HYBRID ARCHITECTURE OF ZIGBEE & LORA NETWORK FOR INTELLIGENT FIRE SAFETY AND BUILDING EVACUATION SYSTEM

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

in

(Electronics & Communication Engineering)

By

Gajanand Sharanappa Birajdar

(41800214)

Supervised By
Dr. Rajesh Singh
Professor, School of Electronics & Electrical Engineering

Co-Supervised by
Dr. Anita Gehlot
Associate Professor, School of Electronics & Electrical Engineering

Transforming Education Transforming India

LOVELY PROFESSIONAL UNIVERSITY

PUNJAB, January 2022

DECLARATION

This thesis is an account of research undertaken between August 2018 and October 2021 at The Department of Electronics and Communication Engineering, Lovely Professional University, Phagwara, India.

Except where acknowledgement is the customary manner, the material presented in this thesis is, to the best of my knowledge, original and has not been submitted in whole or part of degree in any university.

Gajanand Birajdar
Registration No.41800214
Department of Electronics and Communication Engineering
(Embedded System)
Lovely Professional University, Phagwara, India

CERTIFICATE

This is to certify that the declaration statement made by the student is correct to best of my knowledge and belief. He has submitted the Ph.D. thesis "Hybrid architecture of Zigbee & LoRa network for intelligent fire safety and building evacuation system" under my guidance and supervision. The present work is the result of her original investigation, effort, and study. No part of the work has ever been submitted for any other degree at any University. The Ph.D. thesis is fit for the submission and fulfillment of the condition for the award of Ph.D. degree in Electronics and Communication Engineering from Lovely Professional University, Phagwara.

Dr. Rajesh Singh, Professor
SEEE, Lovely Professional University,
Phagwara

Dr. Anita Gehlot, Associate Professor
SEEE, Lovely Professional University,
Phagwara

DEDICATION

“All action is of mind and the mirror of the mind is the face, its index the eyes.” MARCUSTULLIUS CICERO

This thesis is dedicated to my family especially to my parents and all my well-wisher.

ACKNOWLEDEGEMENT

Firstly, I would like to thank God who enabled me to use my wisdom and knowledge for this research work. Moreover, the patience that God has given me in all the hard times during this period of time is unforgettable.

I would like to express my sincere thanks to my supervisors, Dr. Rajesh Singh and Dr. Anita Gehlot for their endless support, guidance and supervision for each stage of this research. I am truly fortunate and blessed enough to have the opportunity to work with such person.

I am grateful to my family and parents for their endless motivation and support. Their endless motivation and support helped me to complete my research work on time. Besides I would also like to thank all my fellow friends and colleagues who always motivated me with their valuable suggestions.

I would like to take this opportunity to record my thanks to entire family of Lovely Professional University, specifically Division of Innovation and Entrepreneurship, for all the support and encouragement.

Date: 14-01-2022 Gajanand Birajdar

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

API	Application Programming Interface
BLE	Bluetooth Low Energy
CF	Carrier Frequency
CNN	Convolutional Neural Network
CR	Code Rate
CSS	Chirp Spread Spectrum
DSS	Decision Support System
DNN	Deep Neural Network
FLoRa	Framework for LoRa
GSM	Global System for Mobile Communications
GPRS	Global Packet for Radio Service
GND	Ground
GUI	Graphical User Interface
ICSP	In Circuit Serial Programming
IoT	Internet of Things
IP	Internet Protocol
LCD	Liquid Crystal Display
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network

LPWAN	Low Power Wide Area Network
MDLS	Multilayer Deep Learning System
MQTT	Message Query Telemetry Transport
NB-IoT	Narrowband IoT
PAN	Personal Area Network
QGIS	Quantum Geographic Information System
RFID	Radio-frequency Identification
SF	Spreading Factor
SNR	Signal-to-Noise Ratio
SPI	Serial Peripheral Interface
ToA	Time of Arrival
UNL	Unique Node Lists
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network

CONTENTS

ABSTRACT

With rapid development across the globe population is also increasing in rapidly. To accommodate these population in an available geographical region it is becoming harder and hence high-rise building is potential solution to meet up the requirement. Buildings are designed and built to last a long time and to accommodate a huge number of people. During this log lasting period buildings may exposed to face many manmade such as explosion, fire etc. or natural such as earthquake, hurricane, etc. disasters which leads to partial or entire loss of human beings and his belongings. But buildings are designed to withstand all these kinds of disasters. Fire is the only natural calamity that benefits human and his ecosystem while still being destructive and deadly. Basically, at present state most of buildings are equipped with furniture, plastics, and other easily combustible materials. Similarly, as insulating materials become more common and are used more extensively in buildings, the risk of fire posing a threat to the building's and people's lives is increasing. Fire accidents happen rarely, but when they do, the consequences can be disastrous. As a result, fire incidents should be avoided at all costs. Hence there is a need of the society to build effective fire sensing devices and intelligent alerting system. As a result, researchers are paying close attention to the development of intelligent building systems around the world. A fire is likely to cause 12 times more deaths than injuries as per the NCRB data available in the country & Incidents at residential buildings account for 42.1%. Low visibility of exit path due to high smoke density during fire accident inside building is also one of the major problems of casualty. In current fire protection system, there are many issues such as false fire alarming, static exit path, no clue about fire flow and people stuck inside building/room etc. They are not sufficient to provide reliable fire detection and predict real time exit path for the people. Implementing key parameter includes reliable fire detection system, real time exit path prediction and display, real time fire flow visualization and estimating people count inside building.

The primary goal of this thesis to focus on the design and development of a precise, reliable and efficient system for fire detection in real time and predicting safe evacuation path during fire accident inside building. To achieve the goal, the thesis is

organized into four objectives. For the same an architecture is proposed where it integrated distinct system like sensor node, Co-Ordinator node, LoRa gateway, vison node and exit display for fire identification, monitoring and predicting safe exit path in real time. Communication technology such RF and LoRa has been used to enhance the data movement between the various nodes. Initially the significance of implementing customization for the design and development of the hardware and firmware are addressed clearly. Further the establishment of long-range network in between the sensor node and gateway is processed for better exchange of data. The suggested framework is unique which addresses both fire prevention and management. This is in contrast to current initiatives to improve fire safety, which rely solely on performance-based rules to improve fire protection elements in buildings (i.e., managing the impact of fire danger). Major limitations of current fire protection systems are identified, and concrete tactics are presented to resolve these limitations using the proposed fire safety framework, to demonstrate the framework's applicability in enhancing fire safety in buildings.

Chapter 1
Introduction

This chapter elaborates broadly on the fire hazard in buildings and the importance of fire detection systems in preventing deaths from fire hazards. Further, this chapter presents the significance and role of the wireless sensor network (WSN) and Internet of Things (IoT) for fire detection. This chapter also presents the motivation, research objectives, thesis organization of the study.

1.1 Fire Hazard

Fire hazards in buildings and similar structures can be characterized as the possibility that a fire, whether accidental or deliberate fire breakage threatens the safety of life, the structure, and the property of a building or similar structures. With rapid global expansion, fire risks in buildings have seen remarkable changes in view of the associated risks, and formed into a matter of conern in recent years. Almost the previous 2 decades (1993-2015), 86.4 million fires resulted in over one million fire fatalities [1]. and overall yearly loss from worldwide fire hazard amounts to around 1% of global GDP [2]. In addition, on average 44,300 deaths due to fire hazards have occurred in both developing and developed countries throughout the world. Between 2010 and 2014, developing countries such as India had the most fire deaths (10k-25,k per annum) and the second-most amount of fires (100k-600k per annum) [3]. As a result, it has become crucial to maintaining adequate fire safety measures in buildings in order to mitigate the harmful effects of fire risks.

Fire safety and mitigation are described as a set of procedures to limit the losses due to fire breakage, as well as to control the spread and consequences of accidental or intentional fires, and to decrease any loss to human health and wealth as much as possible [4]. Fire breakage protection in buildings is currently guaranteed by following the recommendations of the building regulations. Different sets of rules have different requirements and strategies for ensuring fire safety in structures, but the majority of them are relative and originate from comparable fire protection concepts [5]. Building fire safety is implemented through a mix of both active and passive fire prevention devices in prescriptive-based methods [6]. Active fire suppression systems (smoke and heat detectors, sprinklers, and so on) are meant to locate, control, and mitigate a fire in its early stages, and are thus more essential in terms of life safety. Passive fire prevention solutions such as structural and non-structural elements of a structure are built to maintain a building's structural integrity while limiting fire spread. [7]. Their primary objective is to provide enough time for the purposes of firefighting and rescue missions while minimizing financial damages.

The traditional approach to ensure fire safety has numerous drawbacks when it comes to tackling modern fire hazard problems, as well as providing restricted guidance for fire hazard avoidance [8]. Poor performance and functional dependability, as well as expensive installation and maintenance costs, are major drawbacks of active fire prevention systems, which are typically a major issue in developing nations with little financial resources [9]. Passive fire mitigation relies on the fire protection efficiency of each structural parts and building features rather than overall building fire safety, resulting in unquantified building fire safety. Furthermore, the prescriptive method to guaranteeing fire safety is not properly linked to the real fire design and building design process is frequently conducted with the sole objective of getting regulatory clearance in the building [10] .

1.1.1 Sources of Fire Hazard

Sources of fire hazards are all elements contained in a building's structure that can lead to ignition (cause fire), exacerbate the severity of the fire, invalidate the building's fire safety features, and impede evacuation or operations. According to published statistics [3], electrical fire hazards and cooking are the major origins of fires in both civilians and business purpose structures. All open lits, hot surfaces, heaters, arson, pyrotechnics, and vandalism are further causes of igniting in structures as shown in Figure 1.1. Particular attention should be paid to electrical fire hazards, which constitute the majority of fire accidents in the world [11] [12]**.** A high quantity of combustible home goods; inappropriate preservation of combustible tools, garbage, components, and flammable products; and flammable structure components such as composite panels and lumber can all contribute to the severity of a fire after it has begun. Also, by supplying a continual supply of oxygen to the fire, open structures (glass walls, false ceilings, etc.), big windows, and inadequate design of fire compartmentation can induce rapid-fire development and spread [13]. Building fire safety, on the other hand can be compromised by non-direct causes, which can deactivate the fire protection mechanisms of buildings and obstruct evacuation and firefighting procedures. Inadequate building code law and administration, deficiency of common and civic sense such as disabling smoke detectors vandalism, ignoring fire alarms, and lack of resources for active fire system maintenance [14].

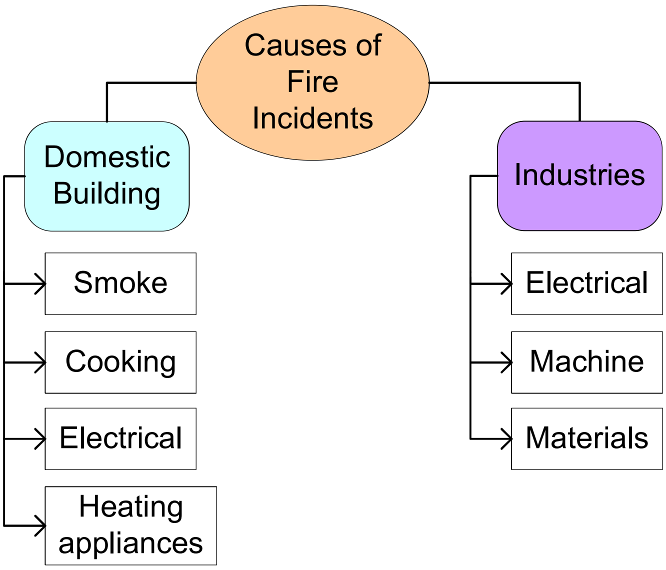


Figure 1.1 Causes of Fire

1.1.2 Stages of Fire in Buildings

Fires in a compartment are frequently divided into two stages: pre-flashover stage and post-flashover stage (Figure 1.2). The time between smoldering (flameless combustion) and ignition is known as the incipient stage of fire in the pre-flashover phase, while the time between ignition and flashover (rapid temperature increase) is known as the initial incremental stage of fire breakage. During the post-flashover phase, the time when temperatures continue to rise from combustion is referred to as the burning stage, and the thereafter cooling is referred to as the decay stage of fire. Although the pre-flashover phase is crucial for life safety, the post-flashover stage is crucial for structural integrity.

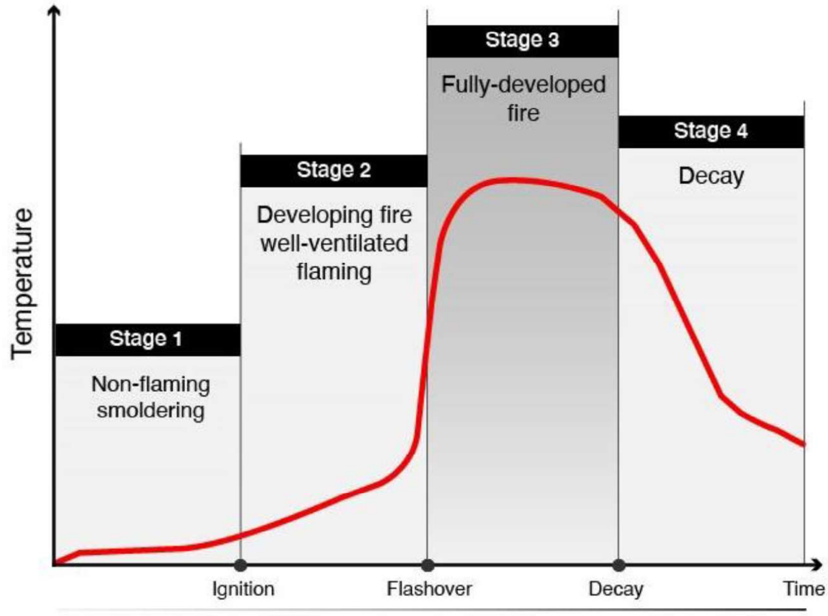


Figure 1.2 Stages of Fire

Combustion produces many poisonous chemicals that are very harmful to humans during the pre-flashover period of a fire, and inhalation (even in small amounts) can be lethal within minutes [15]. During the pre-flash phase of a fire, combustion produces several toxic chemicals that are highly harmful to humans, and inhalation can be fatal within minutes [16]. Small carbon particles and poisonous gas are also found in combustion smoke, which can harm the eyesight and digestive system. Because of the Smoke's high toxicity (vapor, soot particles and toxic gases), more people die in fires as a result of smoke than from the fire itself [17]. Moreover, hot gases and smoke obscure and hinder evacuation paths from the building during a fire, raising the risk of deadly burns and gas inhalation.

1.2 Fire Detection System

The main indicators of fire are ambient heat, flames, air quality, smoke, and respiratory tract. When a fire breaks, the fire and emergency system utilizes water and other means to extinguish the fire. [18]. In this system, the fire and emergency unit lacks a feature to monitor the status of the fire in the building. Fire fatalities can be averted if the fire breakage is noticed at early stages and stranded people are rescued immediately to a safer area. According to the state building code, the safety measures needed in tall structures to minimize fatalities and help people are fire breakage alert systems, smoke formation detectors, water or other forms of chemicals sprinklers, public address systems, safe rescue routes, adequate supply of water, and fire-safe areas. Currently, the advancement in sensors and wireless communication technology makes it possible to implement a wireless system for early fire detection and provide an evacuation route based on sensor data. WSN is the best approach for building fire detection as the sensors provide more accurate zone data at any time. WSN provides the ability to upgrade existing infrastructure with precision and reliability.

1.2.1 WSN and IoT in Building Fire Detection

WSN are interlinked sensor nodes that send data wirelessly to collect information about their surroundings [19] [20]. Sensor nodes are often powered by batteries and deployed in an ad hoc, decentralized way. WSN architecture is shown in Figure 1.3 and it presents that the sensor node and network architecture are the primary components of WSN. Sensor nodes or motes are sensing devices that are deployed across a large region to detect parameters [21]. The sensor node comprises sensors, microprocessors/microcontrollers, a transceiver radio frequency (RF) module, and a power supply [22]. The network design consists of a sink node and a gateway, which serves as a processing unit for sending data to the internet. The sink node controls the sensor nodes and transmits data through a wireless communication protocol enabled gateway. A gateway is a device that combines two different wireless communication protocols. A wireless communication protocol acts as a transceiver RF module at the gateway and receives data from the receiver node's transceiver RF module. Another communication protocol is the Internet provider that connects the gateway to the Internet. In the application of building fire detection, WSNs are used to safeguard the people from the calamity. The evolution of integrated circuit designs lessens the size of computing, with more efficient and rapid performance. The increasing wireless communication technology, along with improved integrated circuits, creates a network paradigm that is efficient for a variety of activities. Smoke sensor, heat sensor, gas sensor, flame sensor is the part of the WSN-based fire detection systems to detect smoke, temperature, gas emissions and fires in the building wirelessly. Sensor obtains the analog data from the physical environment and analog-to-digital (ADC) converts data to digital format [23].

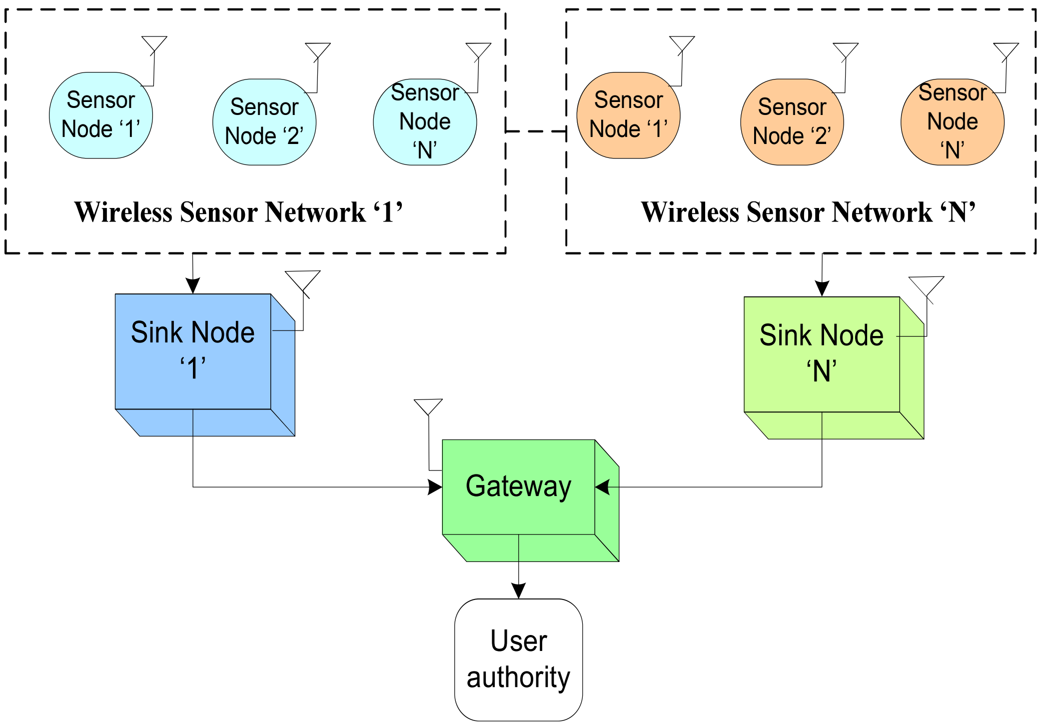


Figure 1.3 WSN architecture

In WSN, wireless communication plays a crucial role in the transmission of sensor data. Currently, several communication protocols offer the possibility of wireless transmission of data to the authorities. The wireless communication protocols in the WSN are selected according to the application and the transmission range for the transmission of the data. However, only a few obstacles interrupt the implementation of WSN in fire detection systems such as energy efficiency, communication range, and scalability. The energy efficiency and communication range of the WSN depend on the type of wireless communication protocol that is implemented for the fire detection application. 2.4 GHz-based Zigbee (IEEE 802.15.14) is a type of short-distance communication protocol implemented in fire detection to activate the automatic alarm system based on sensor data. Furthermore, these technologies make use of short-distance communication extremely with low power. Zigbee protocol is a standard wireless network for the needs of low-cost, low-power IoT applications. It operates on the IEEE 802.15.4 standards. Moreover, The topologies for the Zigbee network are like a tree, mesh, and star network topology [24]. WSN has recently been used in a variety of fields, including military, horticulture, industry, home and household, health and clinical, condition monitoring, and so on [25]. Zigbee technology was created by the Zigbee Alliance. The technology is a low-power wireless communication standard protocol using radiofrequency ranges of 2.4 GHz, 915 MHz, and 868 MHz with a transmission rate of 250 kbps [26].

