ECEN 403 – Senior Design

Concept of Operation Report

FireGuard: Smart Fire Alarm with Occupant Detection

Team 3 Members

Moza Al-Mannai

Alreem Al-Ghanem

Aisha Al-Khalifa

Shaikha Al-Sulaiti

Mentor

Dr. Jim Ji

Course Instructors

Dr.Kais and Dr.Mohammed

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1. Executive Summary

When a fire alarm detects signs of fire, such as smoke or heat, it cannot provide information about whether individuals remain inside the building or where they are located. This causes an issue since people may be trapped inside a room without firefighters knowing their presence or location.

To overcome this problem, we propose FireGuard: Smart Fire Alarm with Occupant Detection. The fire alarm will detect signs of fire, while the occupant detection system will identify whether people are present in the monitored areas and estimate their locations.

Our objective is to develop a fire alarm system that can detect the presence of people and estimate their location at the floor and room level. This information will help firefighters to know which areas to search first and carry out rescue operations.

FireGuard will use mmWave radar sensors to identify occupancy and estimate their locations within the monitored area. Once the fire alarm detects signs of fire, it will trigger the sensing system to identify whether people are present in the monitored areas. This information will then be provided to firefighters through an Android tablet to support the rescue process. By providing information about whether occupants are present and their estimated locations, FireGuard is intended to assist firefighters in prioritising which areas to search first and reduce the time needed to locate people during fire emergencies.

2. Background

Fire emergencies can cause serious injuries and loss of human lives. Therefore, Fire detection systems are important in detecting signs of fire. According to the National Fire Protection Association (NFPA), fires in the United States resulted in approximately 3,920 civilian deaths and 11,780 civilian injuries in 2024[1] .

Traditional fire alarm systems are designed to detect signs of fire. However, these systems provide limited information about the presence and location of occupants inside a building. This information is important for emergency responders during fire emergencies.

2.1 - Motivation of the Idea of the Project

Based on our research, we identified the problems firefighters experience when locating people who may be trapped inside buildings during fire emergencies. This led us to consider a main question: When firefighters arrive, do they know who is still inside and exactly where they are located?

This question motivated us to develop FireGuard , a system developed to detect the presence and location of occupants during fire emergencies to help reduce the number of deaths caused by fires. Our main approach is to provide firefighters with information needed to help rescue operations and reduce the time needed to locate people at risk.

2.2 - Limitations of Available Solutions

Based on our research, we looked at two existing solutions: traditional fire alarm systems and wireless smart fire alarm systems.

Traditional fire alarm systems detect signs of fire, and activate an alarm to warn people. However, they do not provide information about whether occupants are still inside the building or where they are located. This reduces the information given to firefighters during rescue operations [2].

Wireless smart fire alarm systems use connected fire detection and wireless communication to send alerts remotely. However, these systems are mainly designed to detect fire and send alerts rather than providing information about the presence and location of occupants [3].

To solve these limitations, FireGuard aims to combine fire detection with occupant detection to provide firefighters with information needed about people who may still be inside the building.

3. Operational Concept

This section explains how FireGuard is expected to work, including its main objective, who will be using it , and the environment in which it operates. It describes how the system will respond when fire is detected and how the information will be provided to firefighters.

3.1 - System Objectives

The main objective of FireGuard is to help firefighters detect the presence and approximate location of people during fire emergencies by providing information on whether people are inside the building. The system has three main objectives:

1.Detect people

FireGuard aims to detect the presence of people within the monitored area using a mmWave radar sensor [4]. The system is capable of detecting both moving and stationary people, including those who may be unable to move during fire emergencies. This will help determine whether people are located inside the area.

2. Locate People

FireGuard aims to determine the approximate location of people inside the building by room and floor. The system will use the information received from the mmWave radar sensor to identify which monitored areas are occupied [4]. This will help firefighters identify which areas have people who may need help.

