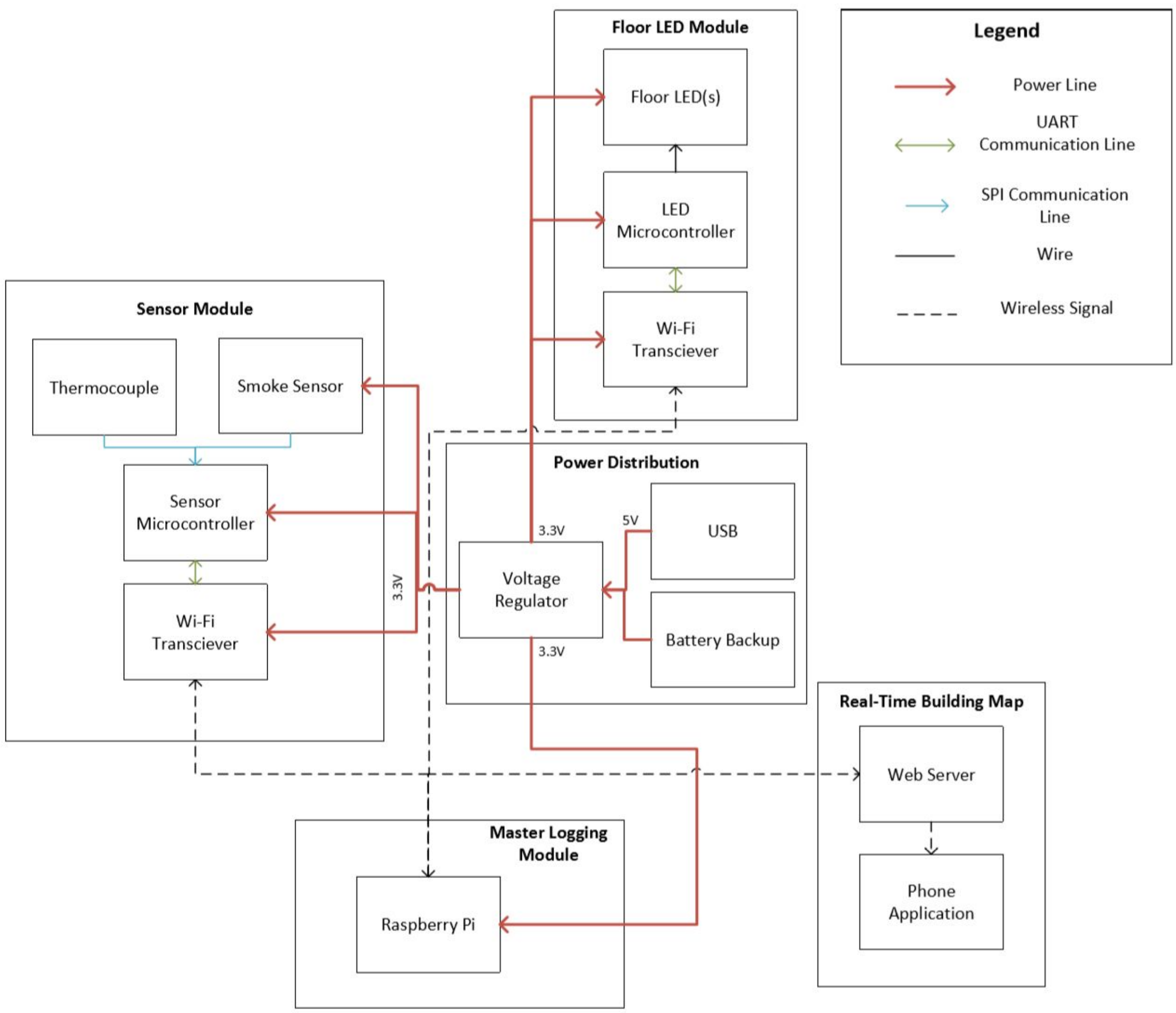

Figure 1. Block Diagram

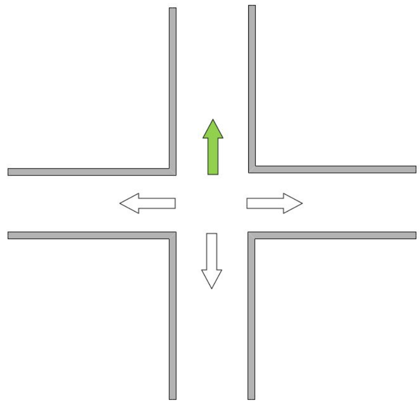

Figure 2. LED Arrow System

2.1 Power Distribution

The power distribution system is a sub-module which will be common to each of the Sensor, Floor LED, and Master Logging modules. Its purpose will be to provide the necessary voltages to power each of the integrated circuits throughout the design.

2.1.1 Main Power

120 VAC wall power must be converted to 5 VDC to power the sensor and floor LED modules. To do this we will use a wall adapter that connects to our PCBs via a barrel jack connector.

2.1.2 Battery Backup

In order to ensure that the system is operational in the event that the fire causes an electrical outage in the building, each of the modules will contain a backup battery system. The batteries will be placed in a pack and connected directly to the power system of the PCB.

As shown in Figure 4, the output of the 5V power adapter will control a PMOS transistor. This transistor will turn on whenever the main power is lost and will conduct such that the battery is then connected to the system. Diodes are also placed in the circuit to ensure that no current flows in the wrong direction and damages the system.

Requirement	**Verification**
1. The system outputs 300-500mA, at a minimum of 3.3V, for 1 continuous hour.	1. a. Disconnect the 5V power adapter and connect the battery. b. Connect a multimeter to the output of the battery backup system. c. Connect a DC electronic load

2. Supplies 3.3V +/- 0.2V within 10μs of main power removal.	to the output of the battery backup system. Set the load to constant current mode with a setpoint of 500mA. d. Begin a timer and wait for at least 1 hour to ensure that the output of the backup system is at least 3.3V for the entire duration. 2. a. Connect the 5V power adapter and battery to the PCB. b. Connect an oscilloscope probe to the output of the 5V power adapter and the output of the battery backup circuit. c. Remove the 5V power adapter. d. Using the oscilloscope, measure the time between the removal of the 5V power adapter and the stabilization of the output voltage to +/- 5% of its nominal value.

