"Safe Route": A Mobile App-Based Intelligent and Personalized Fire Evacuation System

Christian Hayes
Dr. Jiang, Dr. Prodanoff, and Dr. Kaushal
University of North Florida
School of Engineering, CCEC

INTRODUCTION

All modern buildings have fire evacuation protocols, usually to follow exit signs, but these simple evacuation methods are oftentimes insufficient. Escaping a fire requires quick thinking and immediate action, but the safest and quickest way out is not always apparent, and your instincts may lead you down a hazardous path. Safe Route is a mobile application for intelligent and personalized fire evacuation created to help solve this problem by providing real-time navigation assistance for building occupants to escape a fire safely and efficiently. During this study, Safe Route is implemented at the University of North Florida (UNF) to provide a fire evacuation system for the first floor of Building 4.

OBJECTIVE 1: INDOOR POSITIONING SYSTEM

Knowing the indoor location of building occupants is essential for personalized fire evacuation. The first step towards developing an indoor positioning system (IPS) was to deploy Bluetooth Low Energy (BLE) beacons to the first floor of Building 4. The beacon used for this study is the Moko H2 iBeacon. To reduce multipath effects from the indoor environment, several sets of experiments were conducted to calibrate the environment and to determine optimal beacon placement before installation. The experimentation includes the observation of received signal strength indicator (RSSI) values at multiple points on the first floor of Building 4. Experimentation was performed to determine the relationship between distance and RSSI, which is shown in *Figure 1*.

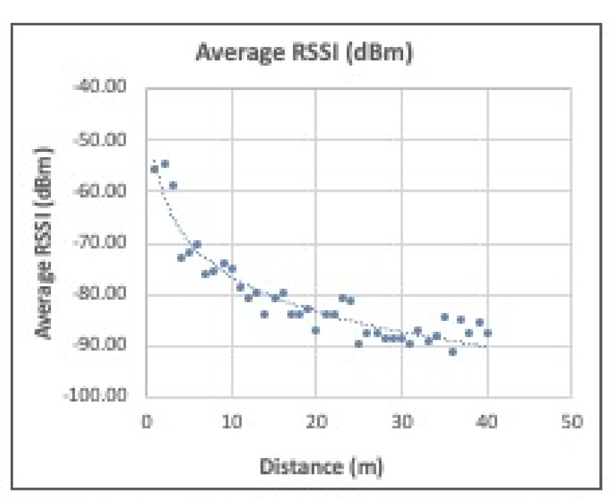


Figure 1. Relationship between distance and RSSI.

A mobile application was created to transmit the RSSI values between each beacon and the building occupant's smartphone. To estimate the building occupants' indoor position, a concept called trilateration is used, illustrated in *Figure 2*. As shown, the occupants must be in range of at least three beacons for trilateration to work properly. When the number of beacons in range of an occupant exceeds three, the indoor positioning accuracy increases because there is more RSSI data to perform calculations on.

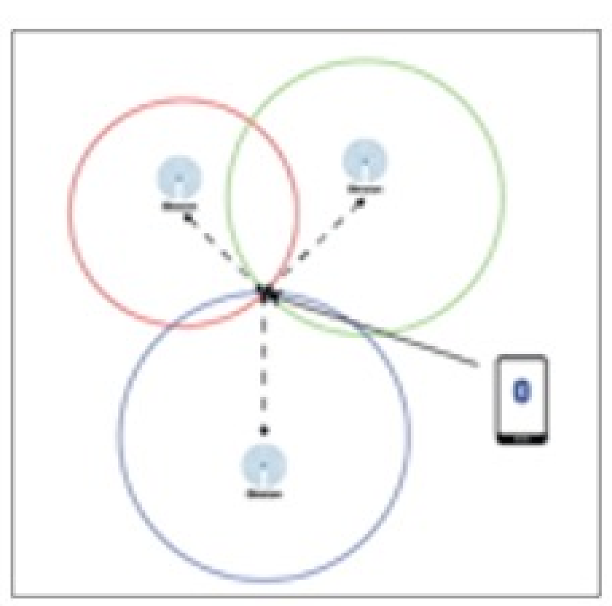


Figure 2. Trilateration technique for positioning.