3. Support Rescue Operations

FireGuard is intended to support rescue operations by providing firefighters with information about the presence and approximate locations of occupants through an Android device. This will assist firefighters in identifying which areas may be occupied and determine where to search first. By giving this information, FireGuard is intended to reduce the time needed to locate people during fire emergencies

3.2 High-Level System Diagram

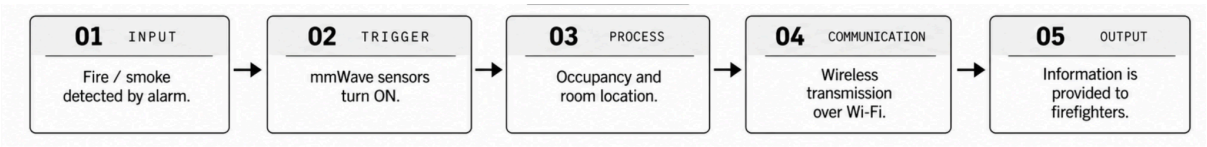


Figure 1: FireGuard System Operational Workflow

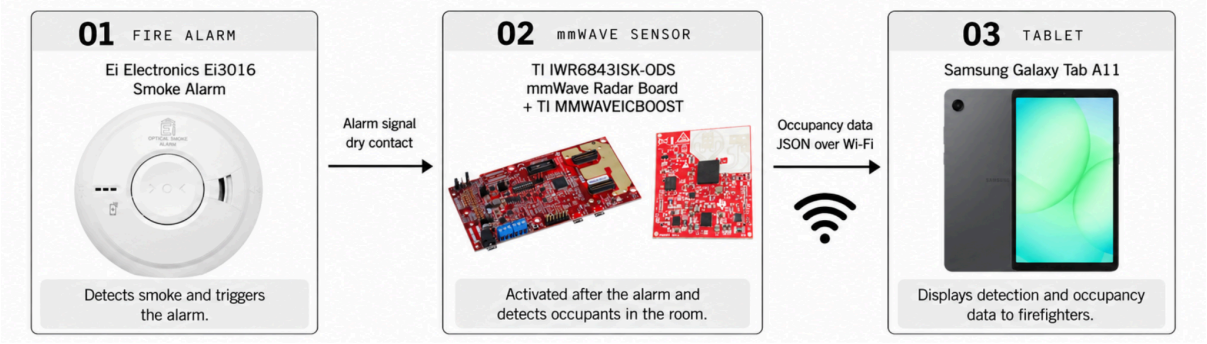


Figure 2: FireGuard Hardware Architecture and Data Flow

3.3 - User Profiles

The main users of FireGuard are firefighters and emergency responders who are mainly responsible for finding and rescuing individuals during fire emergencies. When firefighters arrive at a building, they might be unaware of whether people are still inside and where they are located. Our project aims to give them the information needed regarding the presence and approximate location of people through an Android device. This will allow rescue teams to identify the room and floor that may be occupied. This will also help firefighters prioritise areas where people may be present. The system aims to improve the efficiency of rescue operations.

3.4 - Operational Environment

FireGuard is intended for indoor applications, such as schools, hospitals, and other buildings. The system will be deployed in the selected areas within a building depending on the sensing range of the mmWave radar sensors [4].Where the sensors are placed will depend on the layout of the building including rooms, walls and other obstacles that may affect how well the radar works [4].

The coverage of the system is limited to the zones covered by the installed sensors. Consequently, there are parts of the building that remain unmonitored.Hence, the placement of the sensors needs to be carefully planned to provide sufficient coverage on the selected areas and minimize possible gaps in detection.

The system is designed to work even in adverse conditions such as smoke, darkness and limited visibility in fire emergencies. mmWave radar is meant to detect humans in low visibility conditions as it does not use visible pictures [4].However, the testing process will include evaluation of its ability to detect occupants under these conditions as well as the effect of obstacles and other room layout.

3.5 - Core Operational Scenarios

Scenario 1: Normal Operation

Under normal conditions, the smoke alarm and FireGuard are ready for operation. The mmWave radar system remains in the standby mode until the activation signal is received to prevent unnecessary operation.

Scenario 2: Fire Detection and System Activation

A smoke alarm detects smoke. A smoke alarm activates and sends a signal through the relay module[5] [6]. Upon receipt of this signal, the mmWave radar system will begin scanning the monitored areas for occupants.

Scenario 3: Occupant Identification and Localisation

When the mmWave radar sensors are switched on, they collect data to find out if there are people in the monitored areas [4]. The system uses this data and processing to estimate the occupancy and find the room or floor with coverage available.