2.1.3 Voltage Regulator

The voltage regulator will bring down the 5V power provided by the battery/USB to the 3.3V required by many of the integrated circuits utilized on the PCBs. In some cases, an integrated circuit used on the board may have the option of using a 3.3V or 5V supply. In these cases, we will use the 3.3V power provided by the voltage regulator due to the reduced noise. The output of the regulator will be decoupled with multiple capacitors of mixed impedances to also improve noise immunity.

In order to protect the battery when it is powering the circuit, we will also utilize the enable pin on the voltage regulator. We will do so by making use of a voltage monitor IC which holds the enable pin high unless the voltage sensed at the sense pin reaches the value of the internal voltage reference of 400mV. The sizing of the resistor divider to create our desired functionality is performed in section 2.6.2.

Requirement	Verification
1. Step down a maximum of 5.4V input to a 3.3V output +/- 0.2V for up to	1. a. Connect a 5.4V power supply

400mA of constant current load.	to the input of the regulator. b. Connect a DC electronic load to the output and set the load to constant current mode with a setpoint of 400mA. c. Use a multimeter to measure the output of the voltage regulator and ensure that the voltage is within 0.2V of 3.3V.
2. Cut off power when the supply voltage reaches below 3.4-3.6V.	2. a. Connect a 5V variable power supply to the input of the regulator circuit, indicated by the +5V node in Figure 6. b. Connect a digital multimeter to the Vout pin on the circuit shown in Figure 6. c. Slowly step down the 5V power supply until it reaches 3.5V. Ensure that the multimeter reads 0V at some point after the power supply goes below 3.4-3.6V.

2.2 Sensor Module

The Sensor Module will be the module which allows the system to determine the location and intensity of a fire located in the building. It will take in the temperature and smoke density in the air and transmit the data to the Master Logging module to be processed.