OBJECTIVE 2: FIRE EVACUATION ROUTING

The primary purpose of Safe Route's user interface is to display the safest fire evacuation route. The foundation of determining the safest fire evacuation route lies upon graph theory and Dijkstra's algorithm. Dijkstra's algorithm is used for finding the shortest path between two nodes in a graph network. Before this algorithm can be applied, the indoor floor plan was converted into a network of nodes and routes, as seen in *Figure 3*.

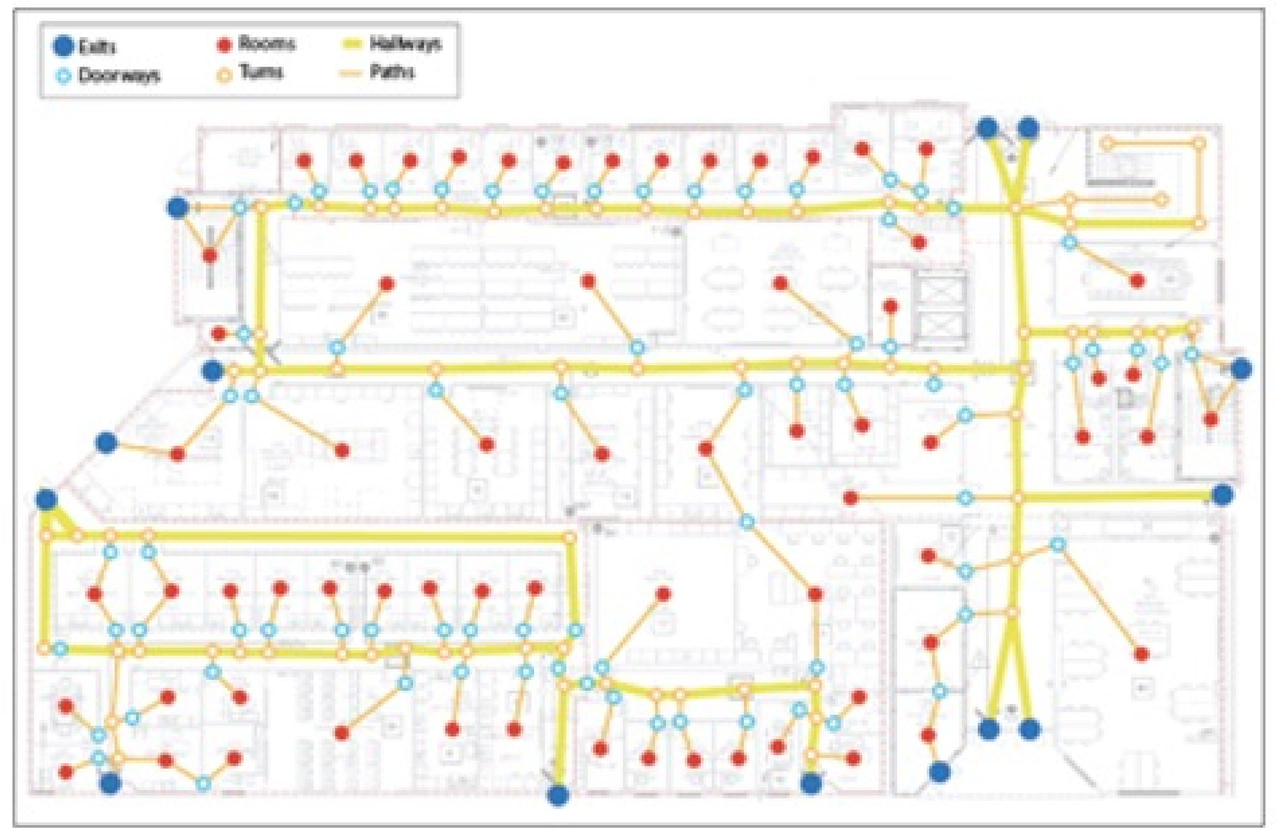


Figure 3. Graph network overlaid on floor plan of first floor.

