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 gas detectors and thermocouples should relay all relevant 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 are 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 uses WiFi to communicate to the “Floor Sign” 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.

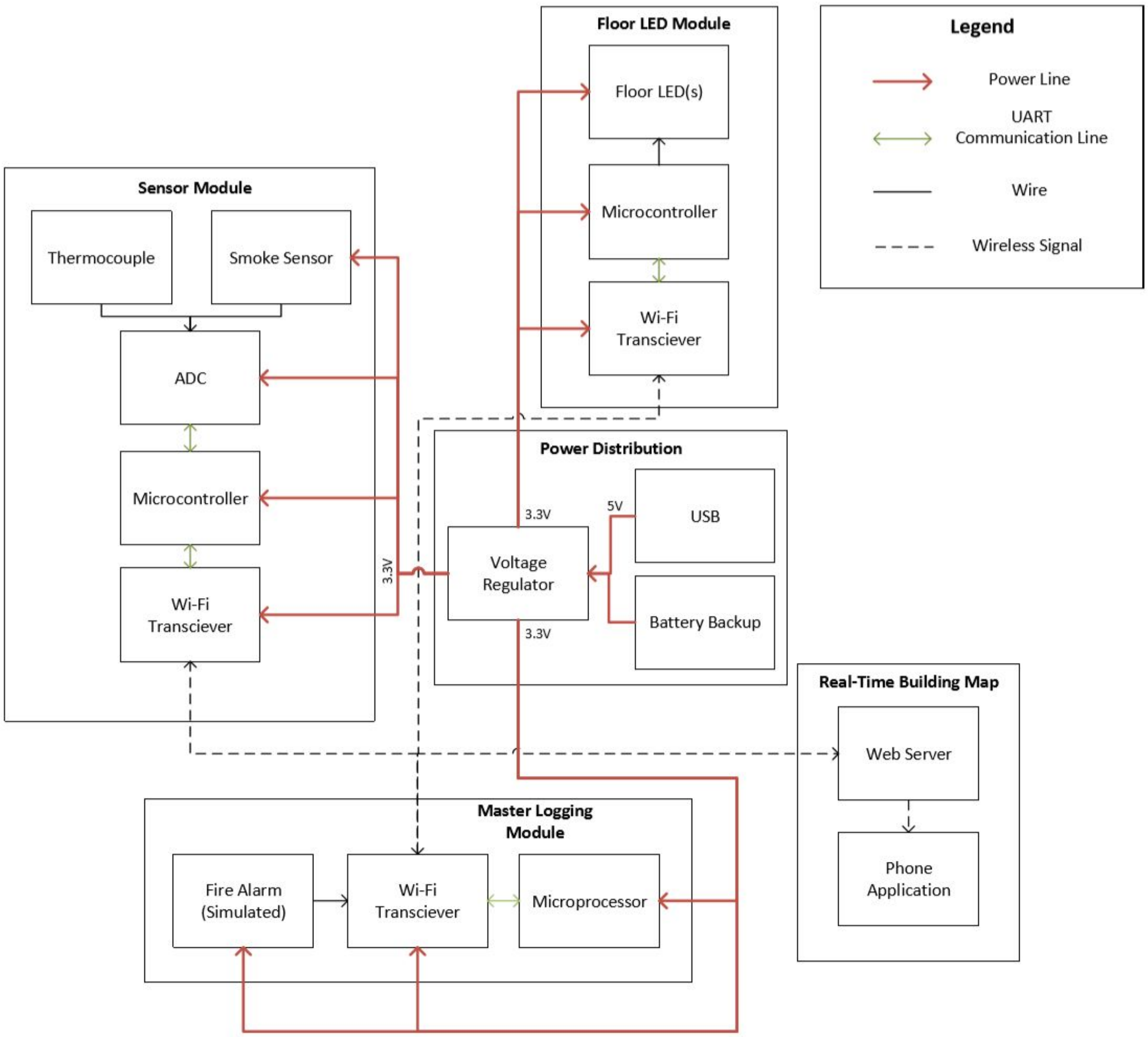

Figure 1. Block Diagram

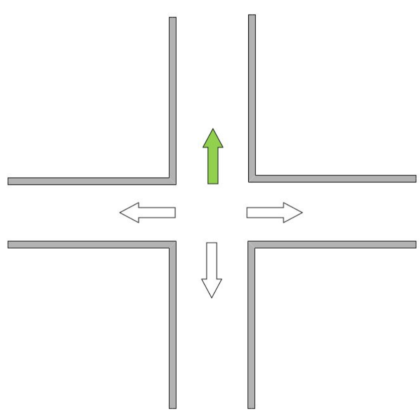

Figure 2. LED Arrow System

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 USB Interface

The USB Interface will serve two purposes. First, it will provide a conversion from wall power to 5V in order to power the rest of the circuit. Second, it will allow us to flash the data code onto the microcontroller/microprocessor.

The USB interface should provide an outlet into which the user can plug and unplug a standard 5V USB cable in order to flash code and provide power.

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. Through the use of hardware, we will ensure that the transition from USB power to battery power is seamless and done only in the case of main power failure.