2.2.1 Thermocouple

The thermocouple will be the method by which the system determines the ambient temperature. As the fire increases in intensity, it will be assumed that the ambient temperature will likewise increase significantly. This information will be used to determine the safest, shortest path to the exit. It should also be used to determine if a certain path can be traveled despite the presence of a fire. In certain cases, it may be possible for an escapee to travel through an area where a fire is present if the temperature and smoke content is deemed to be at a safe level. We will use a K-Type thermocouple due to its wide temperature range and long lifespan at high temperatures.

Before the thermocouple data is passed to the sensor microcontroller, it must first be converted from an analog to a digital value through a very precise Analog to Digital Converter (ADC) designed specifically for reading thermocouple data. This device will be the MAX31855K, as shown in Figure 7. The device will communicate with the sensor microcontroller over SPI.

2.2.2 Smoke Sensor

The Smoke sensor will be the method by which the system determines the parts per million (ppm) of contaminants in the immediate area. A higher ppm detected is assumed to be a larger density of smoke in that area. The sensor is used to determine unsafe air quality conditions and combined with the thermocouple, will determine if the area is safe to travel through en route to an exit.

2.2.4 Sensor Microcontroller

The Microcontroller is the module that processes sensor data. It will take the digital sensor data and hand it off over UART to the Wi-Fi module to be sent to the logger. It will also act as the main controller for the Wi-Fi module, interfacing with the Wi-Fi module's RTOS to tell it when and where to send data.

2.2.5 Sensor Wi-Fi Transceiver

The sole purpose of the Wi-Fi transceiver within the Sensor Module is to send sensor data to the logger for processing.

2.3 Master Logging Module

The Master Logging Module will act as the main information hub for the system. All of the sensor data will be sent to the logger. This data will then be processed in the context of the maze implementation of the building in order to calculate the floor LEDs which should be turned on. The collected data will also be sent to a server to be further processed by a phone application.

2.3.1 Raspberry Pi

The Raspberry Pi microprocessor is the device which will determine what parts of the building are most dangerous based on the sensor data and utilize a maze solving algorithm to find the safest and quickest path through a building. The map of the building as well as the locations of each of the smoke sensors and floor LEDs would be mapped out in the on-chip memory of the processor. This will allow us to program the chip to follow walls and avoid locations where sensors read a high temperature or smoke value. Once the path is determined, the location of the LEDs which are passed by the determined path are sent to the Wi-Fi module to be transmitted.

2.4 Floor LED Module

The Floor LED modules will be the main visual method by which the system directs escapees safely out of the building. At each intersection with more than one possible direction to turn, there will be a set of LEDs which will remain off unless the system determines that the safest escape route involves turning in their direction.

2.4.1 LED Microcontroller

The main role of the microcontroller in this module will be to parse the data sent over Wi-Fi by the logging module. This data will contain the device addresses of the LEDs which should turn on or off. Since there will be multiple Floor LED modules, each of the microcontrollers will be programmed with the device addresses of the LEDs to which it connects. This way, when the microcontroller matches its device addresses to those which are sent by the logging module, it can turn on the correct LED(s).

2.4.2 LED Wi-Fi Transceiver

The sole purpose of the Wi-Fi transceiver in this module is to pass off the data sent by the logging module onto the microcontroller.

2.4.3 Floor LED

The floor LEDs will be arrays of LEDs located on the floor at each possible intersection with more than one turn throughout the building. The LEDs at each intersection will all be connected to a single microcontroller, but only the LEDs which follow the safest exit path will be turned on at a time.

2.5 Real-Time Building Map Application

This block would consist of all of the software needed to display sensor readings on a blueprint of the building on an app. This would include the database used to store the data collected from the sensors and the app which would display the data and use the data to assist with escape.

2.5.1 Web Server

The software would interface with the hardware by sending data through Google's Firebase database. We would receive the data from the master logger and would send the data to the phone application. The data would be sent over Wi-Fi for both the logger-database interaction and the database-application interaction.