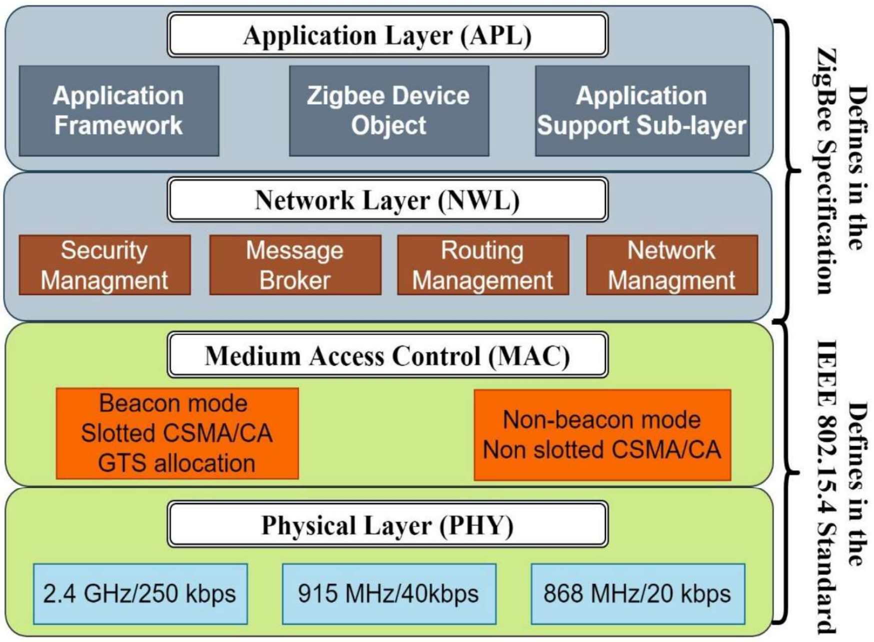


Figure 1.4 Zigbee Protocol stack [27]

The Zigbee protocol architecture is depicted in Figure 1.4, which is comprised of a stack of levels, with IEEE 802.15.4's defining physical and MAC layers of the framework, while Zigbee defining network and application layers completing the framework. The physical layer (PHY) controls different parameters such as output power, channel count, chirp modulation receive sensitivity, transmission and channel rejection, among other things. This layer applies modulation and demodulation operations while sending or receiving the signals. In the 2.4 GHz ISM band, the most of Zigbee applications functions at 250 kbps data rate. In Mac layer, the radio frequency (RF) data between the neighbouring devices get exchanged. The MAC includes methods such as collision avoidance, acknowledgment handling, transmission retries etc.

All network-related processes are supervised by the network layer. Routing features have been incorporated, enabling RF data packets to go from transmitter to the receiver via multiple devices (many hops) (peer to peer). To extend the data transmission range, GSM/GPRS is used as the wireless communication protocol. However, GSM / GPRS has limitations in power communication, which is a power limitation for sensor nodes as they are battery-powered. The development of long-range wireless communication (LoRa) has overcome WSN's limitations in terms of energy requirement and maximum communicable range.

Table 1.1 shows the various wireless communication protocols that exist to implement WSN. This table presents complete specifications of the wireless communication protocols, including frequency, range of transmission, network size, the topology of network, bandwidth, and power consumption. Lora wireless communication can send data over great distances while consuming less power . LoRa, ZigBee, BLE are key developing technologies in low-power wide-area network (LPWAN). Narrowband IoT (NBIoT), and Sigfox are discussed concerning WSN requirements for a diverse set of applicability. Lora is a network independent of the three LPWAN technologies and offers the option to use the frequency bands for free. Lora works with Chirp Spread Spectrum (CSS) technology and transmits up to a range of 5 km (urban), 20 km (rural), as mentioned by the LoRa alliance [28]. Lora is implemented in a star topology in which the gateway and the cloud server are connected using the Internet Protocol (IP) (Figure 1.5). End devices can send suitable small-sized packets to large distances using low frequenc. End nodes are devices integrated with LoRa chips that include sensors, controllers, converters, and other components. Messages from LoRa endpoints are received by the gateway and forwarded to the backhaul system. Backhaul is a type of network connection that connects gateways and network servers (cellular, satellite, Wi-Fi, or Ethernet). Data from end nodes is received by the LoRa gateway, which then transfers it to the network server. A LoRa WAN has a large number of gateways, each of which may receive and deliver the same data. The network server is the one with the intelligence to perform crucial procedures like, it filters out redundant packets from various gateways, performing security screening, and delivering acknowledgment messages to gateways. It has the responsibility of eliminating and scanning duplicate data and security screening. The real time fire safety monitoring is lacking in the Wireless Sensor Netwoks, as real time monitoring enhances the fire emergency officials to have a close eye on fire in the building [29]. The widespread availability of the internet facilitates the use of the internet of things (IoT) in a variety of industries for real-time monitoring from remote location.

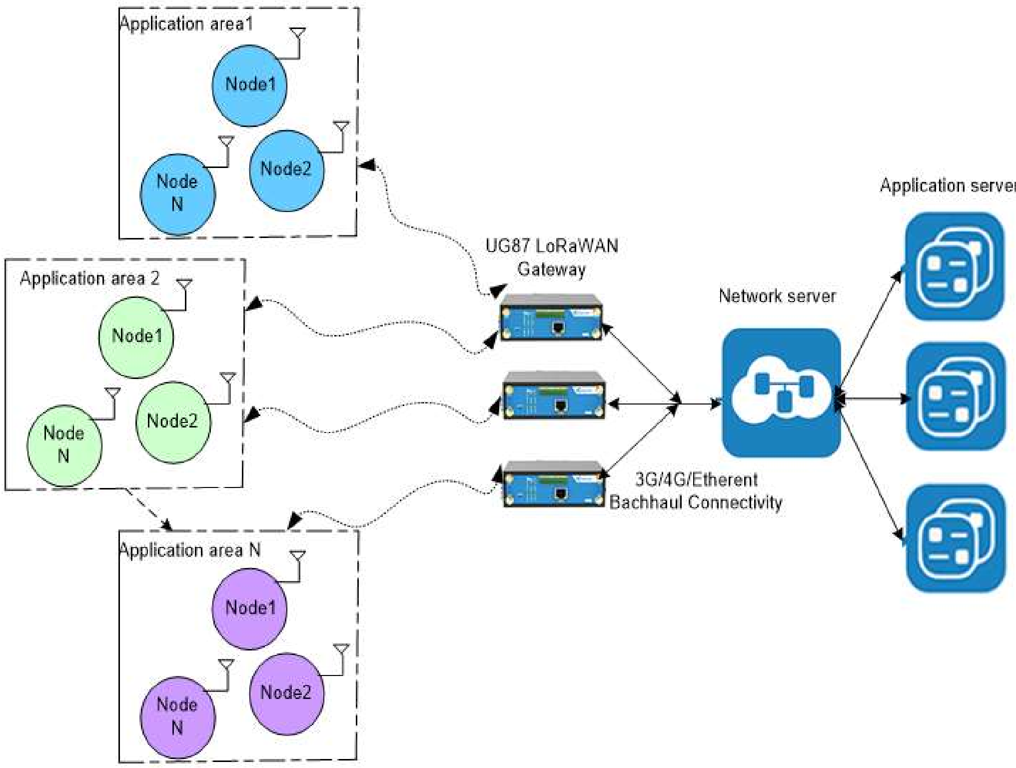


Figure 1.5 LoRa Network Architecture

The IoT-enabled system integrated various built-in detectors to detect parameters such as thermal energy, smoke formation, and flame ignition. The data from these detectors pass through the terminals to verify the potential of the fire breakage and then send the desired result to the authorities through the wireless communication protocol connected to the system. To obtain substantially curcial data without endangering human life, IoT technology can be implemented that provides the fire department with crucial data. After all, the main characteristic of IoT-enabled systems is minimizing false positives, which as a result makes the system more reliable and dependable.

Table 1.1 Wireless communication protocols and their Technical specifications

Parameters	NB-IoT	Wi-Fi	GPRS	LoRa	Sigfox	ZigBee	BLE
Frequency	Licensed LTE freq. bands	2.4 GHz	900 to 1800 MHz	869 to 915 MHz	868 to 915 MHz	2.4 GHz and 868/915 MHz	2.4 GHz
Range of Transmission	NA	100m	1-10km	5 km	10 km	100 m	10 m
Network size	52,000 devices/channel	Approx 32	Approx 1000	10,000 no of (nodes per BS)	1,000,000 no. of (nodes per BS [24]	Approx. 65,000	Limited application
Topology	Star	Point to hub	Cellular system	Star of stars	Star	Tree, mesh, star, P2P,	Star bus
Power consumption	NA	835 mW	560 mW	100 mW	122 mW	36.9 mW	10 mW

1.2.2 Regulation for Fire protection of Electronic Devices

The primary goal of a fire detection and alarm system is to detect a fire as quickly as possible and trigger the alarming system so that further actions can triggered such as informing fire department, evacuation of occupant and initializing fire estinguishing process etc.

"Selection, installation, and maintenance of automatic fire detection and alarm system code of practice," according to Bureau of Indian Standard (IS 2189:2008). [30], following are the general guidance to design and built fire detection and alarming system: a) detect quickly enough to perform its functions b) reliably transmit the detected signal c) convert this signal into a clear alarm signal that will immediately and unmistakably attract the user's attention and indicate the location of the fire, as well as initiate the operation of ancillary services such as fire extinguishing systems, etc d) remain insensitive to events other than those for which it was intended and e) instantly and clearly signal and supervise any malfunction that could threaten the system's proper operation.

Fire detection and alarming syetm can be built using various electronics devices such as fire and smoke detector sensors, hooter system, Sprikler system and Intelligent device for data communication etc. Malfunction of these devices due to any reason can put the whole functioning into jeopardy. This speaks about safeguarding the electronic devices against the evenst such as fire hazard since rise in temperature of surrounding thes devices exceeding 45^0 C will cause its malfunctioning and failure if rises further. Bureau of Indian Standard (IS 12456:2004) for "Fire protection of electronic data processing installation - code of practice" set fourth minimum requirement for the protection of electronic devices not only from fire hazard but also from smoke, corrosion and water [31] .

1.3 Motivation

Several fire-related injuries have occurred in recent years, resulting in significant destruction and several fatalities. According to forensic medicine for medical students, there are the following reasons for deaths from fire hazards in buildings: i) Due to the nature of fire, such as a flash fire or explosion, there was not enough time to escape, ii) There was a state of panic/confusion, iii) The escape routes were blocked because it was covered in smoke, iv) The lack of information on evacuation path to escape from fire, vi) Due to a lack of physiological reserve, they were quickly overwhelmed by fumes/ smoke. Many of these deaths might have been avoided if the flames had been discovered sooner and people had been evacuated. Basically, at the present state, most of the buildings are equipped with furniture, plastics, and other easily combustible materials. Similarly, when insulating materials become more widely used in construction, the hazard of fire to the lives of structures and individuals grows.

Fire accidents happen seldom, but when they do, the effects are severe. Fire is likely to cause 12 times more deaths than injuries as per the NCRB data available in the country & Incidents at residential buildings to account for 42.1%. So, fire incidents must be avoided at any cost. Hence there is a need for society to build effective fire sensing devices and intelligent alerting systems. As a result, academics are paying close attention to the creation of intelligent systems for global construction. Low visibility of exit path due to high smoke density during fire accident inside the building is also one of the major problems of fire casualty. In the current fire protection system, there are many challenges such as false fire alarm, static exit path, no clue about fire flow, and people stuck inside building/room, etc. This system is not sufficient to provide reliable fire detection and predict real-time exit paths for the people. The integration of vision-based systems with sensor-based systems has gained attention in fire detection, as the vision-based system gets activated with sensor data to accurately detects the color and movement of the fire. This system is capable of providing the evacuation route during a fire accident and reducing the loss of life through smoke inhalation. In addition, the wireless communication protocol is crucial for the transmission of information in real-time from sensors and image processing systems to fire departments over long distances to minimize the risk of fire.

1.4 Research Objectives

The main aim of the research is focused on the design and development of a precise, efficient, and reliable system for intelligent fire safety and building evacuation. The four objectives of the research are as follows:

- To design a framework for the intelligent fire detection system
- To develop and implement sensor and vision nodes for real-time detection of smoke and people density
- To establish a communication network using Zigbee and LoRa.
- To design a smart evacuation pathway

1.5 Thesis Organization

The organization of the thesis includes a total of seven chapters.

Chapter 2 covers the review of literature on fire detection and evacuation system is discussed to study the existing technologies. The review of the literature concludes with the research gap from the previous literature.

Chapter 3 cover presents the description of the system architecture along with its internal components which have been used for the implementation of the fire detection and simultaneous evacuation system. This chapter presents the system description along with all its components and hardware design of the system and method for realizing simultaneous fire detection and autonomous evacuation plannings. Further, the customization of the sensor mote, gateway, and RF-based end device is presented along with the circuit design and final prototype.

Chapter 4 analyzes the performance analysis of the hybrid network, including the 2.4 GHz Zigbee RF and LoRa network. The OPNET network simulator is used to simulate the ZigBee network, which includes characteristics such as received traffic, end-to-end delay, retransmission attempt, and performance. Further the evaluation metrics of LoRa like link budget and Time on Air (ToA).

Chapter 5 focuses on the design and development of vison nodes for fire detection and people density estimation. Also presented is DNN based algorithm with its importance for people density detection.

Chapter 6 covers the design and development of the evacuation guidance system are carried in. It presents a decision model built using the shortest path algorithm and implementation on building structure. Further experimental setup and working model of overalls system is presented in detail.

Chapter 7 concludes the thesis by highlighting the prime outcomes of the current research and the significant contribution of the thesis. The scope for future research in this area is also discussed.

1.6 Chapter Summary

This chapter discusses a detailed description of the fire hazard, as well as the causes and reasons for fire emissions in the building. The significance of the fire detection system to enhance fire safety to the people in the building is also presented in this chapter. The implementation of WSN and IoT to implement wireless and real-time fire detection are also addressed along with motivation in this chapter. The objectives and thesis organization of the research work are discussed in this chapter.

Chapter 2
Review of Literature

In this chapter, the review of literature on fire detection and evacuation system is discussed to study the existing technologies. The review of the literature concludes with the research gap from the previous literature.

2.1 Fire Detection and Evacuation System

Fire detection systems are utilized in both residential and commercial structures are currently required by building codes in the majority of nations throughout the world. The most important characteristics of fire to be taken into consideration are smoke formation, flame ignition, and ambient thermal energy and temperature values. The present techniques of simultaneous fire detection under critical circumstances are smoke detectors that measure the level of smoke and flame. Existing smoke detectors use the photoelectric ionization principle and the linear beam to detect smoke. The type of fire to be detected will decide the difference in selecting a smoke alarm. Image processing is another way of detecting flames.

2.1.1 Software-based Approach

An evacuation system is proposed to evacuate people stranded in distress thanks to tracking clusters and the clusters are classified using an Analytical Hierarchy Process (AHP) to identify people at risk [32]. An open system architecture evacuation guidance system (IEGSOS), which integrates the environmental evaluation system, smart guiding methods, and IEGSOS is built on the foundation of service-oriented architecture (SOA), and information interchange technology is employed [33]. EvacuSafe is developed for designers to optimize the layout for structures to maintain performance in terms of their emergency evacuation methods and also it allows designers to analyze and optimize building layout design using various safety criteria [34]. The objective of this research was to use the discrete dynamic simulation for evaluating the movement of agents in buildings during an emergency and the discrete molecular dynamics technique is used for the simulation of evacuation in a panic situation [35].

A system using opportunistic communication provides disaster evacuation guidance and evacuees can use their smart phones to collect information on the location of blocked and crowded roadways caused by a catastrophe, and also spread the information among themselves by wireless communication between adjacent devices over a short distance smartphone [36] . A method is implemented to enhance evacuation plans through Situation-Aware System for enhancing Evacuation Plans (SASEP) and a practical verification was performed out and from the results obtained; SASEP provides a better evacuation path option [37]. An intelligent fire detection system is applied Geo-spatial data mining approach (SPDA) technique along with fire sensors to improve the ability of sensors for fire detection [38]. An interactive three-dimensional model of the structures for giving mobile-based instruction is proposed to the user during an emergency and it determines the user location into the structures and to visualize a three-dimensional model of the structure combined with real-time rescue along with guidance on the smartphone [39]. Dijkstra's algorithm was applied to optimize the escape route of buildings and the characteristics of the attributes of the network nodes with regard to architectural space and an escape route, after which the optimal escape route was investigated based on information about the Fire [40].

An agent-based model analyzes both structures and human evacuation factors and agents are classified into four groups and three cases for simulation modeling [41]. In each scenario, the number of agents varies, and each of the four groups exhibits varying levels of output consciousness. A risk-based model for the optimization of evacuation route under fire scenario is proposed and the risk analysis of parameters like temperature, thermal radiation, and toxic gases are carried out with Dijkstra algorithm to suggest the best and shortest path [42]. A system is proposed taking into consideration an ant colony-based algorithm, to process the shortest route and control instructions of lighting to be displayed on the system for fire evacuation in an emergency [43]. Based on the real-time fire location, the ant colony algorithm further estimates the shortest route and controls lights along with dynamic instruction, in the case of emergency. An extensive Floor-Field (FF) model is proposed for the assessment of rescue dynamics of the pedestrian with the effect of smoke and the fire spreading and assessment of evacuation dynamics was carried out through numerical simulations [44]. It is concluded that location and spreading speed of smoke and fire, affect highly on pedestrian evacuation dynamics and demonstrated through the simulation results. Table 2.1 illustrates the comparison of the different studies that utilized algorithms and simulation in the fire detection system.

Table 2.1 Comparison based on Algorithm/Simulation Software

Ref	Software / Algorithm	Findings	Limitations
[32]	PyroSim, MINEFIRE PRO+	In the case of a fire in an underground mine, a computer simulation of an evacuation scenario	combined with hardware for the feasibility of software
[33]	Fire Dynamics Simulator (FDS)	Proposed a method to reduce simulation time and cost in fire emergency by DDM (Subway Station)	Needs to examine for full-scale fire emergency evacuation. To sync with real-time data in a fire emergency.
[35]	CAEva Simulation Method.	Simulation helps to know how people behave under fire condition	It is extremely difficult to create a simulation of a fire exit scenario.
[40]	Simulation platform GAMA	Simulated with Metro Supermarket Hanoi Recommendation of fire evacuation expert has been taken into consideration	Developing simulation plan of realistic building.

Table 2.1 Comparison based on Algorithm/Simulation Software (Continued)

Ref	Software / Algorithm	Findings	Limitations
[45]	Dijkstra algorithm	Improved Dijkstra Algorithm for finding shortest path during evacuation.	Other factors like smoke stream diffusion, the personal behavioral factor can be considered while deciding the shortest safe path for evacuation in a fire hazard.
[46]	Agent-based Model	Stressed on the importance of proper guidance in case of emergencies like fire for high-rise buildings and Malls.	Agents like fire smoke and toxic gasses are important factors for rigorous simulation
[47]	Dijkstra algorithm	Proposed topological model to evacuate people in a fire as soon as possible. It can be used to avoid congestion under fire accident	It can be further extended to elevator evacuation as well as a larger-scale evacuation network.
[48]	ants colony based algorithm MapX	Ants colony based methodology is applied for computing the shortest evacuation path to control lights with dynamic instruction	Further work can be done on the reduction of computation time and node

Table 2.1 Comparison based on Algorithm/Simulation Software (Continued)

Ref	Software / Algorithm	Findings	Limitations
[49]	Static Floor Field Model and Dynamic Floor Field Model	Result: Location of fire breakage and smoke formation and spreading rates affects highly on the rescue of pedestrian	Investigation of extensive spreading dynamics of the smoke and fire.
[50]	Fire detection and predicting safe exit.	Tested with real-time building With and without fire testing conducted	Human psychological patterns are necessary.
[51]	Numerical Simulation and analysis	Effect of fire spread on dynamics of pedestrian evacuation. The evacuation process and evacuation time are compared with and without fire	Effect of harmful gases and psychological parameters on pedestrian when fire breaks
[34]	1D Evacuation Simulation	Assessment of fire safety of the tunnel	Further investigation is required for quantitative assessments.
[52]	Bee Colony Optimization Algorithm	Clearance and total evacuation time is reduced. Tested using simulation Run	Need to validate using real human experiments Human behavior and nervous level need to be investigated.