The battery backup system should provide greater than 3.3V to the input of the voltage regulator within 10ms of main power removal.

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 also be decoupled with multiple capacitors of mixed impedances to also improve noise immunity.

The voltage regulator should be able to provide an output of 3.3V within 0.2V.
The regulator should be able to provide at least 300mA of current.

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 temperature will likewise increase significantly. This information will be used to determine the safest, shortest path to the exit. It should also 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.

The thermocouple module should be able to report temperatures to the logger board greater than 400 degrees Fahrenheit.
The thermocouple should report values to the logger board with an accuracy of 10° Fahrenheit.

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.

The smoke sensor must be able to detect CO and report the values to the logger at a concentration of up to 2000PPM.

2.2.3 ADC

The ADC will serve as the interface between the analog sensors, and the digital microcontroller. This block will translate the data that is coming from the sensors and relay it to the microcontroller to process. The smoke sensor will utilize the microcontroller's onboard ADC, but for the thermocouple, we will require a very accurate ADC which is made specifically for thermocouples.

ADC must have at least ten bits of accuracy in order to provide sufficient resolution.

2.2.4 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.

The microcontroller must be able to communicate via UART

2.2.5 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.

The WiFi module must be able to communicate over 802.11 b/g/n.
This module must be able to communicate via UART.

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 Microprocessor

The microprocessor is the device which will determine what parts of the building are most dangerous based on the sensor data and use a path-finding algorithm to find a safe path out of the building which avoids the dangerous areas. 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 would allow us to program the chip to avoid walls and sensors which 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.

The processor should solve the maze and determine a safe route as quickly as possible, no slower than ten seconds from the fire alarm trigger event.
This module must be able to communicate via UART.

2.3.2 Wi-Fi Transceiver

The Wi-Fi transceiver on the Master Logging board will serve three purposes. First, it will take the data sent by the sensor modules relay it to the on board microprocessor. Second, it will take the floor LED device addresses from the microprocessor and send them out to the floor LED modules so that the correct LEDs can be turned on. Lastly, it will send the data to the web server so that it can be used by the phone application.

The WiFi module must be able to communicate over 802.11 b/g/n.
This module must be able to communicate via UART.

2.3.3 Fire Alarm

Our system is triggered by the tripping of a fire alarm. This block serves as a fire alarm in our small scale model building. It will have a buzzer to simulate audio. This tripping will tell the microprocessor to start sending data to the web server and to start lighting up the floor LED’s. If the fire alarm is not tripped, the microprocessor stays in an idle state, not sending any data over WiFi. This will allow us to use very little power in the case that there is no emergency in the building.

The fire alarm must involve a 3.3V user-controlled signal in order to interface with the GPIO pins on the microprocessor.

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 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).

The microcontroller must be able to communicate via UART.

2.4.2 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.

The WiFi module must be able to communicate over 802.11 b/g/n.
This module must be able to communicate via UART.

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.

The LEDs should be clearly visible from up to 3 meters away.

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.

The web server must have the ability to be written to and read from for a charge of less than $0.50/day.
The server should be able to update within 500ms.

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. There would also be the functionality for a user to choose a location in the building and a path to be generated to the nearest exit.

The phone application should be able to interface with the web server in order to download the sensor data.
The phone application should be able to display the data sensed by the thermocouple and smoke detectors and refresh at a minimum frequency of once every ten seconds.

2.6 Risk Analysis

The master logging module will prove to be the most challenging part of our project due to the fact that the wireless communications part of this module is unknown territory for our group. None of the members have worked on any sort of Wi-Fi data transfer and having to learn it along with implementing it at this scale will be a challenge. We will need to be able to wirelessly transmit data across a building to interact with multiple nodes across hundreds of feet.

Along with this, 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.

2.7 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 design. It will contain several rooms and hallways made of a flammable material so that we can simulate a fire occurring in the building. Ideally, we would create a frame for the model out of a non-flammable material such as aluminum so that the model could be re-used for testing and demonstration by simply replacing the burnt pieces.

3 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.

4 References

[1] National Fire Protection Agency, ‘Structure Fires in Health Care Facilities’, 2017. [Online]. Available: https://www.nfpa.org//-/media/Files/News-and-Research/Fire-statistics-and-reports/Building-and-life-safety/oshealthcarefacilities.pdf

[2] Ready.gov, ‘Home Fires’, 2019. [Online]. Available: https://www.ready.gov/home-fires

[3] National Research Council Canada, ‘Toxic Gases and Vapors Produced at Fires’, 1971. [Online]. Available: http://web.mit.edu/parmstr/Public/NRCan/CanBldgDigests/cbd144_e.html

[4] Puroclean, ‘How Does a Fire Spread in a Building?’, 2016. [Online]. Available: https://www.puroclean.ca/blog/how-does-fire-spread-building/

[5] Google, ‘Google Nest Protect’, 2020. [Online]. Available: https://store.google.com/us/product/nest_protect_2nd_gen

[6] Archibald Tewarson, ‘Smoke Emissions in Fires’, 2008. [Online]. Available: https://iafss.org/publications/fss/9/1153/view/fss_9-1153.pdf