2.5.2 Phone Application

This app would be developed on android to show a floorplan of the building and all of the escapes. The app would also show a heatmap of the building showing where the building is the hottest and has the most smoke.

2.6 Calculations

2.6.1 Battery Capacity Calculation

Sensor Module			
Function	Parts to Use	Voltage Input	Current Draw (Theoretical Max) (mA)

Wifi and Antenna	ESP-WROOM-02	3.3V	170
Thermocouple	240-080	N/A	0
Thermocouple ADC	MAX31855KASA+T	3.3V	0.9
Smoke Sensor ADC	ADS7833	3.3V	3
Microcontroller	ATmega32U2	3.3V	6
Voltage Regulator	TPS70930DBVR	2.7V-5.4V	0
PG LED	445 Lab	3.3V	0
PG Resistor	445 Lab	2.6V	0.26
Total			180.16

$$Total\ current\ draw\ =\ 180.16mA$$

If we are to discharge the battery at a rate of C/5 (C is the total current capacity of the battery) or lower, our current capacity for the sensor module will need to be:

$$Battery\ current\ capacity\ (mAh)\ =\ Total\ current\ draw\ (mA)\ *\ 5$$

$$Battery\ current\ capacity\ =\ 900.8\ mAh$$

Battery	Capacity
Alkaline	2000 mAh

Therefore, a standard AA Alkaline battery with a capacity of 2000mAh will provide enough capacity.

2.6.2 Resistor Divider Sizing for Voltage Monitor Circuit

The minimum voltage that we will allow for the supply to reach will be

$$V_{mon(UV)}\ =\ V_{out}\ +\ V_{dropout}$$

Where $V_{dropout}$ is the dropout voltage of the linear regulator, which is equal to 0.2V, and V_{out} is the output voltage of the linear regulator, which is equal to 3.3V. Therefore,

$$V_{mon(UV)}\ =\ 3.5V\ .$$

From the TPS3711 datasheet, we know that

$$V_{mon(UV)} = (1 + \frac{R1}{R2}) * V_{IT-}$$

Where V_{IT-} is the value of the internal voltage reference, equal to 0.4V. So,

$$\frac{R1}{R2} = \frac{V_{mon(UV)}}{V_{IT-}} - 1 .$$

$$\frac{R1}{R2} = 7.75 .$$

In order to save power and not sink battery current in the case of the circuit being off, we'll want both of these resistors to have a very high value. We can use:

$$R_1 = 1M\Omega = 7.75 * R_2$$

$$R_2 = 129.03k\Omega.$$

The power consumption when the output of the voltage monitor is low will therefore be no larger than:

$$P = \frac{V^2}{R_1+R_2}$$

$$P = 10.9mW .$$

2.8 Physical Design

There will be no physical design for the escape system itself. However, we will require a small scale model layout of a building in order to demonstrate the working system. This model will be a top-down view of a building we have designed. The frame of the building will be constructed of sheet metal aluminum and we will use aluminum boxes screwed into the base to simulate rooms and walls within the building.