Table 2.1 Comparison based on Algorithm/Simulation Software (Continued)

Ref	Software / Algorithm	Findings	Limitations
[41]	Computer simulation using on Latin Hypercube Sampling	The probability model developed in this study is more reasonable	More accurate mode needs to be developed by considering people's premovement time, people’s density in a different fire scenario.

The fire evacuation simulation takes into account the effect of fire propagation on pedestrian movement and for safe pedestrian evacuation, fire propagation data from the SDS is provided to the floor field Model (FFM) [50]. A quantitative method is proposed to assess the fire safety of road tunnels based on a numerical simulation and the influence of smoke formation on evacuees is assessed using the smoke formation and distribution derived from the three-dimensional CFD [53]. The real-time simulation tool for building fire accidents using cellular automation systems is implemented and this simulation can be used to monitor the condition of buildings in the event of fire [54]. A fire evacuation model using artificial “bee colony optimization (BCO)” is proposed to find the optimal fire evacuation routing solutions for reducing both clearance time as well as total evacuation time [55]. An agent-based evacuation model is presented to investigate the smoke formation effect and blind stranded people evacuation methodology by considering people’s speed, visibility, and evacuation strategy to improve evacuation methods taking into account the amount of visibility [56]. A probabilistic model has been developed for the safe rescue of persons in the scenario of a fire breakage and it has been shown that the probability model predicted here is more suitable for the safe evacuation of persons and is more effective in the event of high mobility and irregular distribution of people on fire [57].

2.1.2 WSN based Approach

A WSN based fire detection system for detecting flames quickly and assisting with rescue efforts is proposed with a network architecture [58]. The IEEE 802.15.4 network is used in the development of a smart fire detection system to monitor and send temperature and smoke sensor data with the aid of a GSM communication module [59]. A video processing-based approach to triggering fire alarms and an RGB (red, green, blue) model based on smoke pixels were introduced and the change from frame to frame in the recorded image was evaluated [60]. To construct the generated map, a graph model is suggested with an adaptive dynamic route query table, and the population density is utilized to limit the escape expectation velocity, which depicts human migration in emergency scenarios [61]. ZigBee based fire detection and alarming system is presented for cultural relic building management in China to eliminate fire in the first place and helps to asses the fire risk of the building [62]. An intelligent fire emergency response system is proposed using IoT to provide directional guidance with respect to the time and position of fire breakage and WSN is used to design an integrated control system to solve the problems in existing fire emergency response systems [63]

An intelligent, integrated firefighting system that makes use of wirelessly interconnected sensord devices and visual cues that provide valuable information to fire departments like real time fire alarming, fire status, and evacuation guidance through Bluetooth [64]. A LoRa-based smoke detection system with an indoor positioning system is proposed to build a wireless smoke sensor and the unique UUID of the indoor positioning system assist trapped individuals and firefighters in the fire field in locating their location, which can substantially improve rescue efficiency . LoRa based wireless security alarm system is proposed for long-distance communication with alarm systems and the system enhances wireless security systems in terms of low cost, more reliability, and flexible networking [65]. A Smart firefighting system is proposed to avoid urban calamities and Large Public Building structures management in case of emergency rescue operations and a dynamic terminal enables to visualizes the building structure and geographical space structure of the surrounding [66] [67].

A fire alarming with a multi-door management system using FPGA during an emergency scenario is proposed and it also shares crucial insights of the floor where the fire breakage happened, which helps overall evacuation process [68]. The combination of image reorganization techniques and digital signage are used for guiding people through a safe exit path during an emergency and environmental conditions are monitored using WSN and RFID Devices [69]. An intelligent evacuation assistance system is presented for indoor evacuation and guidance using field verification technique which minimizes evacuation time for safe evacuation to a safe place more quickly [70]. A real time computation model along with a safe exit path is presented with the combination of WSN and RFID and the system helps to improve rescue operation by providing real-time information of emergency to fire fighters and also digital signage is used to indicate intelligent and safe evacuation route [71]. An intelligent evacuation guidance system is proposed with imagery classification techniques and digitalized signage to guide stranded people to safety [72]. in the proposed system, environmental information was collected via WSN and RFID, IP cameras are used to evaluate group motions, and an assessment methodology is used to discover and circulate a safe path. on the user's smartphones and signage digitally was used to display the output instructions. An evacuation route guidance system with WSN and digital signage to predict safe route during emergency and algorithms were used to compute safe exit path and which triggers digital signage system for safe exit path [73] [74].

2.1.3 IoT based Approach

A cloud-based service for the rescue worker interface (RWI) is proposed to assist fire wardens during a fire emergency by providing real-time information for the effective implementation of the rescue operation. Further using a handheld mobile phone warden can get information like the fire flow, people density in a building, and the warden locations can be traced [75]. Using IoT technology, an intelligent firefighting and guidance system is presented, where the system detects fire events, notifies residents and fire services of an emergency, and also provides a real-time safe path for exit [76]. The real time exit path estimation method is presented for high rise buildings structures in the event of fire emergency which provides information such as data collection, estimation of risk distribution, and compuatation of evacuation route [77]. A fire evacuation system is built with the integration of Cloud technology and RFID techniques that uses mobile phone terminal and computer-based simulation and visualization tools like Path Planner, MobiX3D, Mobile Apps, etc. are used to find evacuation paths reliably [78] An evacuation system has been proposed using GIS and IoT to improve evacuation efficiency and it also helps to obtain information about the building using MATLAB [79]. Using an IoT system is prsented to identify the denisty of stranded people in a structure dutring fire breakage event and it is achieved through multiple channels such as motion detection [80]. An emergency rescue and assistance system based on agents helps to determine automatically the evacuation guidance plan and provide instant evacuation guidance, the situation with IoT devices [81]. A system to be used during calamities for evacuation planning of large-scale concentrations of people is essential and is proposed with IoT and mobile cloud computing platforms [82].

An IoT-based emergency management system with specific route planning has been proposed, and a framework is also proposed to reduce congestion in the corridor, with the space-time mobility of people inside [83]. A cloud-based smart evacuation system has been proposed which estimates significant data from a number of sources in real-time [84]. A combination of IoT and cloud based system is implemented for the compuatation of real time exit paths during a fire breakage and the proposed system also helps to increase safety through evacuation paths [85]. EasyGO is IoT based system based on smart phone indoor navigation and evacuation system and further, the shortest path can be planned to use the calculated moving speed of people. IoT technology-based emergency fire detection system is also obtained real-time information of air quality and human presence in the immediate proximity of fire [86]. An architecture is proposed based on LoRa and MQTT to deliver building automation services and ensure commands transmission and actuation in less than 200 ms [87]. Table 2.2 illustrates different hardware, sensors, and wireless communication protocol that is been implemented as part of the WSN and IoT-based approach.

Table 2.2 Comparison of Hardware/technology Preferred in the Existing System

Ref.	Hardware / Technology	Data Collecting Device	Communication	User Interface
[59]	Raspberry Pi	Gas Sensor (MQ9), Smoke and Temperature Sensor (LM 35)	GSM Wireless Sensor Networks	No methodologies stated for rescue operations
[68]	FPGA, Microcontroller, and Transceiver	Temperature Sensor	Wireless Trans receiver	Direct Alarm System
[71]	XBee, RFID	Temperature values, Humidity values, and Light intensity	Wireless Sensor Networks Technology	Digital Signage (LCD Display)
[72]	RFID, WSN(Zigbee) and IP based Cameras, Multimedia Digital Signage	Humidity, Temperature, and illumination,	WSN, RFID and ZigBee Technology	Mobile phone, Digital Display

Table 2.2 Comparison of Hardware/technology Preferred in an Existing System (Continued)

Ref	Hardware / Technology	Data Collecting Device	Communication	User Interface
[75]	Microcontroller	Smoke	Cloud	App on Smartphone
[79]	IoT, Arduino	PIR Sensor, Temperature Sensor and Bluetooth (HC-05)	Bluetooth, RF Communication	Text Message on user mobile and Audio message
[82]	IoT, Parrot AR. Drone 2.0, Turtlebot2, & DJI Phantom 4	Arduino Uno and illuminance sensor	WSN	Mobile Appliation
[88]	nRF24L01 transceivers. Laptop with Arduino	Fire Sensor (Infrared Flame Sensor)	RF transceivers	Website built using HTML/CSS
[89]	Mobile Phone with RFID Reader capability	RFID tags	RFID Technology	Mobile phone-based App

Table 2.2 Comparison of Hardware/technology Preferred in an Existing System (Continued)

Ref.	Hardware / Technology	Data Collecting Device	Communication	User Interface
[90]	Zigbee, RFID, Camera, Multimedia Digital Signage	-	Wireless Transceiver	Audio Visual, Smartphone Digital Signage (Large Display)
[91]	BIM-VE, Unity3D server	Fire, Smoke, Toxic	-	Mobile Phone, Head Mounted Device, web browser view
[92]	Mobile Phone with RFID and NFC reader	Active temperature and RFID tags	RFID, Cloud Computing Technology	Cloud Computing is used to send SMS to members and fire brigade
[93]	IoT and GIS	Temperature, CO, Optical Density Sensor	WSN	Fire breakage Alarm, Emergency Lightening system

2.1.4 Artificial Intelligence-based Approach

In this part, we provide prior research papers that mostly centered on fire breakage identification and the count of stranded individuals present during incidents. For crowd counting and identifying normal or abnormal occurrences, an automated video surveillance system is used [89]. The use of Histogram of Oriented Gradients (HOG) characteristics for human identification with a cognitive science approach is recommended for traffic management [94]. An RPi-based device is suggested for counting the number of persons in a scene by counting their heads [95]. A small self-contained station For counting individuals, OpenCV and Raspberry Pi have been proposed [96]. Crowd density is estimated by counting individuals and applying the backdrop removal approach and perspective correction [97]. (HOG)-based people counting approach is given, which takes video as input and estimates the number of individuals [98]. A fire alerting system based on RPi and Arduino is presented, which identifies the presence of smoke in the vicinity caused by fire and records images with a camera attached to it before sending an alert signal to a webportal [99].

An effective architecture for getting the feature points is provided by identifieng variations in the picture of fire [100]. A multi-stage method is used to apply a Canny edge detector and an enhanced edge detector to pictures of basic and steady fires and flames [101]. For evaluating forest fire patterns in video scenarios, a methodology based on Fast Fourier Transformation (FFT) and wavelet algorithms is presented [102]. For identifying smoke using k-temporal information of shape and color, an approach based on the block technique is proposed [102]. A smoke detection technique for tunnel environments is proposed, which makes use of motion features, invariant moment approaches, and motion history images. For identifying divergence in consecutive pictures, a color-dependent approach is used [103].

To identify different forms of fire and smoke in pictures, a general rule-enabled approach for distinguishing luminance from chrominance is constructed [104][105]. Furthermore, because of its unique properties of dividing brightness, the use of YCbCr improves the fire detection rate from pictures over RGB [106]. With the help of RPi and OpenCV, a fire breakage detection approach is built for automated detection and alerting authorities through alarm [107]. With OpenCV, a vision system based on the Raspberry Pi 3 is developed to improve home security [107]. A fire detection system using image deep learning is presented, and the tiny-YOLO v3 deep learning image classification model is used [108]. The red portion of RGB distinguishes the regions of fire in an effective computer vision-enabled fire detection technique [109]. In the study, a unique intelligent fire detection methodology is applied in order to get a high identification rate, a low false alarm rate, and a fast speed, as well as to decrease the CNN calculation [110]. During the structure's fire breakage risk analysis procedures, the research produces scenario clusters, and the building fire breakage risk indexes are established depending on the count of fatalities and direct health and wealth loss [111]. A methodology for detecting salient smoke formation and forecasting the presence of smoke that may be used in video-based smoke formation identification systems. As a consequence, by combining a deep feature map with a saliency map, the presence of smoke in a photograph may be predicted [112]. A deep domain adaptation based technique for smoke formation identification is presented to pick a key feature extraction and presentation of smoke formation since extracting the feature from real smoke pictures impairs the trained model's performance [113].

2.2 Conclusion from the Review of Literature

In the review of literature, the existing techniques that are applied in fire detection are carried out. The following are the research gaps that are identified from the review of literature:

- Mostly focused on prototype development.
- The density of people during an emergency is not addressed effectively.
- Still, there is a challenge in the context of Retrofitting with an existing system.

2.3 Chapter Summary

The chapter discusses the existing literature that focused on the different techniques implemented in fire detection and evacuation path. The chapter includes the conclusion from the existing literature and a research gap that supports the formulation of objectives and methodology. It is concluded from the literature that the implementation of static LED displays, warning messages, and evacuation paths need to be connected wirelessly to provide a real-time monitoring system. To estimate people stuck inside the building, approaches like RFID tags and CCTV cameras are appropriate.

Chapter 3
System Description

This chapter presents the description of the system architecture along with its internal components which have been used for the implementation of the fire detection and simultaneous evacuation system. This chapter presents the system description along with all its components and hardware design of the system and method for realizing fire breakage identification and evacuation. Further, the customization of the sensor mote, gateway, and RF-based end device is presented along with the circuit design and final prototype.

3.1 System Architecture

IoT is an emerging technology that is adding enormous capabilities to every sector and application with its real-time monitoring capabilities that can be performed from any place. Along with it, the robust and advanced wireless communication technologies that have evolved over the recent decade are meeting the requirements for reliability in IoT. In view of the objective of the study, the challenge of establishing a real-time evacuation path during a fire breakage is possible through a suitable conjugation of wide area network (WAN) and personal area network (PAN), that lets us overcome the hurdles in network establishment in the context of license band, reliability, energy consumption and cost. Using these methodologies, a hybrid and novel IoT-enabled framework based on the 2.4 GHz Zigbee and LoRa communication systems is proposed in this study, with the hybrid architecture consisting of five components: safety operation controller, end device, vision node, LoRa gateway and evacuation path display controller.

In the architecture (Figure 3.1), the vision node and end devices are the key devices that are installed in the building for executing the on-field requirements of sensing and identifying parameters like fire, gas, temperature, and smoke with the help of connected sensors nodes and vision nodes. Initially, the system creates a PAN conjugated to a

WAN to let all the individual components connect and share the extracted information as specified using the onboard algorithms. The end devices are responsible for sharing the sensory and visual information into the network after formulating suitable and secure packets containing the ID parameters along with the data using the integrated 2.4 GHz Zigbee. On receipt of the information into the network, the safety operation controller validates the packet through the ID information and then analyzes the data to identify any abnormal shift in data trend. If any abnormal trend is identified, it simultaneously flags the incident as a fire accident and simultaneously sends a request to activate the sprinkler system corresponding to the place where the fire accident was identified. Meanwhile, the controller of exit path display analyzes the sensor extracted values extracted from the end deployed nodes, and in case of a fire accident, it uses its onboard routing algorithms to guide the people in safe evacuation from the building.

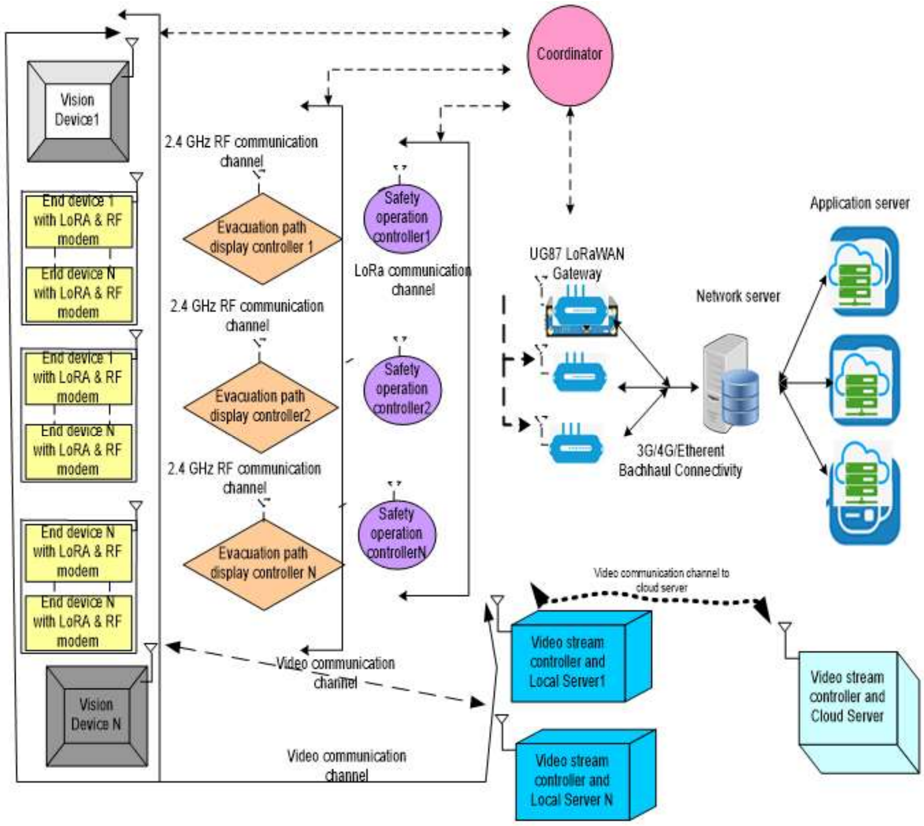


Figure 3.1 Hybrid Architecture using 2.4GHz RF Module and LoRa for detecting Fire breakage and Safe evacuation in the Building structures

3.1.1 Data Collection Devices

Data collection devices are responsible to sense their surrounding parameters like smoke, fire, temperature, gas etc. and communicate the same thorugh 2.4 GHz based Zigbee to the controller of evacuation path display, safety operation controller and to the LoRa gateway as depicted in Figure 3.2. It comprises of flame and smoke detectors that are deployed for sensing fire and smoke in the surrounding. The primary and common reasons for a gas and fire sensor integration is for identifying any possible gas leakage whic is also a crucial reason for the building fire explosion. All of these sensors are connetced with the controller board, which processes the signals received from all of them. End device is provided with Liquid crystal display (LCD) for the display and visualization of the sensor data. A power supply circuit is also integrated to ensure a proper supply of the external power to the various components integrated on the end device.

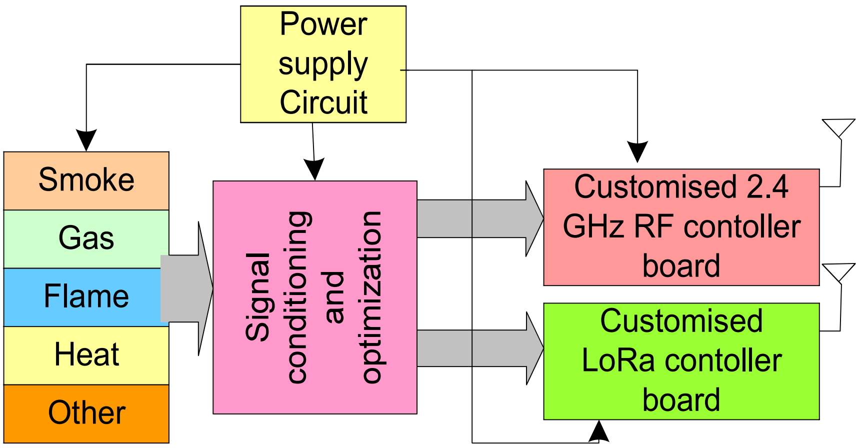


Figure 3.2 Functional Block Diagram of Data Collection Device

3.1.2 Safety Operation Controller

The safety operation controller as shown in Figure 3.3 is comprised of an RF 2.4 GHz controller board for its communication with other nodes, a sprinkler system to activate the fire exhaustion procedures, and a power supply controller to ensure proper power supply to the components. Once the device is set up and powered on, it constantly monitors the data value received from the end device, whenever the data value received is identified as an event of fire breakage, it feeds the data values into the onboard algorithm's module that is specified for the fire exhaustion procedures. Simultaneously, this event activates the sprinkler actuation system which then controls the sprinkler's water pressure and interval if needed, corresponding to the data received about the fire breakage. Automatic sprinkler systems are commonly viewed as the most important aspect of a building's fire extinguisher strategy.