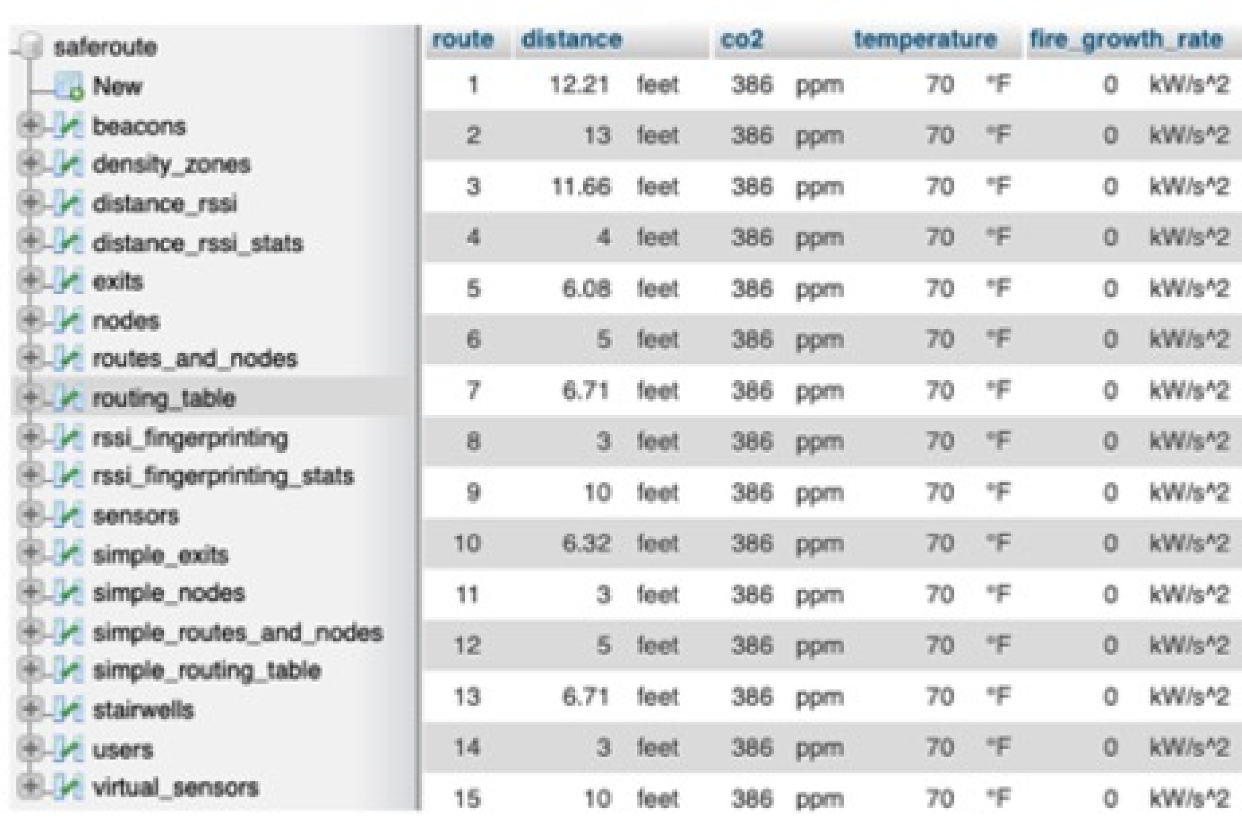
During a fire evacuation scenario, some paths may be more hazardous than others. Therefore, the algorithm had to be customized by giving each path a safety score based upon a variety of factors, including temperature, fire growth rate, and carbon dioxide concentration, among others. *Table 1* shows the factors used in the routing algorithm to determine path safety scores. Once a personalized evacuation route is determined for each building occupant, this route will be displayed to them via the Safe Route mobile iOS application, with navigation assistance helping them safely escape.

Table 1. Factors used in routing algorithm to determine path safety scores.