Scenario 4: Displaying Information to Firefighters

The occupancy information is transmitted to an Android tablet and displayed for firefighters and emergency responders. With this information, they can identify which rooms might be occupied and target their search efforts during rescue operations.

Scenario 5: Decision Support for Rescues

The displayed information helps firefighters make decisions on which areas to search first. FireGuard is designed to decrease uncertainty and potentially reduce the time to locate occupants. But firefighters still have to follow established safety procedures and verify conditions during the rescue.

4. Analysis of the Proposed System

In this section, the FireGuard system and its potential impact in enhancing fire emergency response are discussed in detail. It considers expected system effects on firefighter safety, occupant identification and rescue prioritization, and response efficiency. It also describes the major benefits of mmWave radar, such as providing occupancy information without collecting identifiable images.The analysis also includes the constraints, costs and performance trade-offs of the system to find out the feasibility and efficiency of the system in real fire emergencies.

4.1 System Impact

Our proposed fireguard system provides a significant impact from the occupants of the building to the firefighter. Improving the firefighter safety concerns; by providing insights and useful information before entering the risky territory in case of a fire, This will help in having faster emergency responses in case of fire and more informed rescue decisions based on the prioritised rooms where people may require urgent rescue. The mmWave radar can detect occupancy without relying on visible light images, thus useful in rooms with smoke in fire cases[7][4]. At the same time this sensor provides a full privacy of the people, it does not contain a camera,thus can provide spatial information without capturing identifiable facial images[7][4]. The system will provide a potential reduction in rescue delays, because of the automatic displayed information regarding presence and location of people, not making firefighter search room by room unless they are done with the room displayed to be occupied, which will reduce the time and makes the plan much more efficient.finally is that our system provides a huge role in safety of the human lives in all aspects.

4.2 Advantages, Disadvantages, Trade-offs, and Limitations

A. Advantages:
    a. Occupancy localization: providing room-level occupancy information[4]
    b. Operation in extreme circumstances:mmWave radar detects occupancy in smoke or in darkness, without relying on visual images.[7][4]
    c. Privacy: our system uses radar data not facial images identification[7][4]

d. Automatic activation:smoke alarm triggers the radar system , allowing the radar to remain in standby during normal conditions.[5][6]
e. Prioritised information display: The Android application displays room-level occupancy information to support rescue decisions.
f. Efficiency: Help responders prioritize their search, potentially reducing time spent checking unoccupied rooms.

B. Disadvantages:
a. High initial cost: Multi-sensor systems plus additional electronic components increase the initial cost.
b. Complex system integration: The complexity requirements are increased by integrating mmWave radar, smoke alarm, wireless communication and an Android tablet interface.
c. Dependence on communication:As the network size and router increase, wireless networks are subject to data overflow or errors.[8]

C. Trade-offs:
a. Cost versus function: mmWave radar and hardware increases system cost but provides occupancy information unlike the basic fire alarms.
b. Privacy versus monitoring details: Radar provides spatial sensing without video images, while cameras can provide visual information that radar-based occupancy sensing does not[7][4].
c. Wireless convenience versus communication reliability: Wireless communication simplifies the data delivery to the connected devices, but communication errors remain a concern[8].
d. Detection sensitivity versus false alarms: Highly sensitive detection may improve recognition but requires more careful calibration to manage errors[7][4].

D. Limitations:
a. Limited radar performance under different conditions: mmWave sensing is affected by environmental variation, interference, calibration drift, and multitarget detection issues[7][4].
b. Dependence on sensor data quality: The accuracy of the occupancy measurement is dependent on quality of the radar measurements and can be limited in the case of poor input data[7][4].

c. FireGuard's detection accuracy, response time, room coverage and performance under simulated fire conditions have not yet been experimentally validated.

5. Financial Feasibility

FireGuard should be budgeted below $1,000. The prototype is equipped with mmWave radar sensors, a radar development board, a smoke alarm, a relay module, and a tablet to display the occupancy data. Additional costs for power supplies, wiring, mounting materials and other support equipment may be incurred for systems integration and testing.

The TI IWR6843ISK-ODS mmWave radar sensors are used for detecting occupants in the monitored environment[4], and the TI MMWAVEICBOOST development board supports radar configuration and data processing[9]. The fire detection trigger for the radar system is the relay module and smoke alarm[5][6]. An Android tablet serves as the user interface, displaying occupancy information to support emergency response and rescue prioritization[10].