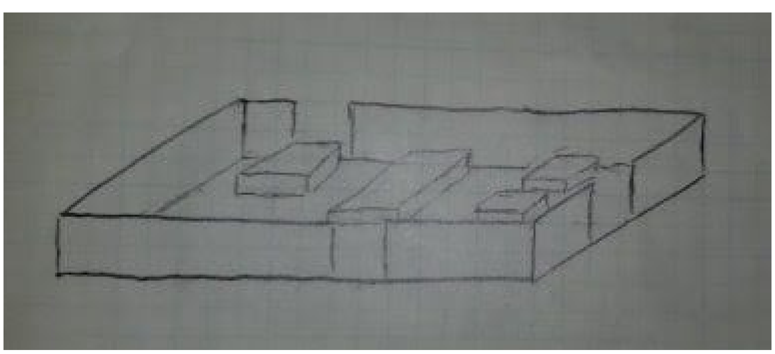

Figure 3. Mock Building Design

2.9 Circuit Schematics and Simulations

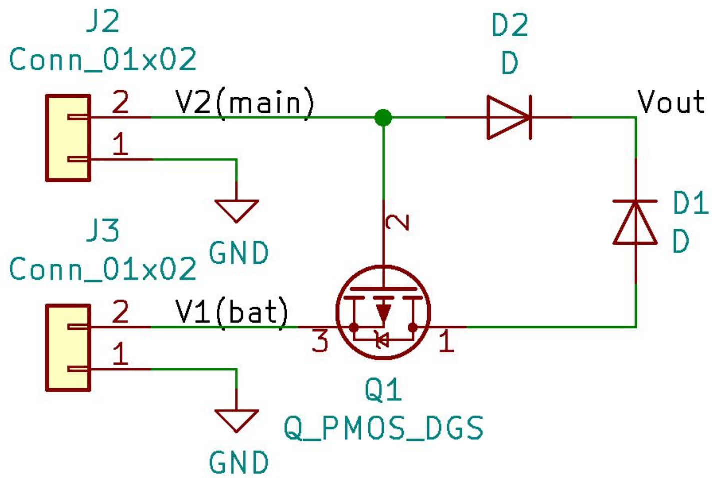

Figure 4. Battery Backup Circuit

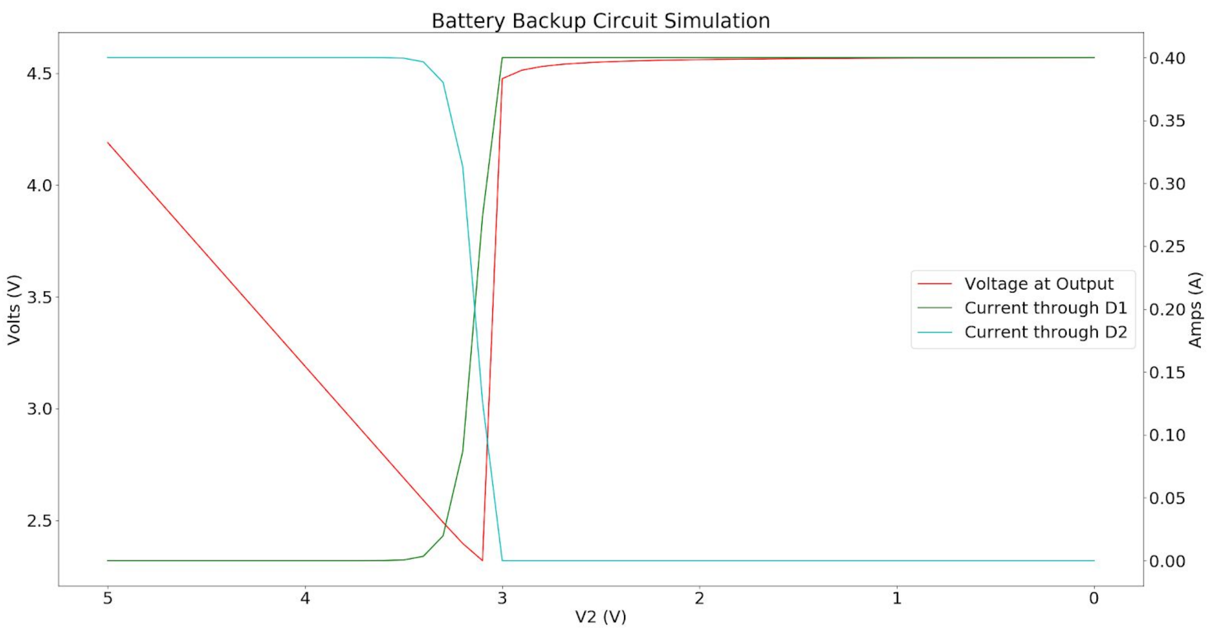

Figure 5. Battery Backup Circuit Simulation

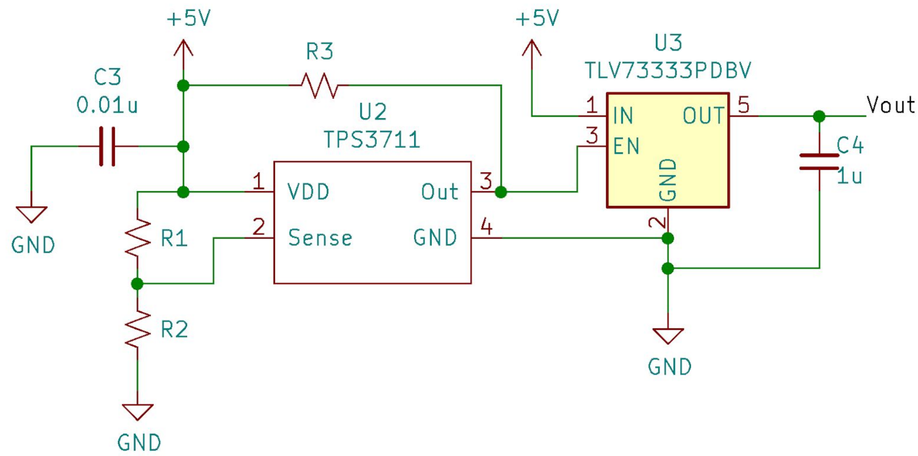

Figure 6. Voltage Regulator Circuit

2.10 Tolerance Analysis

The master logging module will prove to be the most challenging part of our project. We will need to be able to wirelessly transmit data across a building to interact with multiple nodes across hundreds of feet. Particularly for larger buildings, there will be hundreds of nodes since every intersection is going to contain one wireless node. This will require a lot of communication occurring throughout the building and we will need to have a way to check that the correct data is being sent to the correct node.

4 Discussion of Ethics and Safety

Our users do not interact with our system in the usual way. The system only directs people to a safe exit, so our biggest safety issue is with the floor LED system. It is possible for building occupants to misinterpret the signs, leading to people not leaving the building in an efficient and safe manner. In order to avoid misinterpretation, we have tried to simplify our sign system as much as possible. As seen in Figure 2, the system will be arrows placed on the ground, and the arrow that lights up shows the correct direction to move.

In a similar light, if the system malfunctions or fails, it may end up directing people into an unsafe area. Our solution to this problem revolves around the floor LED subsystem to not latch a value sent by the master logging subsystem. Once the master logger sends a packet of information, the floor LED PCB will light up the corresponding arrow for a short duration, and then turn off all arrows. It will then wait for the next set of instructions from the master to relight an arrow. This way if the logger fails, there will be no arrows lit up to potentially misdirect people.