Factor Name	Real Values (Transformed Risk Values)
Temperature (°F)	32-104 (0), 105-140 (1), 141-176 (2), 177-212 (3), 212-297 (4), over 298 (5)
Fire Growth Rate (kW/s²)	0 (1), 0.0001-0.0029 (2), 0.0029-0.012 (3), 0.012-0.047 (4), over 0.047 (5)
Visibility (meter)	over 99 (0), 66-98 (1), 33-65 (2), 17-32 (3), 0-16 (4)
Carbon Monoxide Concentration (ppm)	0-50 (1), 50-100 (2), 100-3200 (3), 3200-12600 (4), over 12600 (5)
Human Density (human/m²)	0-0.8 (0), 0.8-1.8 (1), 1.8-2.8 (2), 2.8-4 (3), over 4 (4)
Carbon Dioxide Concentration (ppm)	0-5000 (0), 5000-10000 (1), 10000-15000 (2), 15000-30000 (3), 30000-40000 (4), over 40000 (5)
Distance (meter)	0-10 (1), 10-30 (2), over 30 (3)
Age	18-40 (1), 40-60 (2), over 60 (3)
Gender	Male (1)/Female (2)
Body Type	Athletic (1), Normal (2), Fat (3)
Respiratory Disease	No (1)/Yes (2)
Physical Disability	No (1)/Yes (2)

RESULTS

Dijkstra's algorithm was used to calculate the shortest and safest path from a starting position to one of the exits. The algorithm was modified to calculate the overall safest path based upon a routing table, which is stored in a database. The database and all project files are stored on a UNF webserver. *Figure 4* shows the database along with an example of the routing table. A mobile iOS application called Safe Route was created that incorporates both the IPS and fire evacuation routing algorithm. The app was tested on an iPhone XS, as seen by *Figure 5*. The routing algorithm works well, and the robustness of the IPS algorithm is still being improved. To enhance the user experience, navigation assistance was added by displaying directional arrows, text, and spoken directions.



route	distance		co2		temperature		fire_growth_rate	
1	12.21	feet	386	ppm	70	°F	0	kW/s^2
2	13	feet	386	ppm	70	°F	0	kW/s^2
3	11.66	feet	386	ppm	70	°F	0	kW/s^2
4	4	feet	386	ppm	70	°F	0	kW/s^2
5	6.08	feet	386	ppm	70	°F	0	kW/s^2
6	5	feet	386	ppm	70	°F	0	kW/s^2
7	6.71	feet	386	ppm	70	°F	0	kW/s^2
8	3	feet	386	ppm	70	°F	0	kW/s^2
9	10	feet	386	ppm	70	°F	0	kW/s^2
10	6.32	feet	386	ppm	70	°F	0	kW/s^2
11	3	feet	386	ppm	70	°F	0	kW/s^2
12	5	feet	386	ppm	70	°F	0	kW/s^2
13	6.71	feet	386	ppm	70	°F	0	kW/s^2
14	3	feet	386	ppm	70	°F	0	kW/s^2
15	10	feet	386	ppm	70	°F	0	kW/s^2

Figure 4. Database showing table names and routing table example.