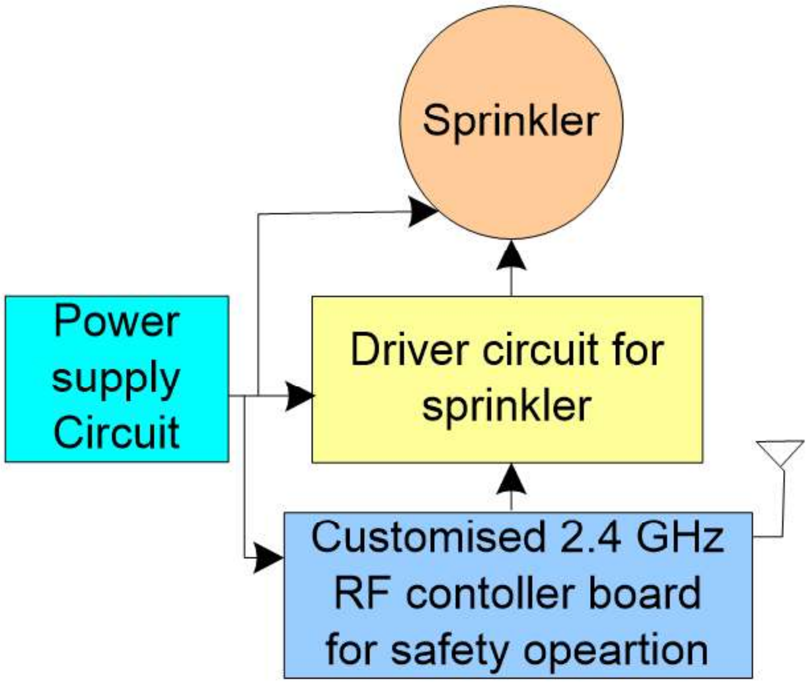


Figure 3.3 Functional Block Diagram of Safety Operation Controller with Sprinkler System

3.1.3 Proteus Simulation and Circuit Diagram of End Devices and Safety Operation Controller

Proteus circuit simulator is a software program created by LAB center Electronics Ltd that is primarily used for designing schematics, modeling Electronics and Embedded Circuits, and designing PCB Layouts. Professionals use the Proteus simulation program to develop schematics and simulations of various electrical circuits because creating circuits in a simulation like this saves time and reduces the potential of mistakes or component damage during actual implementation. The operations of the data collection device and the safety controller device are simulated using proteus as shown in the Figure 3.4, the data collection node is having a flame sensor, Temperature sensor, and Humidity sensor as the input components, along with a Zigbee module for communication. The safety controller system on the other hand will have a Sprinkler system, Virtual terminal, and 16x2 LCD as the output components of the circuit. A virtual terminal is integrated for the virtual implementation of the serial communication for sharing data within the nodes. The 16x2 LCD used here is to display the result for testing. In case when the data collection device does not sense any abnormal sensor values, the safety controller device is updated with the same information and the system remains on standby without any activation of alert or sprinkler system as shown in Figure 3.4

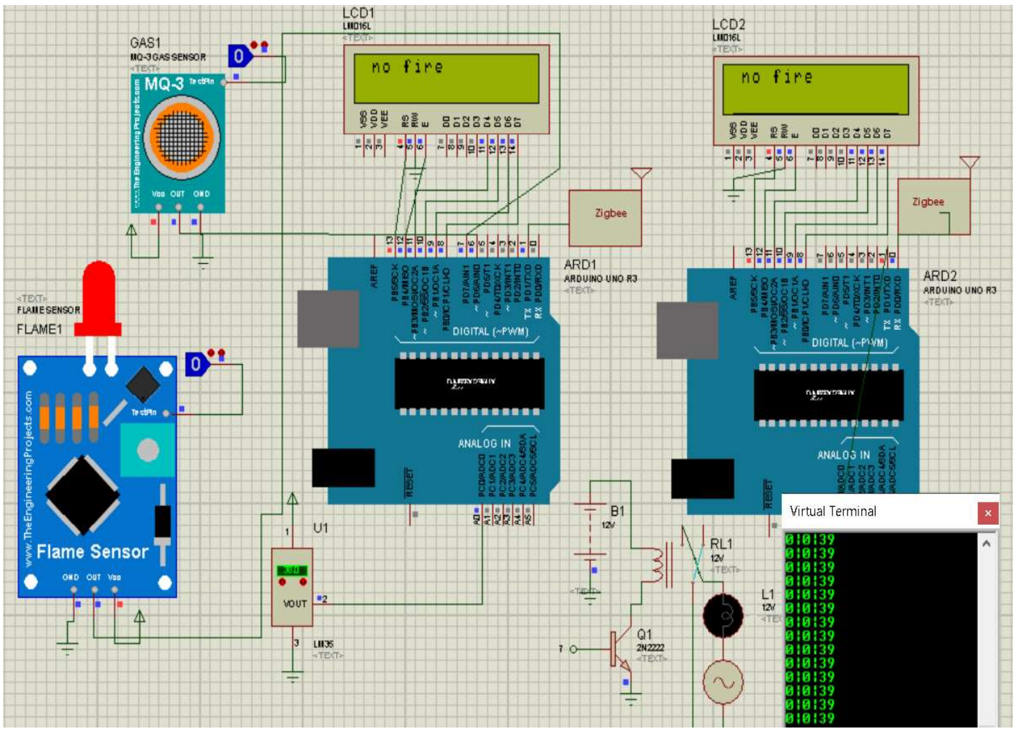


Figure 3.4 Proteus Simulation of the End device and Sprinkler (No Fire)

The data collection system continuously monitors the values from the sensors and processes them using its onboard algorithms (Figure 3.5) in case of a situation when the system senses the output from the temperature sensor rising beyond the threshold value, it flags the event as a fire breakage and in turn, gets out of the standby mode and logs the alert information along with the ID information into the coordinator node. The safety controller system corresponding to the position of fire breakage receives a wake-up signal wherein it is updated with the fire information and as a result, the onboard algorithm of the safety controller system activates the sprinkler procedures to exhaust the fire following the specific pattern of pressure and interval corresponding to the data received from the coordinator node.

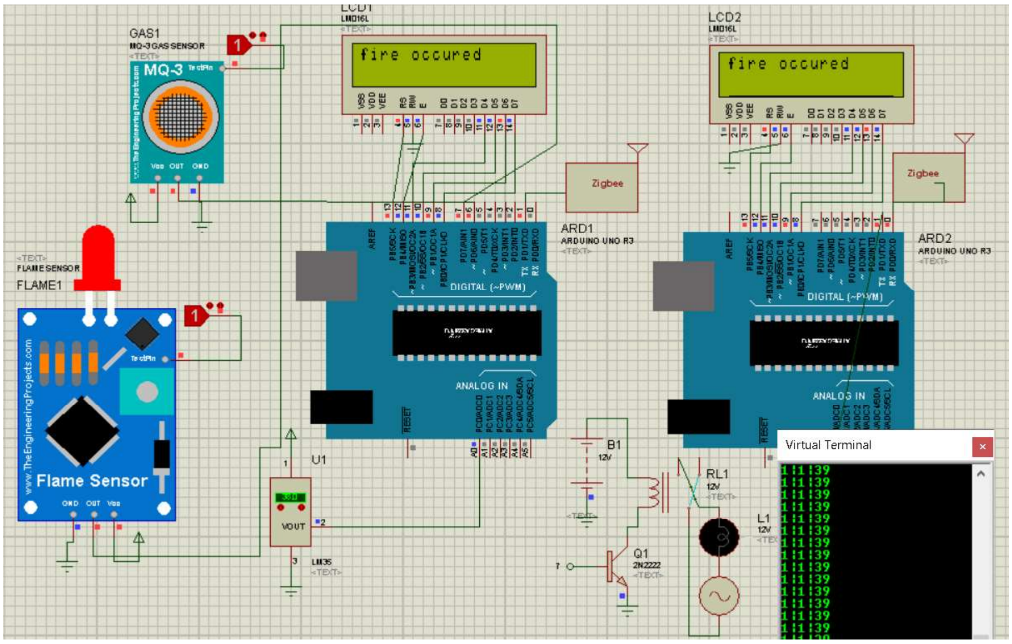
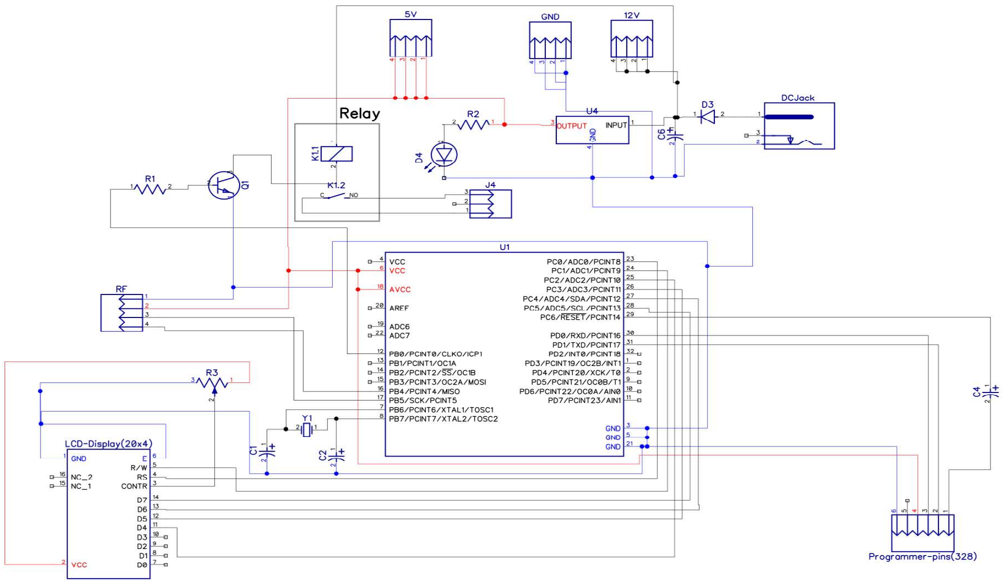


Figure 3.5 Proteus Simulation of the Data Collection Device and Sprinkler Device (Fire detected)

Detailed circuit diagram of the data collection node and sprinkler system is depicted in the Figure 3.6 wherein an atmega series microcontroller has been used as the main computing unit to compute and control all the peripherals and appliances. A 12V compatible relay is integrated as an actuator to digitally control high voltage appliances. A LCD display for displaying required information in the node and a programmer for programming the main board through UART interface has been provided. Powering options including 12V, 5V and 3.3V has been provided in order to power all the peripherals without the need of multiple external power supplies.



Vcc 5V	Blue Color trace
GND	Blue color

Figure 3.6 Circuit Diagram of data collection device and Sprinkler System

3.1.4 Evacuation Display System

The evacuation display system is responsible for displaying a safe path for the stranded people inside the building in order for them to get out of the building to safety safely. The device (Figure 3.7) comprise of light-emitting diode (LED) matrix used to illuminate safe routes in case of a fire breakage condition, 2.4 GHz-based Zigbee technology for receiving the sensor extracted values from the coordinator node, and a power supply unit to supply regulated and suitable power to the components in the system. The evacuation display systems deployed inside the building will be on standby at any point in time to decrease power consumption. In case of a flagged fire breakage anywhere, the system will analyze the data received from the data collection devices and will decide a routed path that is safe for the people to follow in order to get out of the building safely. The coordinator will generate an output as an array containing the ID of the evacuation display to be activated and their corresponding directions in the path. The same evacuation displays will be waked up and will be supplied with their corresponding directions. In view of the data received, the evacuation display systems will illuminate the guidance direction on their display which will assist the people to safe evacuate from the building.

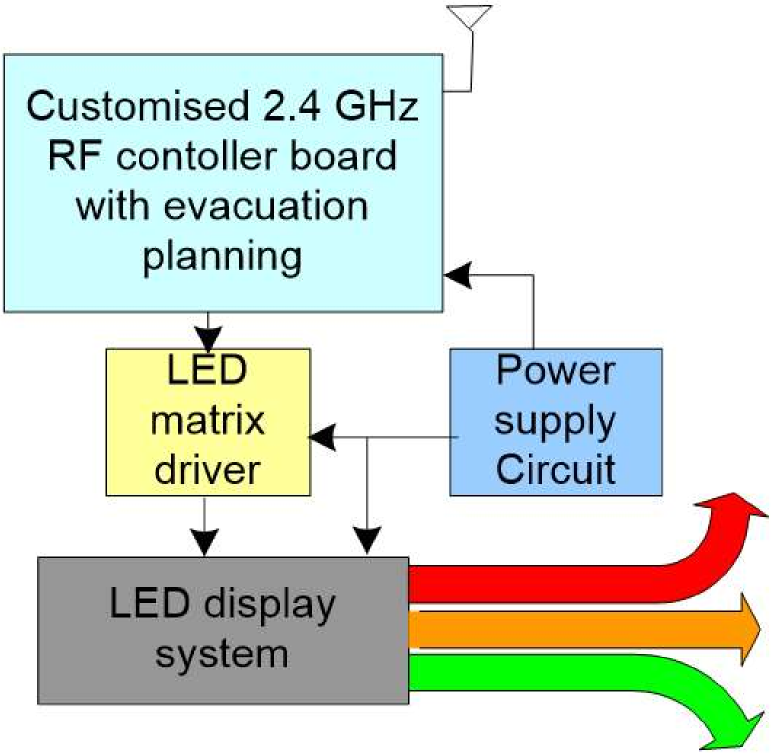


Figure 3.7 Functional block diagram of the Evacuation Display System

3.1.5 Proteus Simulation of Evacuation Display

The working of the evacuation display is simulated using proteus wherein the system has an integrated 2.4 GHz RF module integrated to it for enabling its communication abilities and a LED matrix is integrated using shift circuits to display the appropriate direction in case of emergency. Once the coordinator node has received the values from the data collection devices, analyzed them and generated a path array. The corresponding evacuation display systems will be waked and supplies with the needed information. The evacuation display system will receive the data using the virtual terminal for serial communication and then the internal algorithms of the evacuation displays will compute the information and will generate a series of LED numbers to be illuminated in order to display the appropriate path directions. The same will then be executed and corresponding paths will be displayed in the LED matrix integrated with the system as shown in Figure 3.8 and Figure 3.9 wherein the evacuation display is illuminating a path for left direction from its referential point and right direction from its referential point respectively.

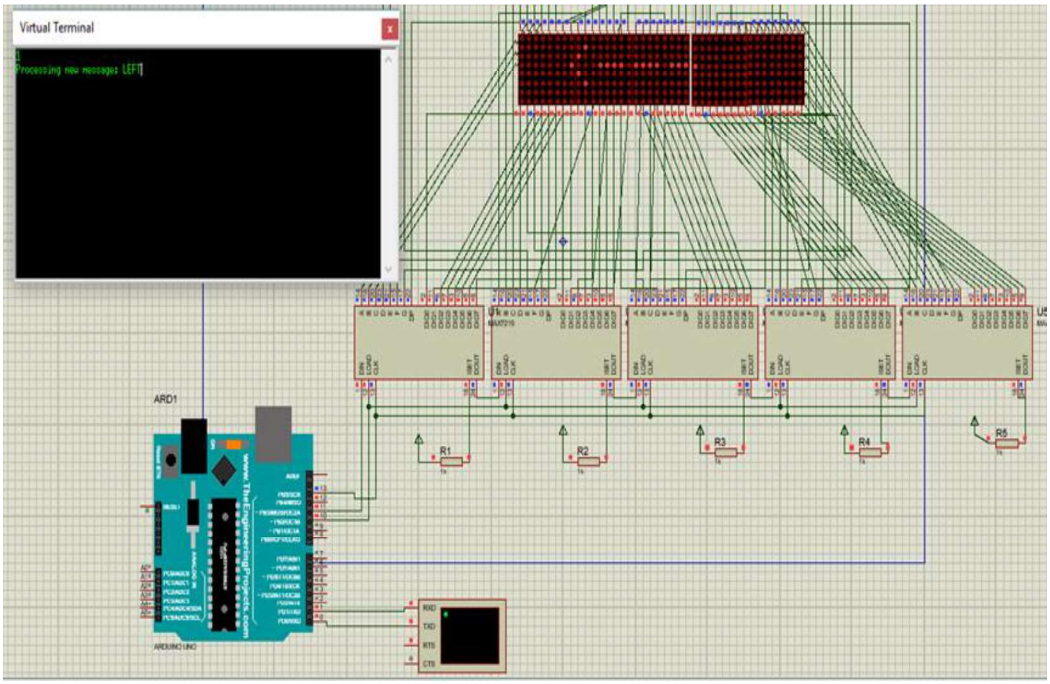


Figure 3.8 Proteus Simulation of Evacuation Display (Left Direction)

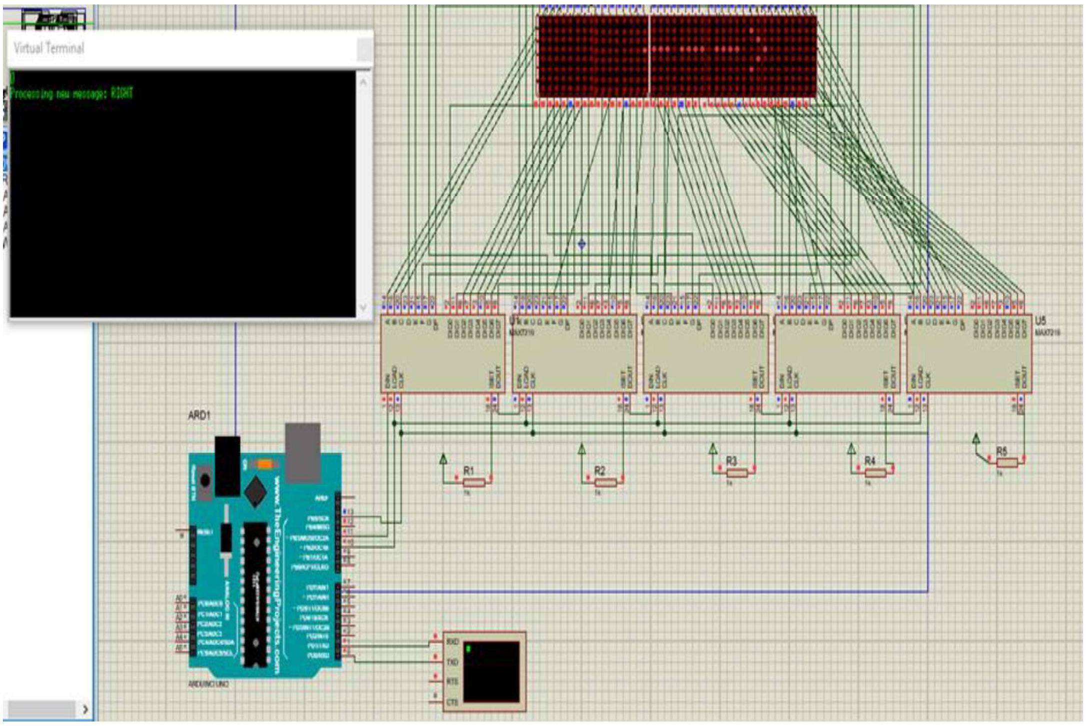
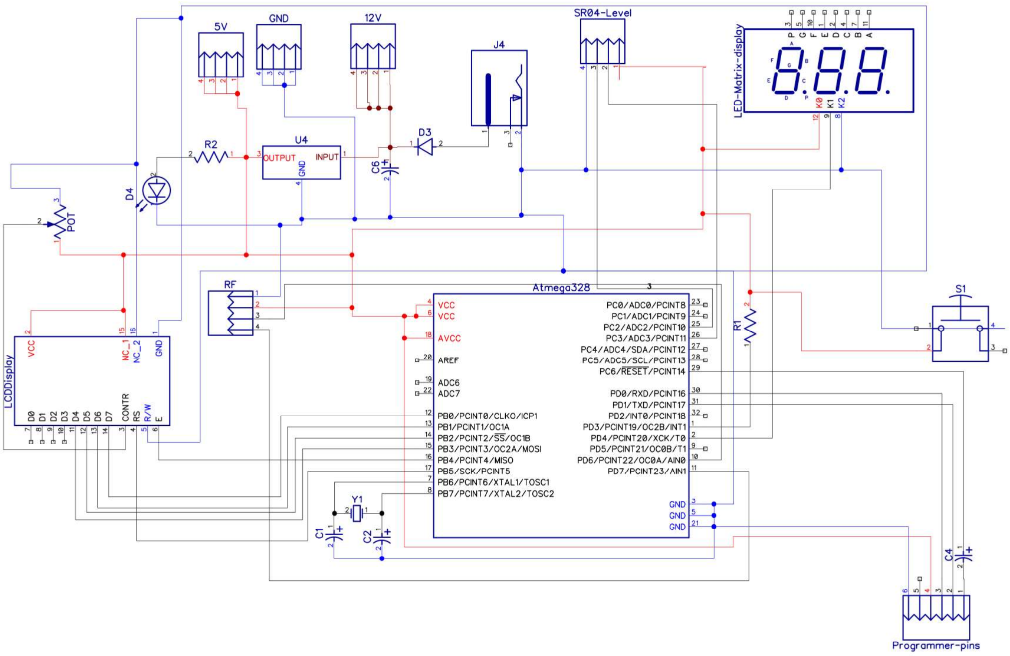


Figure 3.9 Proteus Simulation of Evacuation Display (Right Direction)

Figure 3.10 depicts the circuit diagram of the evacuation display that is objected to be used for displaying the safe path for the stranded people inside the effected building. The circuit diagram shows an atmega seried microcontroller being used as the master computing unit for computing and analysing all the desired parameters and informations. It is integrated with power supply pins, programmer pins for UART programming, LCD display for displaying purposes and led matrixes for displaying the direction towards the safe path.