Another safety issue that could occur is in the case that no exit has a safe escape path. If all exit paths are compromised, the escapee may still be trapped in a room or hallway without our system having any ability to help them. Ideally, the path-finding algorithm would contain backup escape methods such as climbing out a window or onto the roof. However, neither of these cases are ideal and could still lead to injuries. While additional functionality of the phone application is not currently in our work scope, the phone application can provide room for additional functionality to solve these problems in the future such as showing the fire department the location of the trapped person.

It is clear that this project deals very closely with the safety of the public, which is covered in the IEEE Code of Ethics #1: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment.” In order to comply with this code, we will test our system very thoroughly in a variety of situations and environments before releasing it to the market. We will also be sure to provide ample documentation and warnings to ensure its proper use. If ever we discover a flaw in our design, we will ensure that this is known to the users of the system before we work tirelessly to fix it.

In addition, our project relies on the use of sensor data to provide information regarding an emergency. This can possibly infringe on IEEE Code of Ethics #3: “To be honest and realistic in stating claims or estimates based on available data.” We must be very careful in our calibration of this system so that when it is in operation, the sensors do not use the available data to lead users astray and into unsafe situations. In order to make sure we abide by this code, we have researched unsafe levels of Carbon Monoxide and heat and we will work towards designing our sensor module such that it follows these limits as closely as possible. Throughout the project, we will continue to test and adjust our design to ensure that all data is used appropriately.

5 References

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