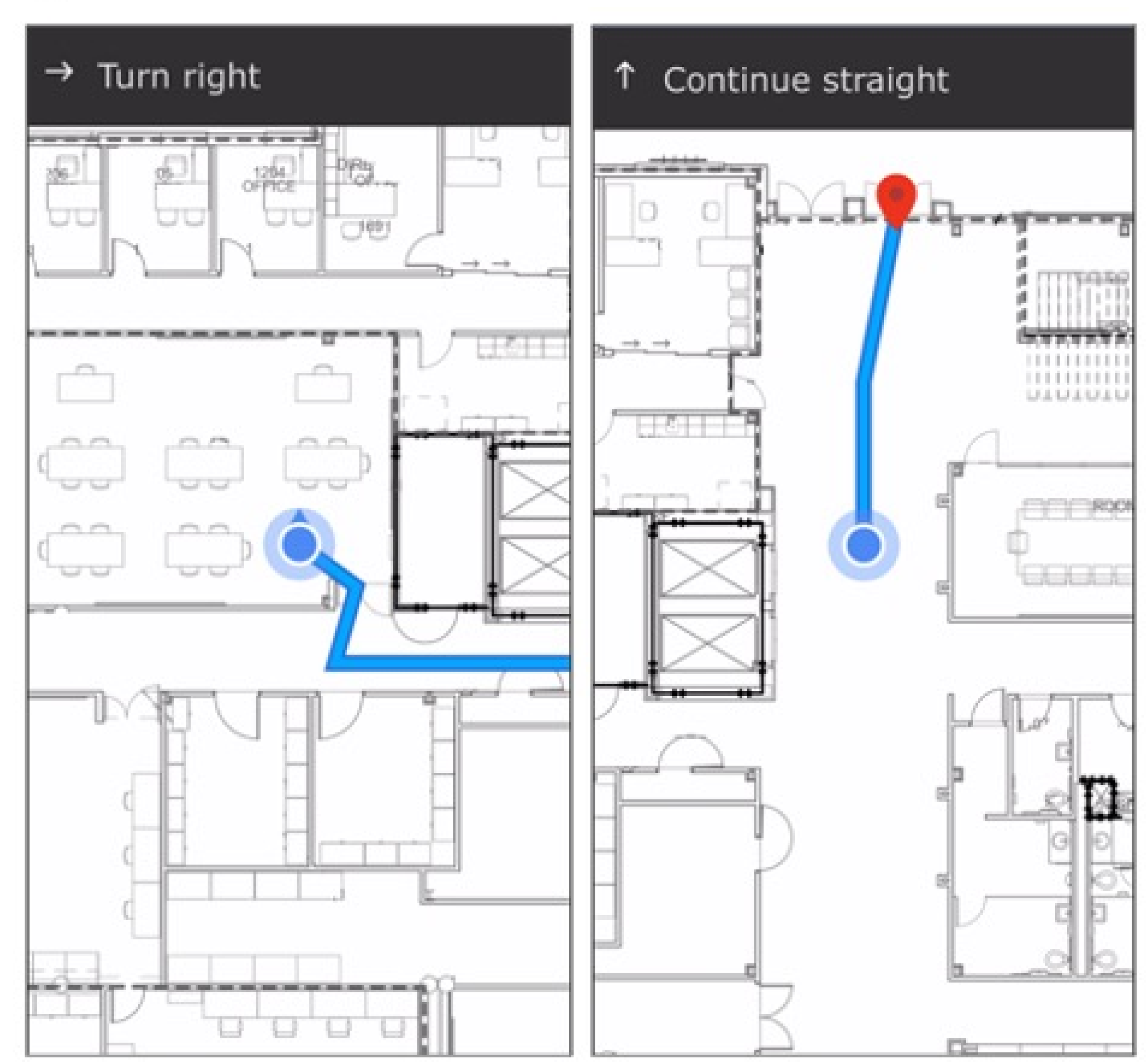


Figure 5. Example of using the Safe Route mobile app during a simulated fire evacuation scenario.

CONCLUSIONS

The Safe Route mobile app works in conjunction with carefully positioned BLE beacons to enable an IPS. A custom routing algorithm was built to help guide building occupants to the safest exit in a fire evacuation scenario. The evacuation routing algorithm and navigation assistance were tested by using a custom simulation of predefined user positions to eliminate potential bias from the IPS. The routing algorithm worked smoothly, and accurately guided the user towards the nearest exit. Creating the IPS algorithm is a difficult process partially due to environmental disturbances that affect beacon RSSI values and because of the complex algorithms required. Consequently, a more robust IPS algorithm is still being formulated to enhance the accuracy of user positions, which are estimated based upon RSSI values from nearby beacons. The IPS can be improved by utilizing a more robust algorithm and applying various statistical considerations.

FUTURE WORK

This study utilized nine beacons for the IPS, and because each beacon has a limited range, the accuracy of the IPS is less than ideal. Therefore, future researchers should install significantly more beacons as well as continue to improve the IPS algorithm. Once the positioning accuracy improves to a more suitable level, the fire evacuation system could be expanded to span multiple floors or even the entire building. Additionally, the Safe Route app could be commercialized or made open-source for use in fire evacuations anywhere in the world.

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