5.1 Preliminary Estimation of Target Budget

Item	Qty.	Price	Link	Total
TI IWR6843ISK-ODS mmWave sensor	2	202.13$	404.26$	https://www.ti.com/tool/IWR6843ISK-ODS
TI MMWAVEICBOOST carrier board	1	287.60$	287.60$	https://www.ti.com/tool/MMWAVEICBOOST#order-start-development
Ei Electronics Ei3016 optical smoke alarm	1	91.60$	91.60$	https://electricalwholesaler.uk/products/aico-optical-smoke-alarm-ei3016

Ei Electronics Ei128RBU relay module	1	54.87$	54.87$	https://www.eibabo.com/en/ei/output-relay-230v-relay-module-for-smoke-detector-ei128rbu-eb11215418
Isolated alarm-status interface	1	19.95$	19.95$	https://www.ki-maker.com/products/in-4?utm
ABS electronics enclosure, 255 × 200 × 80 mm	1	16.98$	16.98$	https://www.amazon.com/LeMotech-Dustproof-Waterproof-Electrical-255mmx200mmx80mm/dp/B075X15KXJ/ref=sr_1_1?dib=eyJ2IjoiMSJ9.rmEF0Qnbvz2eG-krDZIM4r0oFVE53ubYiSQAaJAcJhTftOAW9NJie-cahSwHuVbayO1iW96oNybaOe_Hlb-zzQMejuADFQ3tlcALm2dh2JnCK7qlL0HsgwljIGttEFilyis2OzVWZuRjHsD6Z36J9HnQUEap02FnzyESJEaES8Alr7N-dAQLU2uRjy4_KPskZTtKBYt2dsw9cQ--G29tE3nk8pFXQi0lr_F9FDEhcP1ZMl-pq_XNYka1F8cR-il_L9GVTlU1oEMIA8WeZLbLqmXp1rDllCDidjsFi8RsPeQ.WHvTSxjAyaOVS4XNXvqCs_KcOJA2qxOskMuZtHv7rwc&dib_tag=se&keywords=ip67+waterproof+boxABS+electronics+enclosure%2C+255+%C3%97+200+%C3%97+80+mm&nsdOptOutParam=true&qid=1792599896&sr=8-1
Polycarbonate Antenna Window	1	86.90$	86.90$	https://www.bolo.qa/products/KO0Q6SXK45C-1mm-polycarbonate-roofing-sheets-clear-acrylic-plastic-sheetroofing-canopies-roofing-cladding-panelsun-protection-heat-insulatingfor-greenhouses-05m-x-2m164ft-x-656ft
NodeMCU ESP32 Development Board – Wi-Fi & Bluetooth Enabled	1	$10.71	10.71$	https://www.voltaat.com/products/esp32-development-board?keyword=NodeMCU%20ESP32%20Development%20Board%20%E2%80%93%20Wi-Fi%20%26%20Bluetooth%20Enabled
			972.87$	

6. Glossary, Acronyms, References

6.1 Glossary

term	Definition
FireGuard	Our proposed system, smart occupancy detection fire alarm. Designed to detect occupancy and provide locations for the rescue team.
Occupancy detection	It's the process of revealing whether there is human presence in the monitored area.
Occupancy localization	It's the process of approximating the room and floor of the humans.
Occupancy Information	The data tells us whether humans are present in the monitored area and their location.
mmWave radar	Sensor used that uses millimeter-wave radio signals in order to detect the presence of people
Smoke alarm	Device that detects smoke and triggers a warning signal,sound or light.
Relay module	Electrical switch device used to trigger the radar in response to fire alarm
User interface	The means through which users interact with the system.
Operational environment	The setting in which our system is meant to operate in. such as schools,universities and hospitals.
Sensor Coverage	The area within the sensor capability to detect humans.
Wireless Communication	The transmission of information without the need of cables between the system’s components.

6.2 Acronyms

Acronyms	Full form
CONOPS	Concept of Operations
mmWave	Millimeter Wave
NFPA	National Fire Protection Association
TI	Texas Instruments

UI	User Interface
Wi-Fi	Wireless Networking Technology used for Local Network Communication
IEEE	Institute of Electrical and Electronics Engineers

6.3 References

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