5V	Red Color trace
GND	Blue color
12V	Brown Color trace
Other	

Figure 3.10 Circuit Diagram of Evacuation Display

3.1.6 LoRa Gateway with Hooter

The gateway based on LoRa (Figure 3.11) is used to communicate the real-time values received from the coordinator nodes containing information about the current status, values, and updates about all the individual nodes including data collection, sprinkler system, and evacuation display system. The gateway has the capability to communicate with two communication methods i.e., Long Range RF and Internet. It is comprised of a LoRa module to communicate with the coordinator node, a Wi-Fi modem for establishing the connection with the custom IoT server, a hooter arrangement to alert the authorities through audio noise in case of emergency.

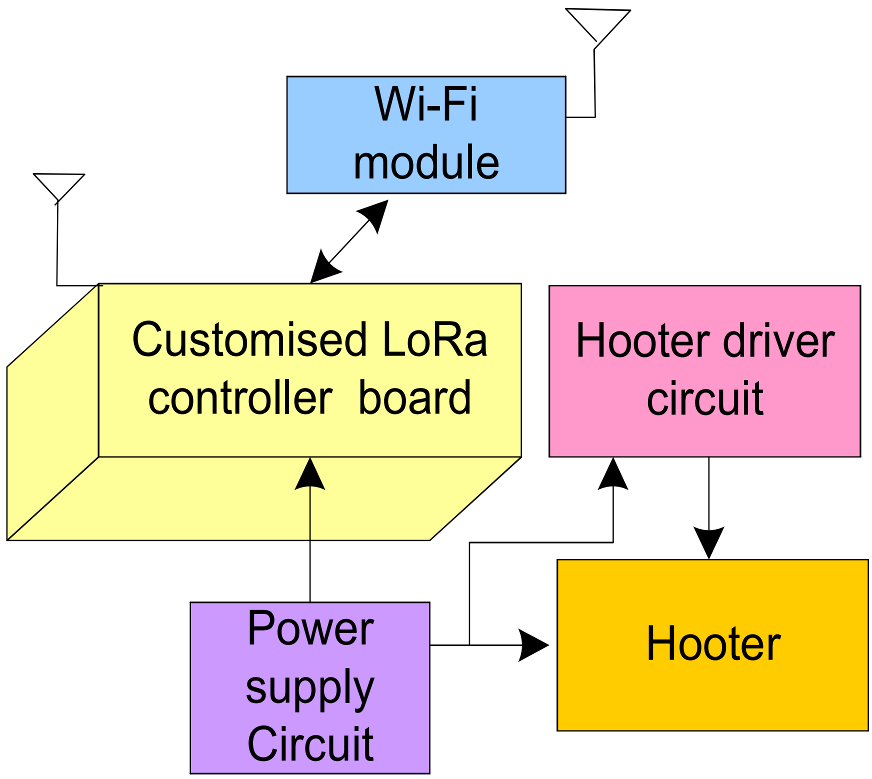


Figure 3.11 Functional Block Diagram of LoRa Gateway with Hooter

3.1.7 Proteus Simulation of Hooter and Circuit Diagram of Gateway

Once the gateway receives something suspicious or a flagged situation of fire breakage from the coordinator node, it activates the integrated hooter in order to alert the authorities for an emergency. The same fire alarming system is simulated in proteus simulation environment with hooter and displayed output in oscilloscope as shown in Figure 3.12. The computing unit of the gateway generates an analog signal which is then fed into the hooter whose simulation of activating the hooter by using a microcontroller and output is displayed in an oscilloscope. The circuit diagram of gateway and hooter system is shown in Figure 3.13.

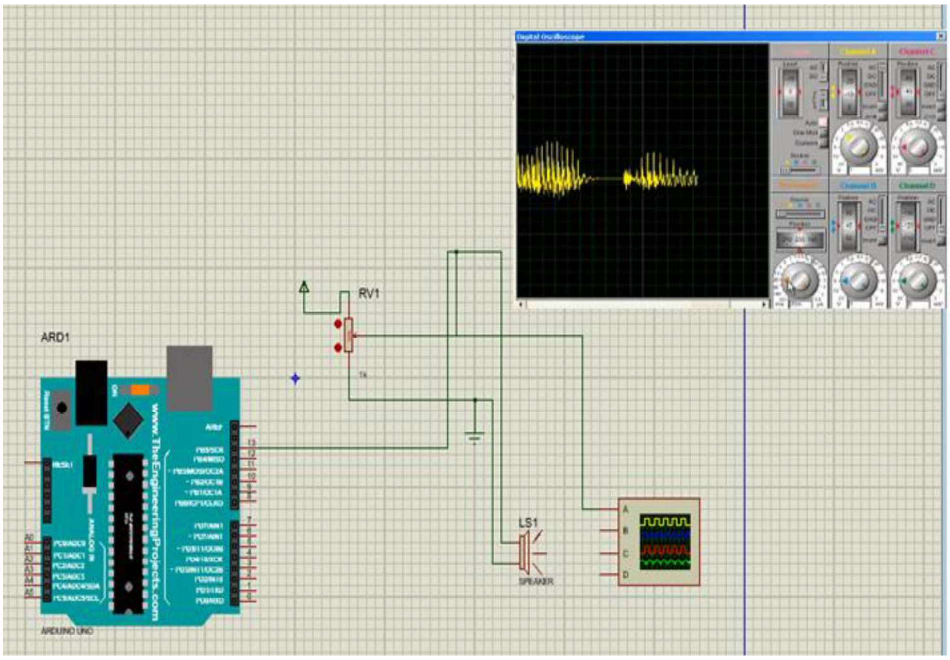


Figure 3.12 Proteus Simulation Of Fire Alarming System

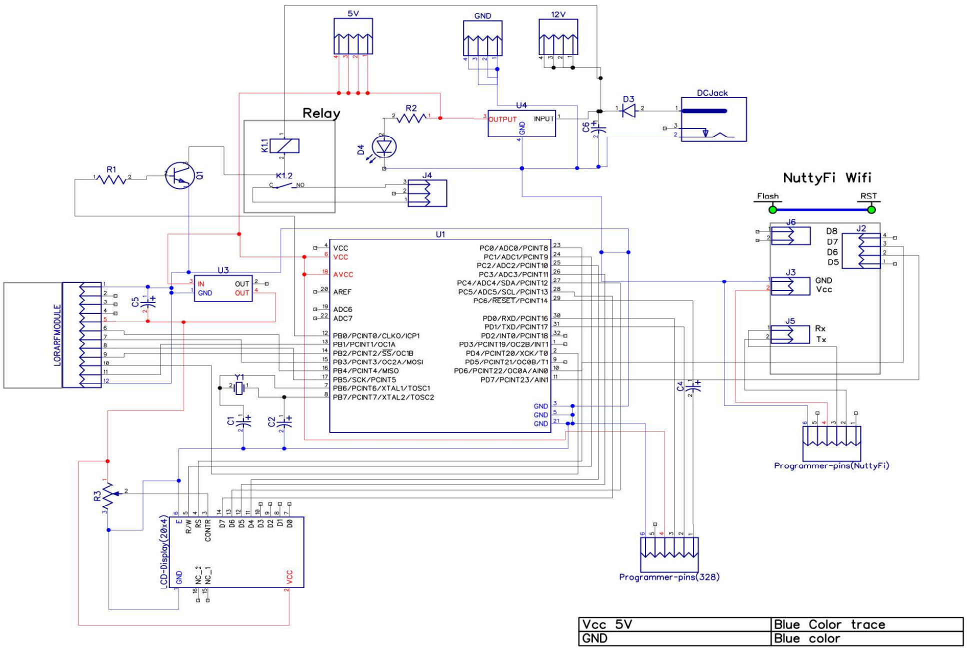


Figure 3.13 Circuit Diagram of Gateway

3.1.8 Coordinator Node

The coordinator node (Figure 3.14) comprises a computing unit for executing defined tasks, a co-processor to aid its computational and concurrent processing power, and a power supply to supply suitable and regulated power to all its components. It is responsible for all the communications between the nodes and the gateway. The system avoids any point-to-point communication between the nodes to prevent any loophole for security breaches, so all the nodes are entitled to share their corresponding data with the coordinator in the form of suitable packets containing ID and Information. The coordinator's onboard algorithms then analyze the data and formulate them into suitable categories upon which then the required instructions or commands to be executed are sent to the designated nodes to which they adhere. Simultaneously the coordinator is also responsible for sharing the data with the gateway using its long-range RF module so that needed steps can be taken by the concerned authorities to prevent or minimize any financial or biological losses.

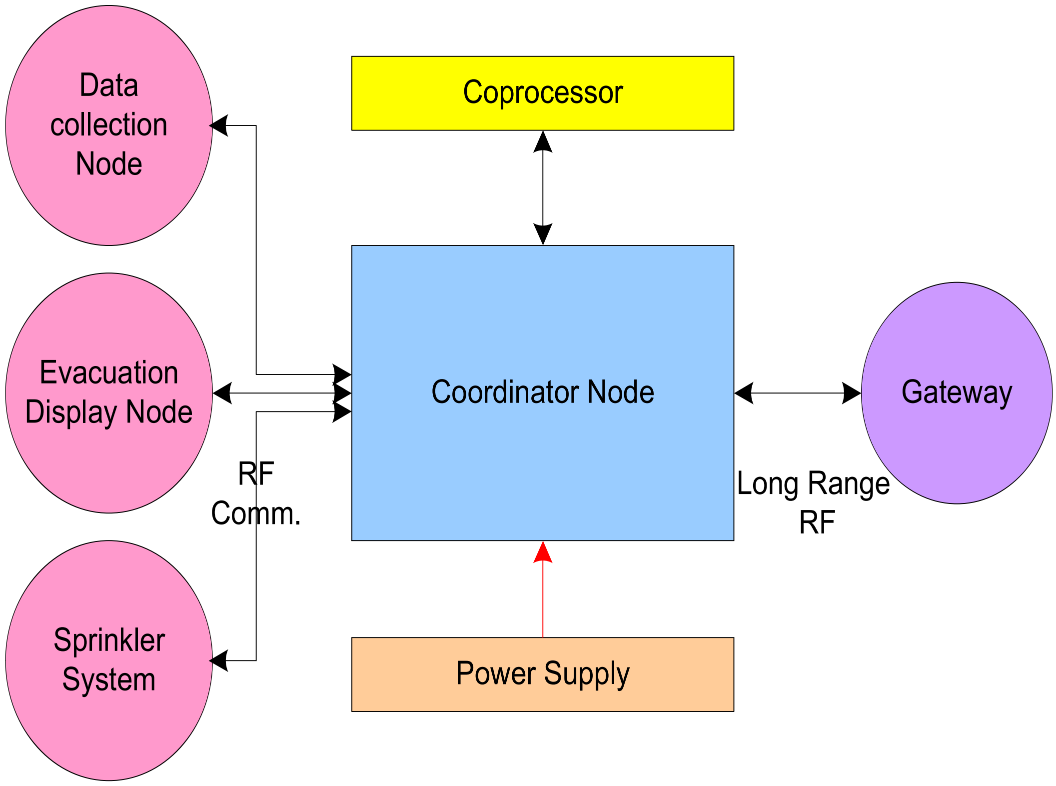


Figure 3.14 Coordinator Node

3.1.9 Vision Node

The vision node as shown in Figure 3.15 is responsible for assisting the system with visual feedback, wherein it comprises a raspberry pi as the main computing unit, an attached camera for video feed, an audio recorder to record the surrounding audio data, and a power supply circuit to supply the appropriate amount of power to the internal components. The vision node hosts intelligent algorithms which are used to capture the video feed of its field of view and process it to extract the current status data depending on the activities or condition of its field of view.

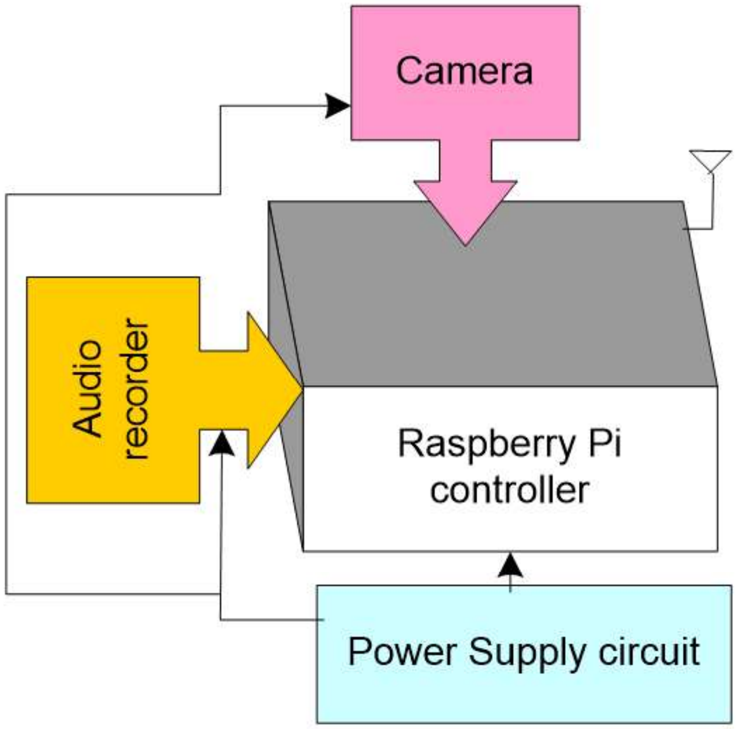


Figure 3.15 Functional Block Diagram Of Vision And Information Recorder Device

In this case the vision node delivers an information log verifying the fire breakage signal sent by the data collecting node, which is considered as extra layer of information and used by coordinator for comparing and assessing the present condition and eliminating any false alarms. The vision node's onboard algorithms are also capable of examining the number of people stranded in the fireplace, the density of smoke, etc. which also helps the concerned authorities and personnel to devise further mitigation procedures extensively. Additionally, the vision node helps the authorities by providing a real-time video stream of the condition that is crucial to prepare for the upcoming beforehand.

3.1.10 Overall System Dataflow

As shown in Figure 3.16, the system will comprise of primary 4 levels of data flow as the first layer being of the field-deployed nodes those will generate the initial data and will share the same with the coordinator node securely. The first layer will include the Data collection node, Sprinkler system, evacuation Display System, and the Vision Node.

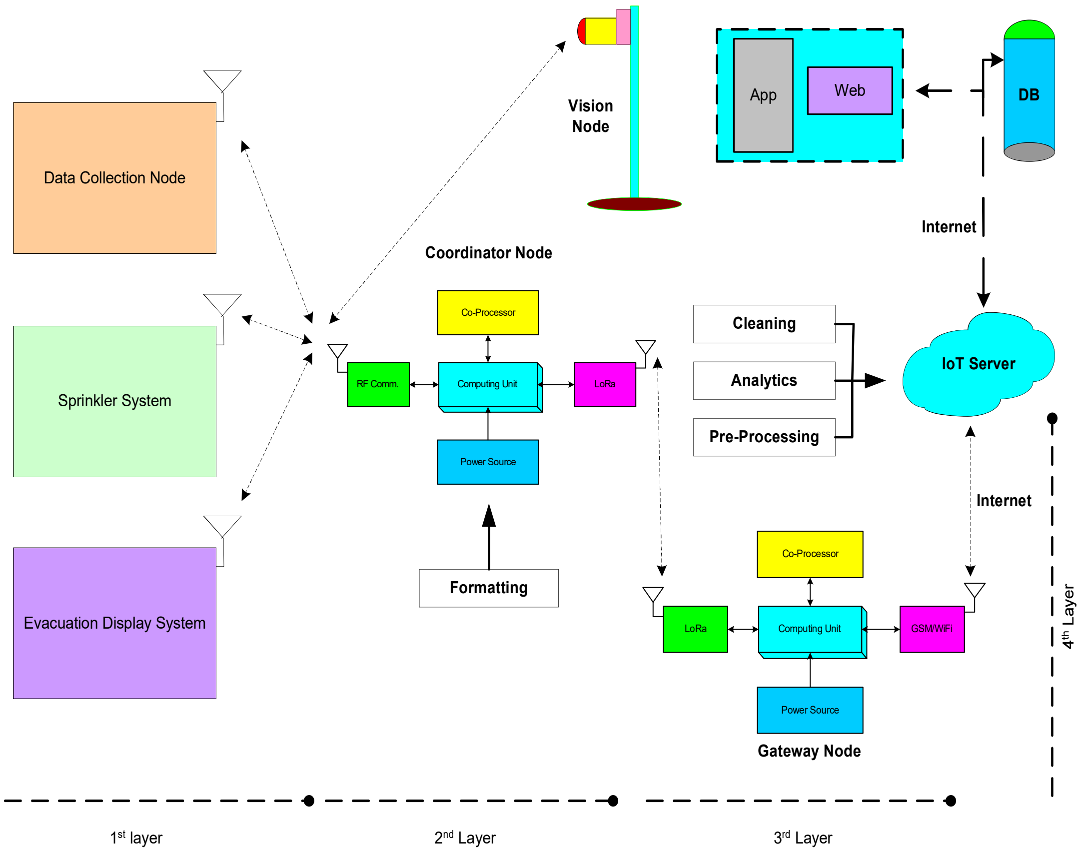


Figure 3.16 Overall System Dataflow

The 2nd layer of data will be initiated by the coordinator which will be responsible for establishing all the communications between the nodes which will ensure no point-to-point communication to take place amongst the nodes itself and the data and command can only be routed through the coordinator to all the nodes. The 3rd layer of data will be at the gateway which will receive data from all the coordinator's nodes and will perform specified tasks and log those into a server. The 4th and final layer of data will be at the cloud server which will allow execution of procedures for remote alert, data acquisition, and further analysis.

3.2 Customization of Hardware

In this part, we will go over the importance of tailoring the hardware for the building's fire and safety applications. Customization allows the researcher to build and construct hardware based on the unique requirements and application [36], making the system more trustworthy and efficient. In general, while designing any hardware node, the most important factor to consider is energy usage. The energy usage must be examined because the hardware nodes are placed in an outside setting and rely on a battery. As a result, each component incorporated on the hardware board must consume little energy throughout the active and sleep phases. To achieve this goal, we used the 2.4 GHz-based Zigbee and LoRa communication protocols, which require less energy while transmitting data. The compuating unit, which analyses the sensory data from the embedded sensors, is another important component. We picked the ATMEGA328P controller unit since the data processing complexity is minimal. Furthermore, the components used to create the hardware have various operating voltages, therefore a power converter is required to deliver the correct voltage. The perspective of past research and the working hypotheses is reflected in through the explanation of four components which are the part of proposed system. The results and their consequences should be addressed in the broadest possible context. Future research directions may be emphasized as well.

3.2.1 Customized design of Data Collection Node

The PCB layout and customized e for the data collection node are depicted in Figure 3.17 and Figure 3.18 wherein in the list of primary components an ATMega 328 has been used as the main computing unit, a 2.4GHz RF module is integrated into the system for enabling the RF communication and a Liquid Crystal Display is integrated to display any crucial information.

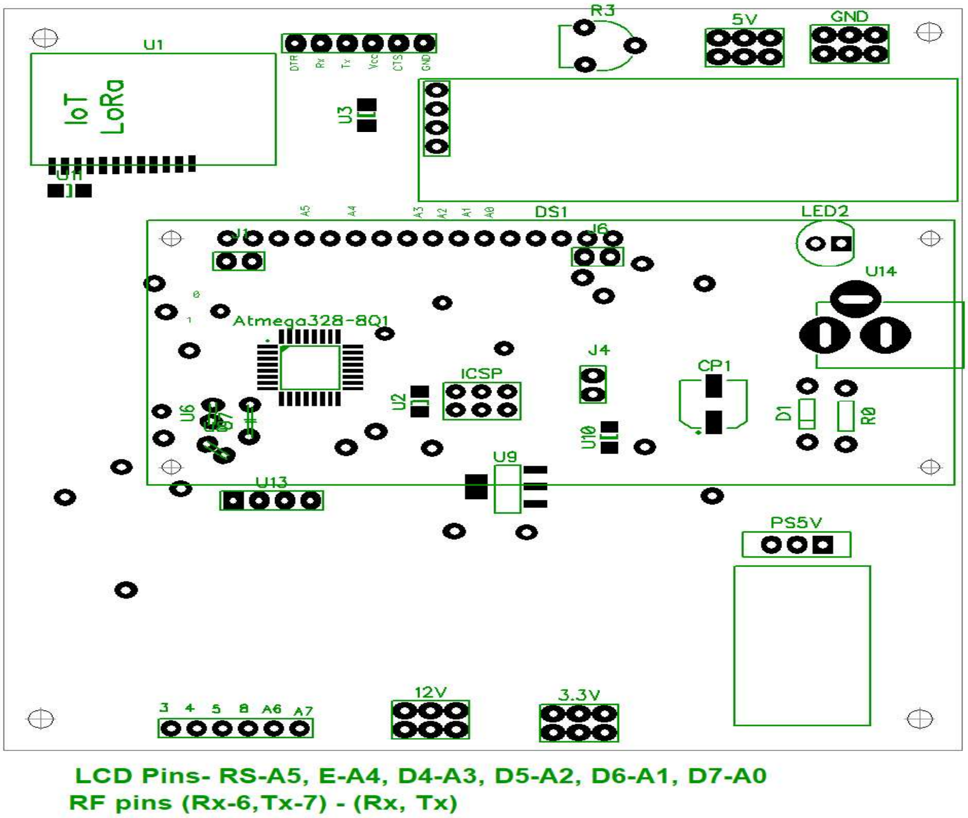


Figure 3.17 PCB layout of Data Collection Node

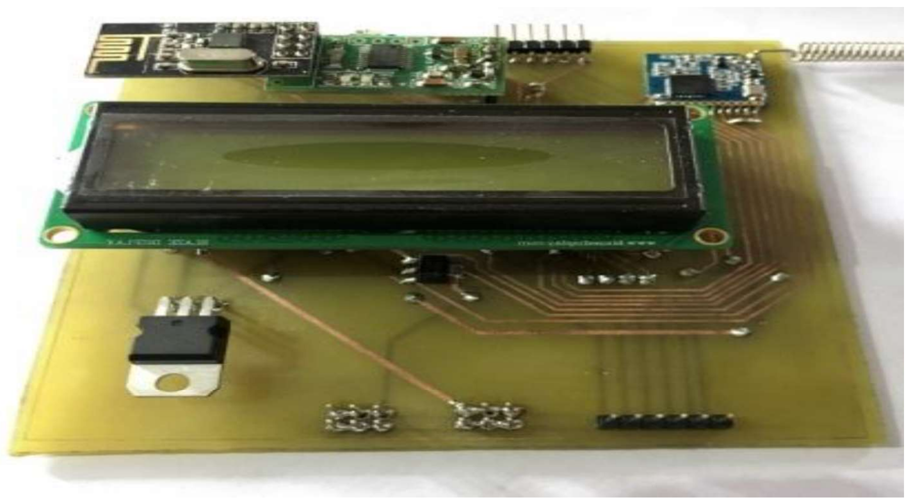


Figure 3.18 Customized Hardware Prototype of Data Collection Node

The customized board is enabled with crucial power regulating circuitries to make it capable of providing diverse and appropriate amounts of power to all its internal components. Along with this, the prime core booting pins have been removed to ensure no physical tampering with the core boot firmware of the system during its operation. The circuit design of the system is made as compact and possible to make it suitable for being deployed inside the building in confined spaces.

3.2.2 Customized design of Safety Operation Controller

Figure 3.19 and Figure 3.20 depicts the PCB layout and customized node of the safety operation controller, in which an ATMega 328 is used as the main computing unit, a 2.4GHz RF module is integrated into the system for enabling RF communication, a relay actuator is integrated for driving the equipment using 5V logic, and a Liquid Crystal Display is integrated for displaying any critical information.

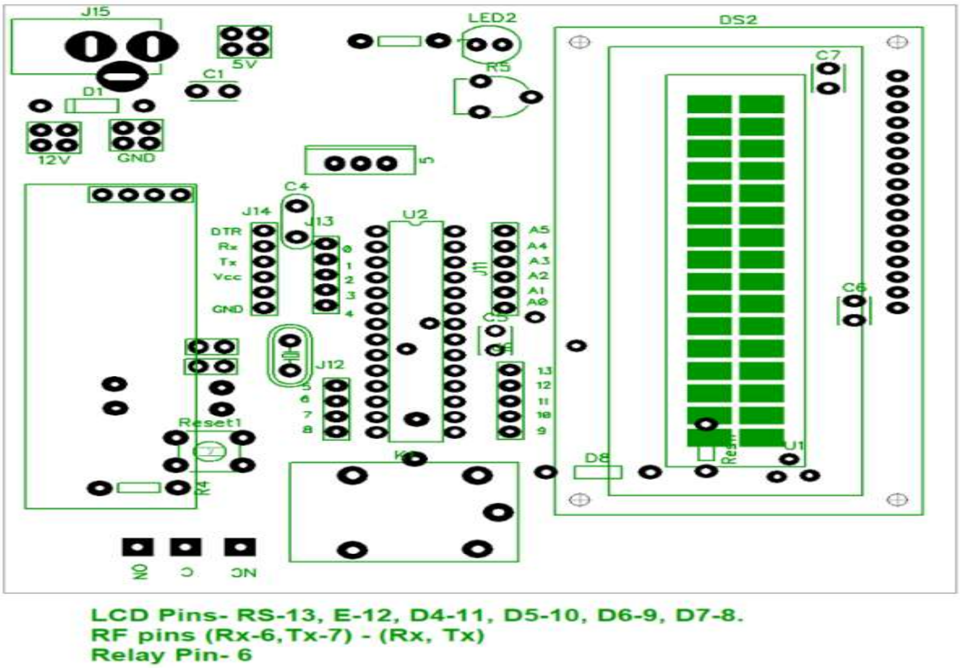


Figure 3.19 PCB layout of Coordinator Node and Safety Operation Controller

The customized board is outfitted with critical power regulating circuitries, allowing it to supply different and suitable quantities of power to all of its internal components. In addition, the prime core booting pins have been removed to ensure that no physical tampering with the system's core boot firmware occurs during operation. The node is made to perform reliably in its operation of receiving the commands from the coordinator node and actuating the sprinkler system desirably. The connection of safety operation controllers are as follows:

- The relay for actuating the sprinkler system is connected to PB0 of the atmerga328p microcontroller.
- 2.4GHz RF module is integrated with UART pins.
- LCD Display is connected and controlled through PC0, PC1, PC2, PC3 pins of ATmega328P.
- One FTDI port embedded in the gateway for programming the ATmega 328P

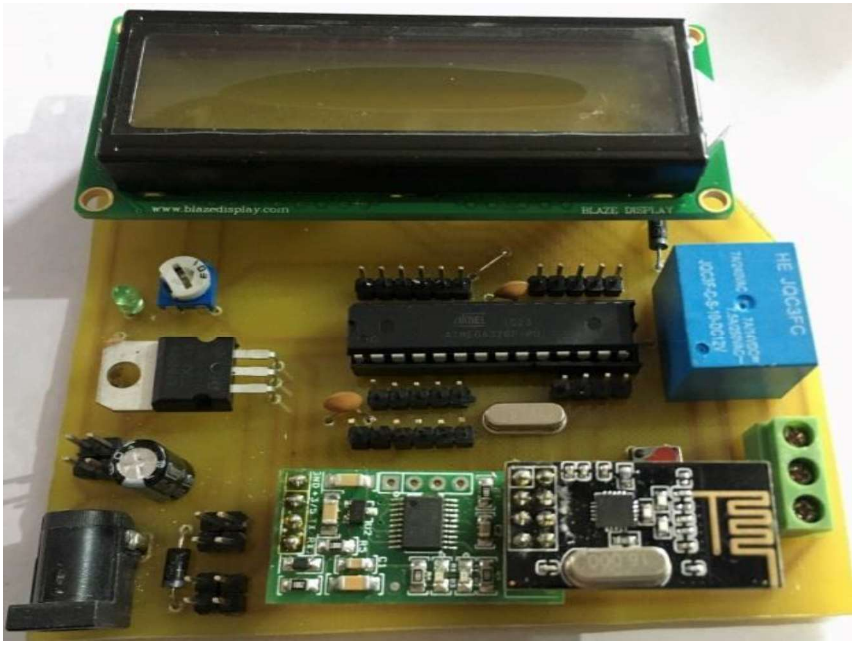
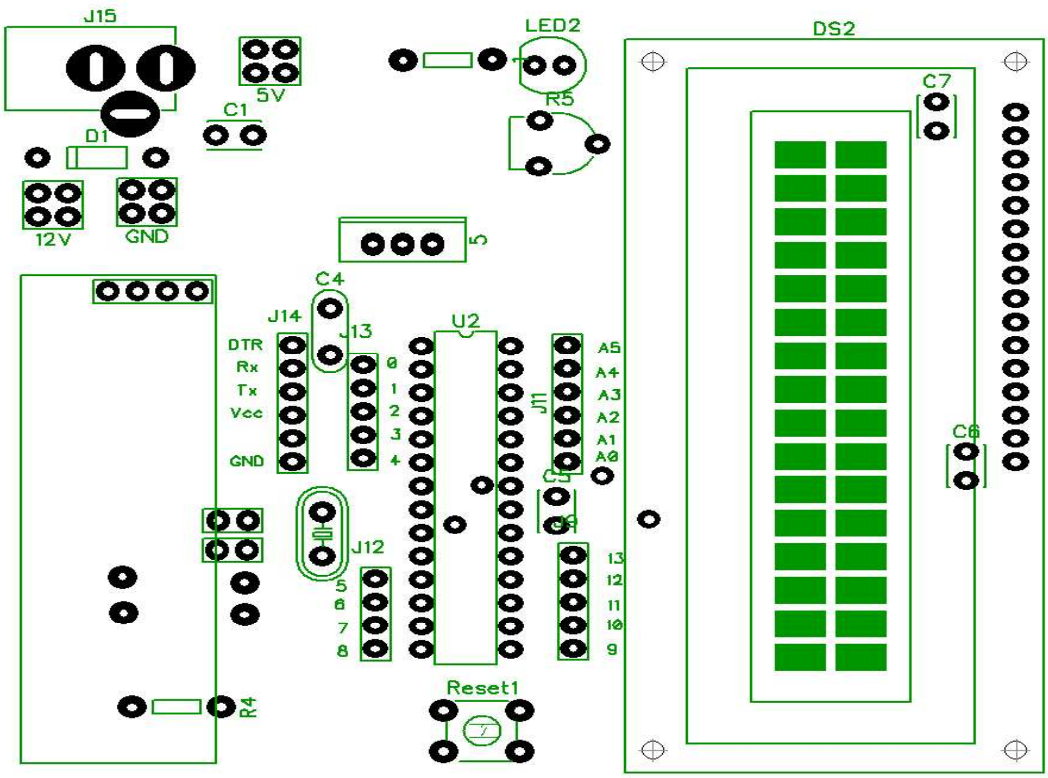


Figure 3.20 Customized Hardware prototype of Coordinator Node and Safety Operation Controller

3.2.3 Customized design of Evacuation Display System

Figure 3.21 and Figure 3.22 depicts the PCB layout and the customized design of the evacuation display system wherein it comprises an ATMega 328 as the main computing unit, an RF 2.4 GHz module for letting the system communicate with the coordinator over RF, a led matrix display illuminates the direction for a safe exit. An LCD for displays information on the system, a power management circuit lets the system be powered by a direct 12V DC power adapter, and a crucial power distribution arrangement to output regulated power supply of 12v, 5v, and 3.3v. Similar to other nodes, this system also has removed the prime boot configuration pin to prevent any tampering that can be done by changing the boot firmware of the system. The design is also quite compact to be having a good form factor for its deployment and operations. On receipt of the path information from the coordinator, the system will compute it and will illuminate the led patterns to show the safe exit path for the people to get out of the building. The connection of the evacuation display system is as follows:

- Led Matrix is master controlled through the PD4 pin of ATmega328P.
- 2.4GHz RF module is integarted with UART pins.
- LCD Display is connected and controlled through PB0, PB1, PB2, PB3 pins of ATmega328P.
- One FTDI port embedded in the gateway for programming the Atmega328P



LCD Pins- RS-13, E-12, D4-11, D5-10, D6-9, D7-8.
RF pins (Rx-6,Tx-7) - (Rx, Tx)

Figure 3.21 PCB layout of the Evacuation Display System

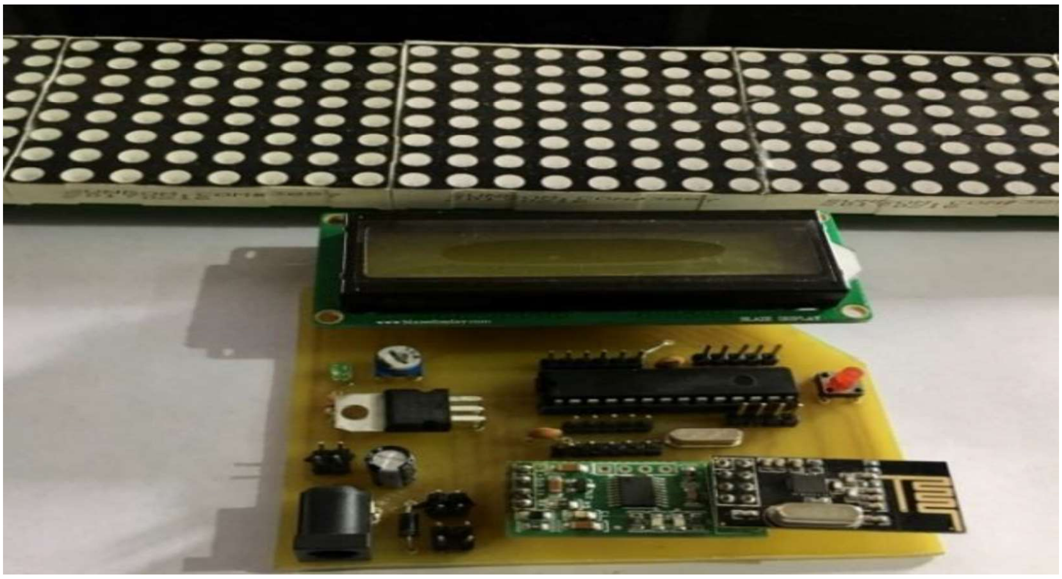


Figure 3.22 Customized Hardware Prototype of the Evacuation Display System

3.2.4 Customized design of LoRa Gateway with Hooter

The PCB layout and customized design of the gateway with the hooter are carefully curated to meet the requirements of the system is shown in Figure 3.23 and Figure 3.24. wherein two communication protocols support embedded into it as the Long-Range RF communication through the LoRa module and internet communication through the Wi-Fi module. The Wi-Fi module with its technical specifications is presented in table 3.2. It is solely responsible to communicate with the coordinator that has information about all the field-deployed nodes and the server and thereby with the authorities. The specifications of the customized gateway are presented in table 3.1.

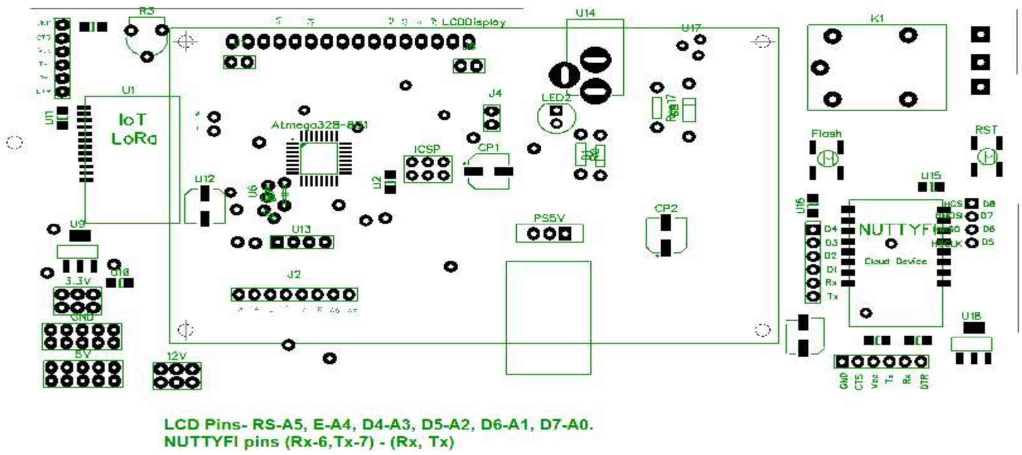


Figure 3.23 PCB layout of LoRa Gateway with Hooter

Figure 3.24 Customized hardware Prototype of LoRa Gateway and Hooter

So, its proper work is quite crucial to ensure the success of the system and to help the authorities and other stakeholders plan out procedures. The primary pin configurations of the gateway are as follows

- The MOSI, MISO, SCK, GND, Vcc and RESET pins of the LoRA modem are connected with 15,16,17 GND, +5V, and RESET pins of customized ATmega328 controller respectively.
- D6, D7 pins of the ESP8266 Wi-Fi module connect to the PIN 11 and PIN 10 of the ATmega 328P controller respectively.
- Hooter is connected to the +5V actuator, pin A0, pin, and GND pins of the customized board respectively.
- Two FTDI ports are integrated in the gateway for programming the “Atmega 328P microcontroller” and also to program the ESP8266 Wi-Fi module.

Table 3.1 Specifications of Customized Gateway

Parameter	Specifications
Microcontroller	ATMega328P
Communication module:	SX1278 LoRa module [433 MHz-LPWAN), ESP8266 Wi-Fi module [2.4 GHz-LAN)]
GND	8 Pins
Voltage converter:	+3.3V and +5V
Power trails:	++12V (6 trails), +5V (8 trails) and +3.3V (6 trails)
Power jack:	2 [1 for ATmega 328P controller, 1 for ESP 8266 Wi-Fi module] +12V External power supply
Programming pins:	2 FTDI [ATmega 328P controller, 1 for ESP 8266 Wi-Fi module] and 1 ICSP

Table 3.2 Specifications of ESP8266 Wi-Fi Module

Parameter	Feature
Processor	Tensilica L106 32-bit processor
IEEE standard	802.11 b/g/n
Frequency	2.4 GHz
Data rate	72 Mbps
Network Protocols	Ipv4, TCP/UDP, HTTP
Tx power	14 dBm (802.11n), 20 dBm (802.11 b) & 17 dBm (802.11 g)
Sensitivity	-71 dBm (802.11n), -75dBm (802.11 g) & -91 dBm (802.11 b)
Voltage	2.5 V to 3.6 V
Current	Average: 80mA

3.2.5 Hardware prototype of Vision Node

Figure 3.25 depicts a vision node built with a Raspberry Pi as the main CPU unit and a Pi camera for the video feed. The vision node is in charge of providing visual support to the other node's decisions as well as the authorities' knowledge. The node is designed with sophisticated algorithms that can recognize and assess the current state of the environment, such as fire breaks, smoke density, number of persons present, and so on. In the event of an emergency, it also aids authorities by streaming a live broadcast of its area of vision to a remote dashboard. It is designed to run in with battery power even in the event of a power outage. The suggested system is built with the Raspberry Pi since it is inexpensive and reliable. It gives us provision for the selection of programming architecture as and when needed as well as the use of applications that might be employed. It can host web pages if an Apache HTTP Web server is installed on it. In addition, a DNN model for object detection may be deployed within the Raspberry Pi. The Raspberry Pi 3 Model B is utilized in this system, and it features a 32 GB class 10 micro-SD card, two USB ports, 512 Megabits of RAM, a 700 MHz single-core ARM11 CPU, a 15-pin PI camera (CSI), and an HDMI connector.

Figure 3.25 Vision and information recorder with Hardware prototype

In 2006, work on the Raspberry Pi project began. It is a low-cost computer featuring a multi os compatible mini-computer with a 700 MHz ARM-architecture CPU, 512 MB RAM, and an Ethernet port as well as two USB ports. It is capable of rendering FHD video files and has an inbuilt Video core IV graphics processing unit (GPU). Table 3.1 lists the specific characteristics of the Raspberry Pi 3.

Table 3.3 Functionalities of RPi B

Parameter	Features/Values
Model Name	Raspberry Pi 3 Model B
GPIO Pins	40 Pinouts
Ethernet Port	Available
Wireless Connectivity	Available
Form Factor	Genric
Memory Size	32 GB
SoC Type	BCM2837A0/B0

Pi Camera is integrated with a Raspberry Pi module to capture real-time images. The Raspberry Pi camera module is a tiny, portable camera that works in conjunction with the Raspberry Pi. To communicate with the Raspberry Pi, the MIPI camera serial interface protocol is utilized. It's frequently used in surveillance projects, machine learning and image processing. Table 3.2 details the features of the Pi Camera that we employed in our system.

Table 3.4 Camera Features (Night vision)

Parameters Name	Features/Values
Model Support	Raspberry Pi 3 Model A & B
Pixel	5 MP
Interface	MIPI Serial Interface
Resolution	1920x1080
Support	1080p, 720p and 480p
Sensor	5-megapixel OV5647 sensor
Model	RS2161

3.3 Chapter Summary

This chapter contains a thorough explanation of the entire system architecture for recognizing and facilitating safe evacuation from the building during fire incidents. The architecture's sub-modules, such as the Data collecting section, vision node, Coordinator node, LoRa gateway, fire alerting system, are depicted with functional block diagrams, PCB design, customized hardware prototypes, proteus simulations, and component interface. Finally, the relevance and specifications of different sensors and actuators utilized to detect, regulate, and display fire events are addressed.

Chapter 4
Performance Evaluation of Zigbee and LoRa

This chapter discusses the performance analysis of the hybrid network, including the 2.4 GHz Zigbee RF and LoRa network. The OPNET network simulator is used to simulate the ZigBee network, which includes characteristics such as received traffic, end-to-end delay, retransmission attempt, and performance. The evaluation metrics of LoRa like link budget and Time on Air (ToA) are also evaluated and logged in hardware through programming. The hardware is installed in real-time to ensure that it is logging data on the cloud server.

4.1 Zigbee Network

The OPNET Network Simulator is used to replicate the behavior and performance of any network. OPNET Network Simulator stands out from other simulators because of its strength and adaptability. It enables you to design and simulate various network topologies. OPNET Network Simulator is a free and open-source program. This Simulator provides information on a large variety of project situations. It is a special simulator to design and analyze the various long and short-range communication protocols. It offers a virtual environment or work container for simulating, evaluating, and forecasting the IT infrastructure performance, such as technology such as apps, servers, and networking topology. It provides a larger set of features aimed at improving network research and development productivity. Design and test unique wireless topologies and technologies, as well as assess improvements to standards-based protocols. Simulate all network kinds and technologies, including IoT, LTE, and WLAN, to compare and contrast the effects of various technological designs on end-to-end behavior. It allows you to speed up R&D initiatives and save money by testing and showcasing technological concepts before they go into production.

The Zigbee network simulation is performed for the proposed system and performance analysis is evaluated with respect to various key parameters. Figure 4.1 depicts the realization of Zigbee framework using Riverbed simulation model . It is experimented using start topology and configuration is done as per the parameters mentioned in Table 4.1. We utilized data like transmitted and received load information, packet delivery success percentage, channel throughput, retransmission tries, and end-to-end delay across layers in this case.

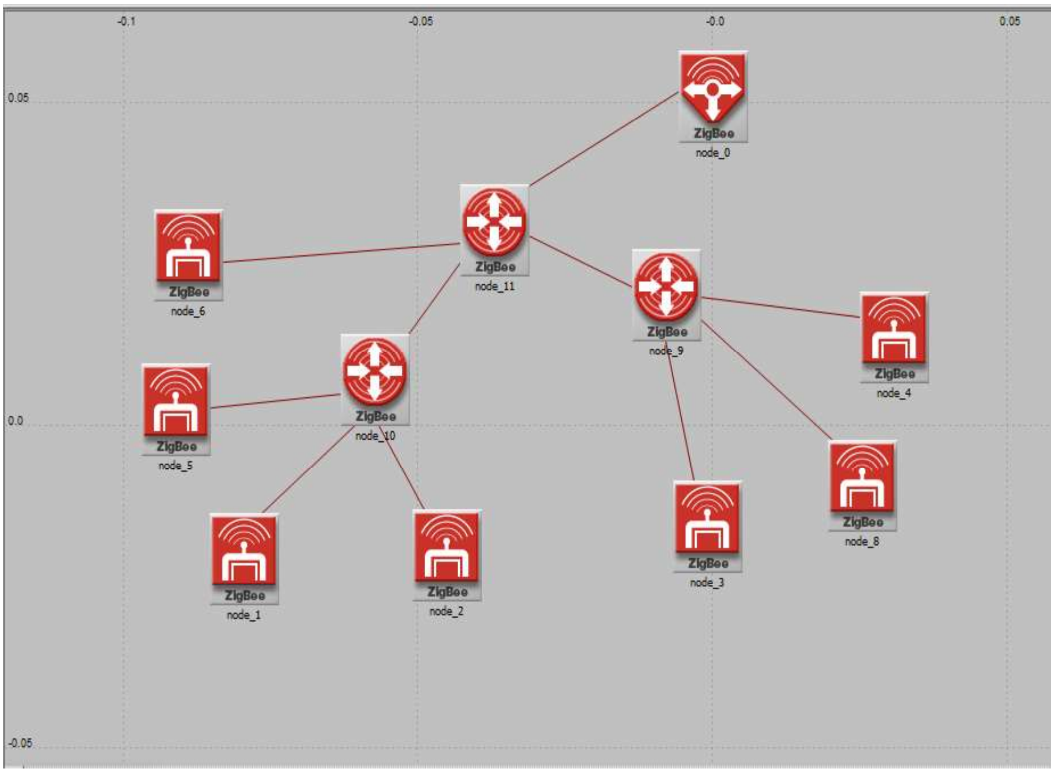


Figure 4.1 Distribution of nodes based on Star Topology

Table 4.1 Configuration for Simulation of ZigBee network

Network Layer configuarion	
Zigbee Coordinator	1
Zigbee router	03
Zigbee End device	07
Packet size	1024 kbs (cont)
Packet interval time	Constant (1.0)
Physical Layer configuarion	
Data rate	Auto calculate

Receiver Sensitivity	-85
Transmission Power	0.05W
Transmission band	2.4 GHz

The simulation result of packets received by ZigBee network nodes is shown in Figure 4.2. The simulation continues throughout the timeline. Throughout the period, packets appear to be received at a rate of 900 bits/sec. Figure 4.3 depicts the packet delivered from the source node to the destination node across a timeline. It is set up to receive data at a rate of 450 bits per second. We received a PDR of around 0.80 as a result of the analysis. To put it in different way, nodes have achieved communication with an accuracy of 80%.

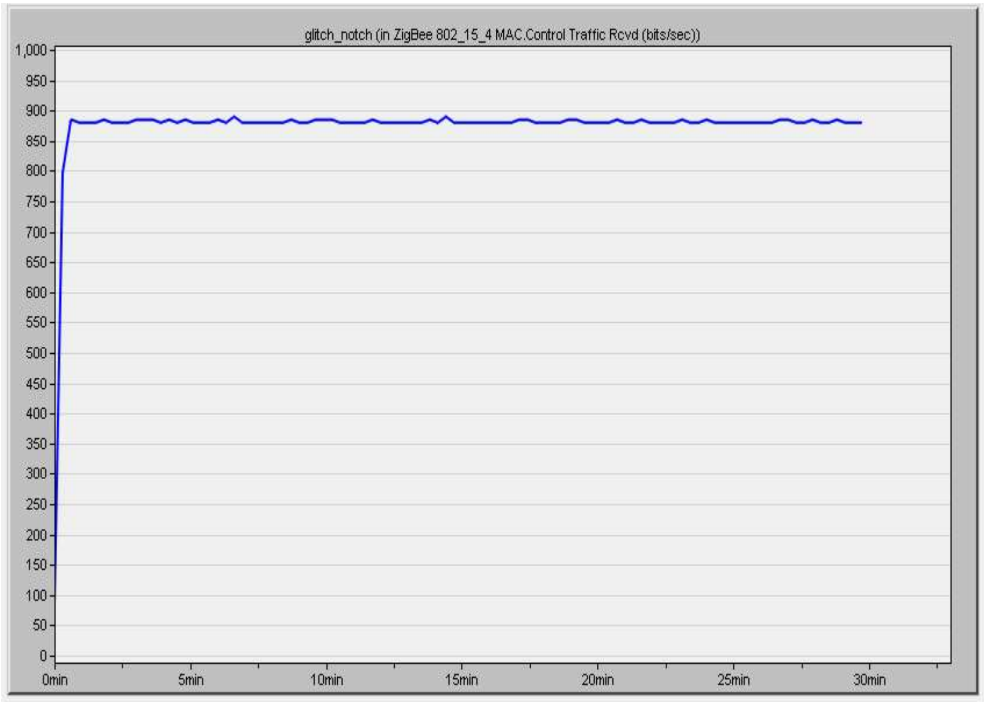


Figure 4.2 Traffic Received by Nodes (Bits/Sec)

4.1.1 End to End Delay

The total time spent by the packet creation and node transfer operations is referred to as end-to-end delay. It is comprised of the overall time spent on route discovery, propagation, queuing, and transfer time. The analysis of end to end delay is carried as shown in Figure 4.4. It is observed that the highest end to end delay is 0.016 seconds found at 20 mins and the shortest end to end delay is 0.008 seconds found at 11 mins.

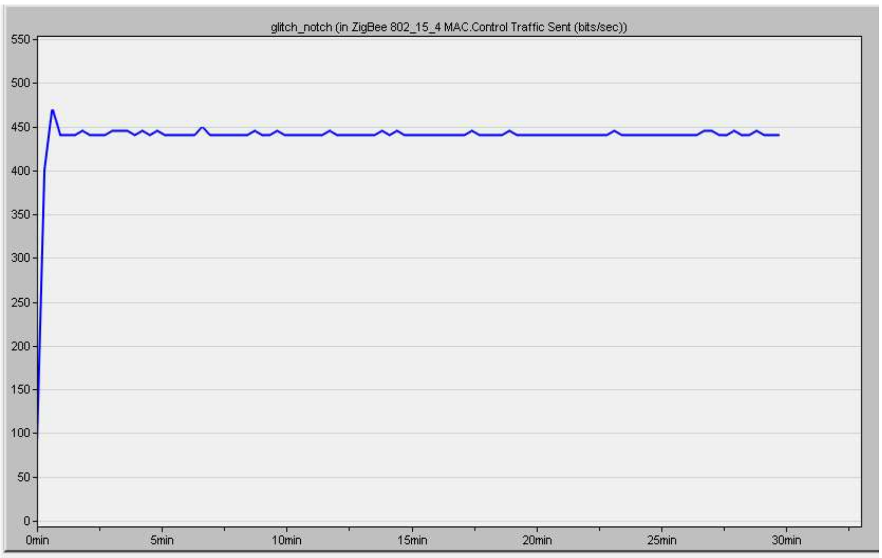


Figure 4.3 Traffic sent by Nodes (Bits/Sec)

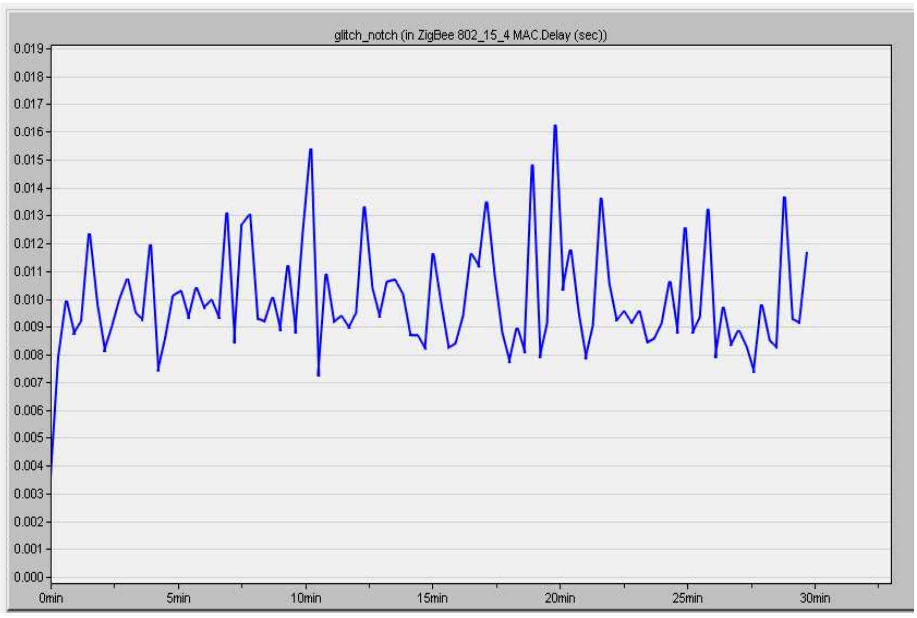


Figure 4.4 MAC End to end Delay in the Network

4.1.2 MAC Throughput

Throughput is the rate at which successful transmissions are logged from a source node to a target node.. The maximum throughput is 58kbps at 7 minutes on the simulation's timeline axis, and the minimum level throughput is 53kbps at several places. Figure 4.5 MAC Throughput depicts the average throughput carried, which is 53 kbps.

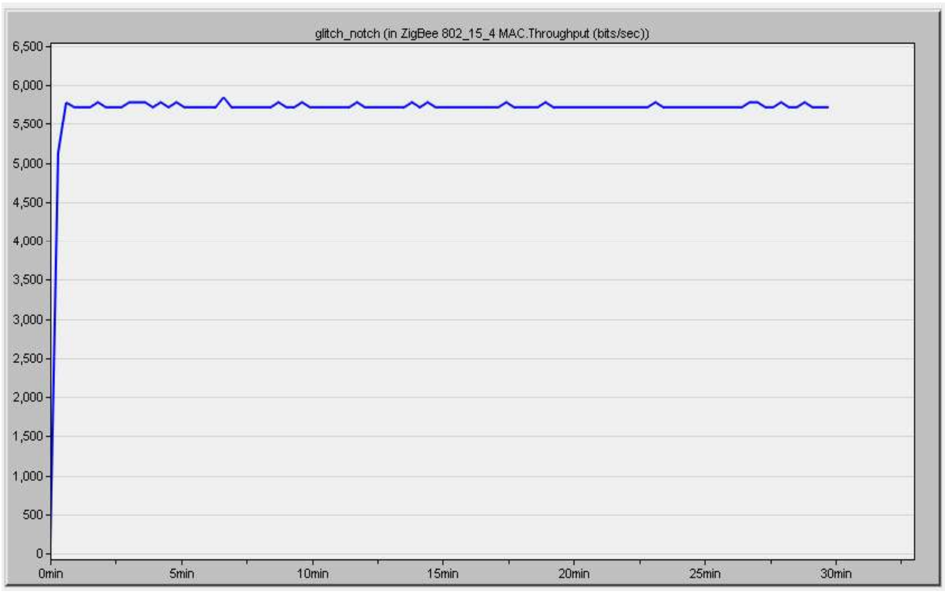


Figure 4.5 MAC Throughput

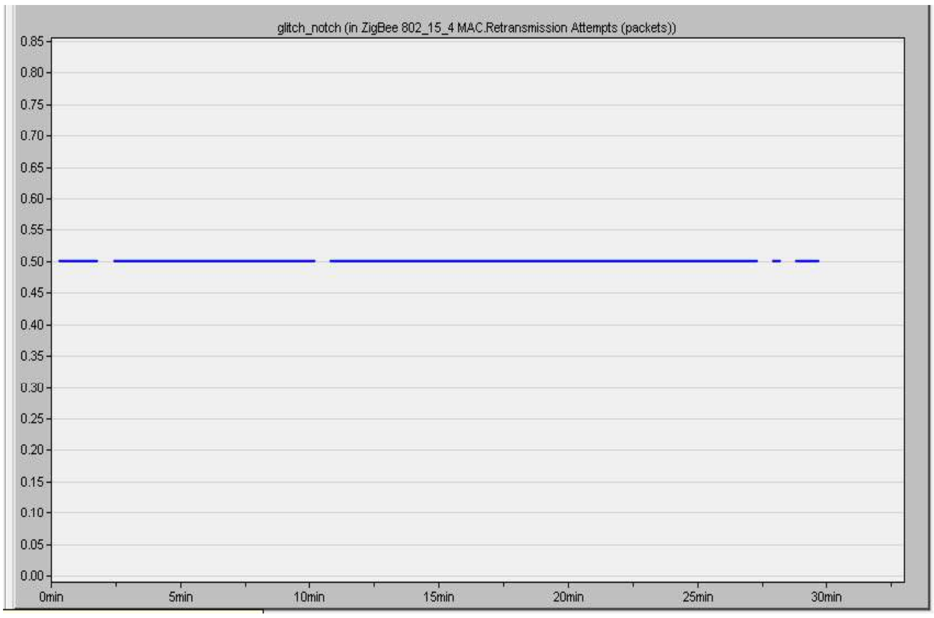


Figure 4.6 MAC Retransmission Attempt

4.1.3 MAC Retransmission Attempts

Retransmission attempts are the total number of times the data was tried to be transmitted by all 802.15.4 MACs in the formed internal network till the packet is sent successfully and received at the destination or the maximum attempts limit threshold is crossed. Figure 4.6 MAC Retransmission Attempt depicts 0.5 packets of retransmission attempts during a simulation duration of 30 minutes.

4.2 Evaluation Metrics of LoRa

The LoRa communication protocol has key characteristics that are used to estimate network performance. It is assessed by altering factors such as the bandwidth (BW), spreading factor (SF), and coding rate (CR). The results of the link budget, LoRa sensitivity study and bit rate are shown below. A FLoRa simulation is carried for calculating the energy consumption of nodes by altering the parameters like bandwidth, spreading factor, transmission (Tx) power, number of gateways and number of nodes with a 433 MHz carrier frequency. The bit rate, link budget, battery life of sensor node, time on-air (ToA) and receiver sensitivity based on LoRa are evaluated by varying parameters like code rate, bandwidth, spreading factor (SF), Tx power, and payload size.

4.2.1 Time on Air (ToA)

To evaluate the ToA in this study, we used the following parameters: preamble = 8 symbols, payload = 28 bytes, Tx power = 14 dBm, and Carrier Frequency = 433 MHz. Here we considered three diffrent bandwidths: 125 kHz, 250 kHz, and 500 kHz. ToA is determined using SF7 and SF12, as well as a Code Rate of 1, 2, 3, and 4. When the SF is increased from 7 to 12, the ToA increases by 50%, and when the bandwidth is increased from 125 kHz to 500 kHz, the ToA decreases by 50%. The ToA for a payload size of 28 bytes is shown in Figure 4.7. The ToA graph at different Code Rates shows that the ToA starts to increase after the SF 9. The 125 kHz BW has the largest ToA of all three BWs, while the 500 kHz BW has the lowest. The rise of the ToA is discovered to be closely related to CR; for example, at CR=1, the BW1 ToA is 56,58 ms, whereas at CR=4, the BW1 ToA is 78,08 ms.

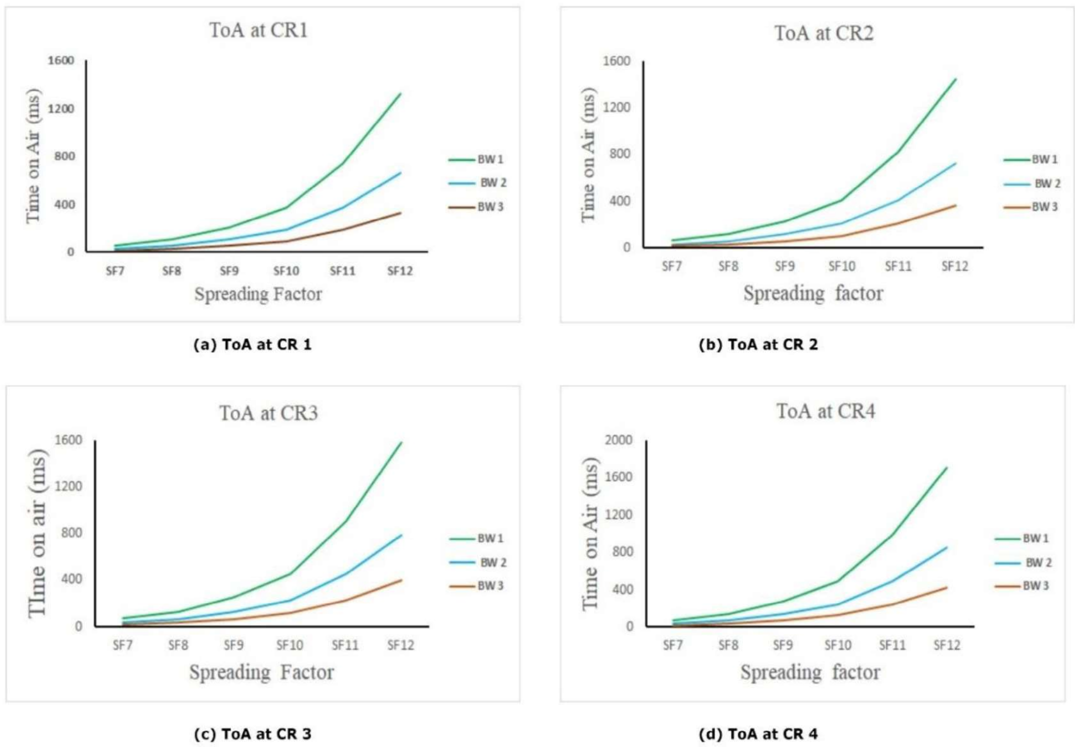


Figure 4.7 Time on Air (ToA) for SF7-SF12

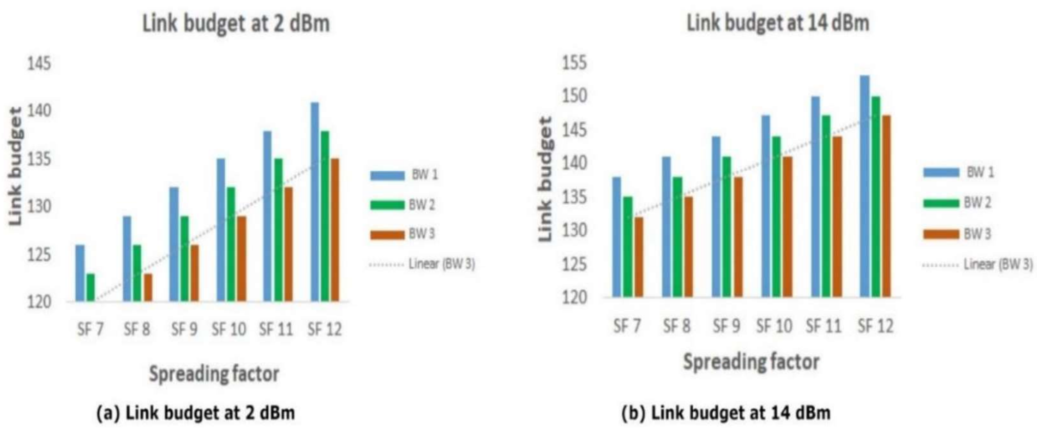


Figure 4.8 Link budget at 2 dBm and 14 dBm

4.2.2 Link budget

The link budget or power received is know as sum of losses and benefits. The three BW are 125 kHz, 250 kHz, and 500 kHz, and the link budget is calculated using SF 7 and SF 12. These bandwidths are denoted by the symbols BW1, BW2, and BW3. The transmission powers are 2 dBm and 14 dBm, respectively. As shown in Figure 4.8, an increase in Tx leads to an increase in link budget. Further, Link bdget increase in the SF increases. The link budget reached a highest of 14dBm at SF 12 and BW 125 kilohertz. Lowest of 2 dBm for 500 kilohertz was measured at SF7. For achieving a high link budget, low bandwidth power and high transmission power are ideal configurations.

4.3 Experimental Setup

In this section, the identified simulation parameters are logged in the hardware for real-time implementation. The system is implemented in a dummy environment to detect the temperature and fire. The end devices installed in outdoor layer is used to detect the parameters of gas, flame, temperature and smoke. To evaluate the performance of the hardware, safety operation controller, vision node and evacuation path display controller are also deployed in a real time environment.

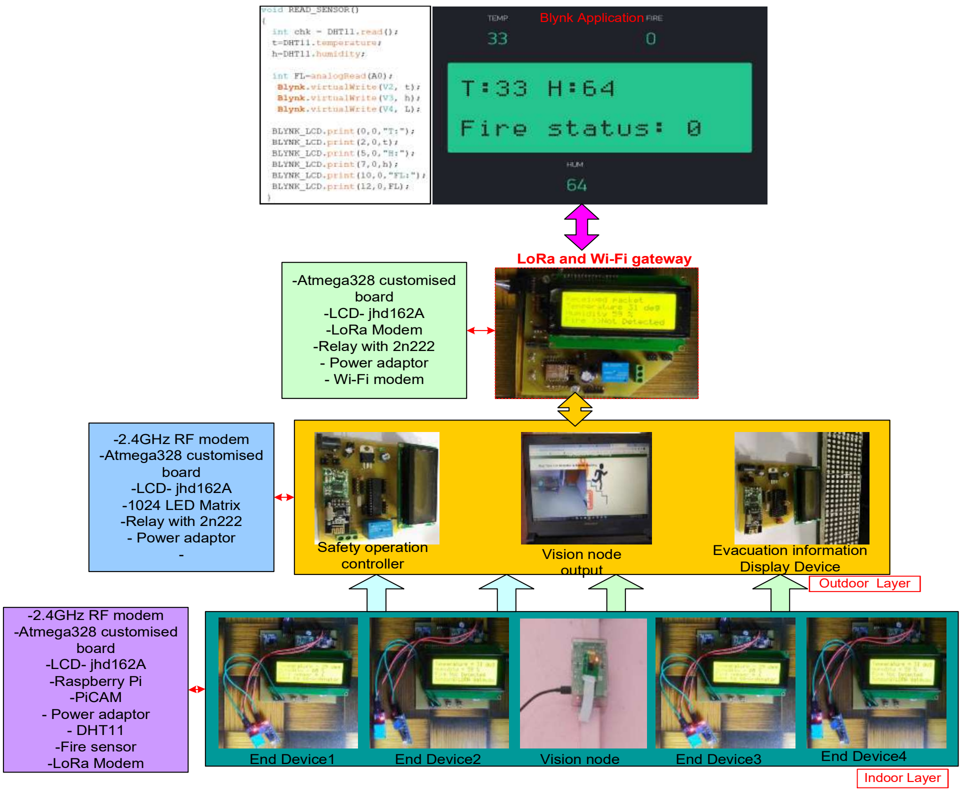


Figure 4.9 Real-Time Experimental Setup with Devices and Gateway

The deployment of complete system in real time is illustered in Figure 4.9. We used a cloud-based Blynk server and application to view sensor data on the cloud server. End devices are installed at various places throughout the building in a real-time environment. Here end devices are integrated the DHT sensor and flame sensor for sensing the humidity, temperature and fire inside the building. The end device with the assistance of the LoRa base RF link sends the sensor data to the specific gateway. The safety operation controller and evacuation path display controller are also installed at various locations close to end devices to collect the sensor data via 2.4 GHz Zigbee module.

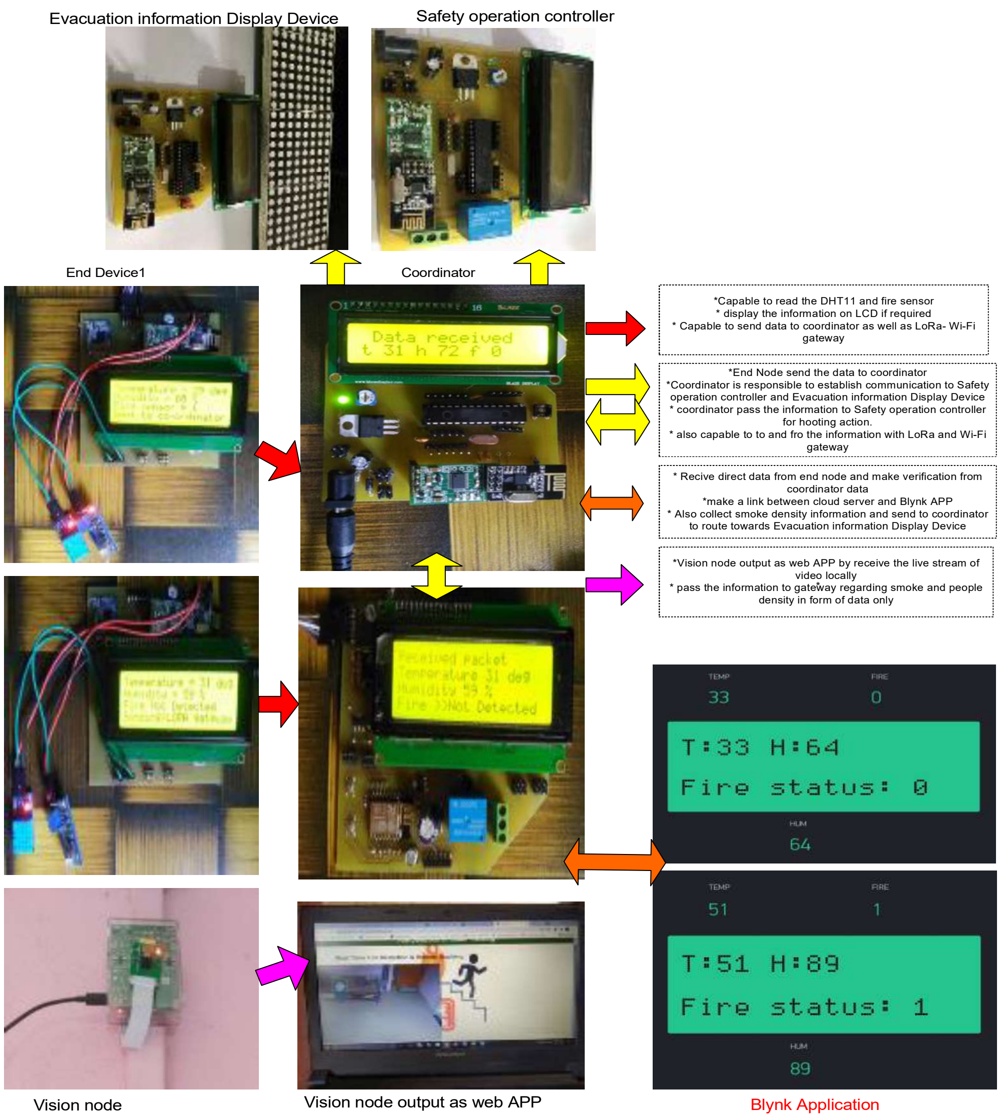


Figure 4.10 Working of Hardware and Results Visualization

The sensor data is logged to the cloud server, which is the Blynk server, by the gateway that is combined with LoRa and WiFi modem. Figure 4.9 depicts the characteristics of the hardware such as communication protocol and the controller used in the indoor and outdoor layers. The sensor value obtained via LoRa communication is displayed on the Blynk dashboard. We turned on all of the nodes and assessed their performance in terms of sensing temperature, fire, and visualizing the data from the building after deploying all of the hardware in real-time. Furthermore, the study examines how this data is communicated to the gateway and cloud server.

The operation of the hardware devices is depicted in Figure 4.10, where the end devices communicates the sensor data such as fire status, humidity and temperature. As previously stated, the end device is a hybrid comination of LoRa and 2.4 GHz Zigbee protocol. The sensor data is sent from the end device to the display controller of exit path via 2.4 GHz Zigbee and then to the LoRa gateway. The fire status, temperature and humidity data are displayed on the LCD integrated with end devices, the evacuation path display controller, and the gateway. The sensor data is logged to the blynk server by gateway through internet connectivity.

Figure 4.11 Blynk Dashboard Showing No Fire Detected

The blynk dashboard, shown in Figure 4.11, visualises temperature, humidity data and fire status. In the blynk dashboard, the two different results have been presented. Blynk is a complete set of software for prototyping, deploying, and remotely managing linked electronic devices at any scale, from small IoT initiatives to millions of commercially available connected items. In Figure 4.11 the dashboard illustrates the the instance where fire is not detected for the temperature value as 33^0C, humidity level as 64. Another instance is shown in Figure 4.12 illustrates, where a fire is reported with humidity level of 89 and temperature of 51^0C and. This shows that the hardware can visualise the building's real time sensor data on the cloud-based blynk server.

Figure 4.12 Blynk Dashboard Showing Fire Detected

Table 4.2 compares the proposed system to past studies that have been implemented for establishing evacuation paths during building fire. The comparative analysis is done on the basis of some parameters such as hardware used, network simulation, user interface communication technology, and data aquisiation devices. According to the results of the comparative assessment, the proposed system outperforms past work in terms of fire detection using customised hardware with the integration of 2.4 GHz and LoRa communication protocol and Atmega 328P microcontroller. Furthermore, a hybrid design is presented for implementing an IoT-enabled evacuation system. In this study, Zigbee network simulation and LoRa evaluation metrics are carried. The proposed architecture is implemented using the blynk cloud server application, which logs hardware data into the cloud server.

Table 4.2 Comparative analysis of existing work with study

Reference	Hardware used	End Device	Simulation of network	Communication prtotcols	User Interface
[56]	Bluetooth enabled MT (mobile terminal) indoor location technology	Temperature	Not realized	Bluetooth	Fire location with alarm message is sent to user mobile phone
[59]	Raspberry Pi	Gas Sensor (MQ9), Smoke Sensor, and Temp. Sensor (LM 35)	Not realized	GSM and WSN	No work on evacuation
[79]	Ardunio	Temp. Sensor (LM 35), PIR Sensor, RFM23B RFID, Bluetooth Module (HC-05)	Not realized	Bluetooth	Text Message, Audio Signal on user mobile.
[82]	a DJI Phantom 4, Parrot AR. Drone 2.0 & Turtlebot2	Arduino Uno as a sensor and Illuminance sensor	Not realized	Wireless	Mobile Application
Proposed	Zigbee and LoRa integrated hardwares	Sensors and Vision Node	Evaulation metrics of LoRa and OPNET Simulator for zigbee	Zigbee and LoRa	Dynamic exit Display Cloud server and Web Application

4.4 Chapter Summary

In this chapter, performance analysis of the hybrid network is carried out to identify the optimal configuration that needs to be logged in the hardware. In the simulation of 2.4 GHz Zigbee, throughput, end-end delay, and retransmission attempts parameters are evaluated. In LoRa, the evaluation metrics such as ToA and link budget are calculated by a varying spreading factors, CR, and bandwidth. Spreading factor 7, Code Rate 4, and bandwidth 125 kHz are the optimal parameters is logged in the hardware for real-time implementation. Real-time implementation is carried out with hardware and concluded that the hardware logged the real-time data on the cloud-based blynk server.

Chapter 5
Fire Detection and People Density Estimation

This chapter focuses on the methodologies and processes adhered to for automatic fire breakage detection and stranded person estimation in a fireplace using machine vision. In addition to the hardware description provided in Chapter 3, this chapter describes the internal methodologies used for optimizing OpenCV models for edge computing, training and validation of the deep learning-based model to make it compatible with Raspberry Pi, accurate classification and counting of remaining stranded people in a fire breakage area, and the custom web interface for the concerned authorities to monitor and access the information. Along with it, detailed procedures for video surveillance utilizing the web interface and data visualization are also covered.

5.1 Open CV optimization for Raspberry Pi

OpenCV is a free and open-source computer vision, image processing, and machine learning library that is mostly used for various applications related to images and videos wherein it provides easy methodologies to manipulate, analyze and process up to pixel levels, which makes it a suitable option to be used for object classification or recognition in images frame feeds. OpenCV also offers a range of support for direct integration with machine learning models, including K-Nearest Neighbors, Decision Trees, Bayes Classifier, Neural Networks, Support Vector Machines, and others. These approaches may be applied to variety of applications, including form analysis, object detection, face detection, surface matching, text detection and recognition, and so on.

Using these cutting-edge technologies nowadays it has been possible to recognize things in real-time from input frames collected by vision nodes using conjugation of Open CV and Deep Neural Network. To get the desired results, we can also customize algorithms in Python and OpenCV. However, keeping in mind problems like memory constraints, processor performance limits, etc. utilizing the Raspberry Pi for bigger, more sophisticated neural networks it is is quite difficult and inefficient. Models including single-shot detectors like MobileNet and SqueezeNet, which comparatively provide more efficiency and have a comparatively lower memory/processing footprint during its execution, are useful for low computational power devices and should be considered. For the same reason, we've used a MobileNet network for our application. These networks are better suited for a computation unit like the Raspberry Pi for several reasons including speed, fewer memory footprints, smooth exchange between accuracy and performance, etc. The procedures inherited to improve and optimize the OpenCV for the Raspberry Pi module are depicted in Figure 5.1

Additionally, due to its limited RAM and processing power, on-board training of models for human counting and fire detection on the Raspberry Pi is not suitable or efficient. Taking this into consideration, in our work, we have used a comparatively high-resourced system for training our custom model.

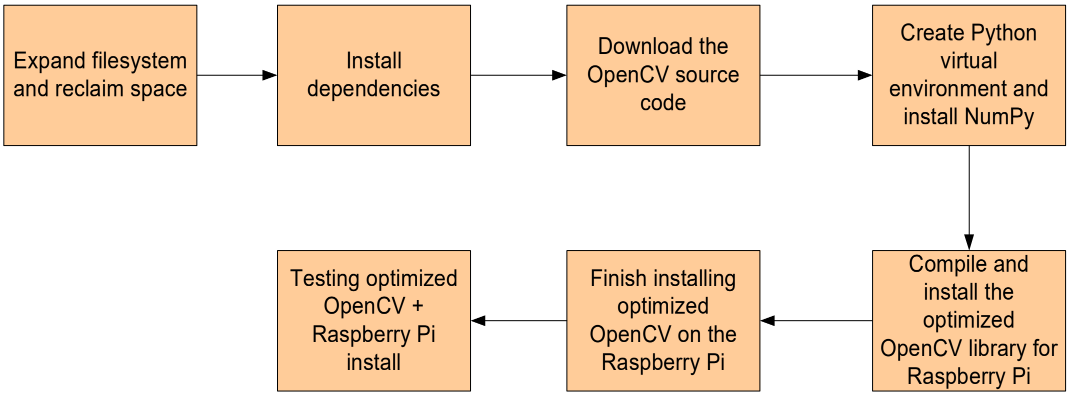


Figure 5.1 Steps Followed for OpenCV Algorithm Optimization for RPi Usage

5.1.1 Training Dataset Accumulation

Deep learning is fundamentally different from typical computer vision-based fire breakage identification systems. The primary difference is that instead of being examined and labeled by a human, the attributes are extensively gathered on their own in the network after training using a huge quantity of training data from diverse sources and scenarios. One of the key limitation of vision-related opeartions is a lack of data for assessing and training the suggested technique. In our quest for a suitable dataset, we examined many data repositories which are used for research in the relevant disciplines.

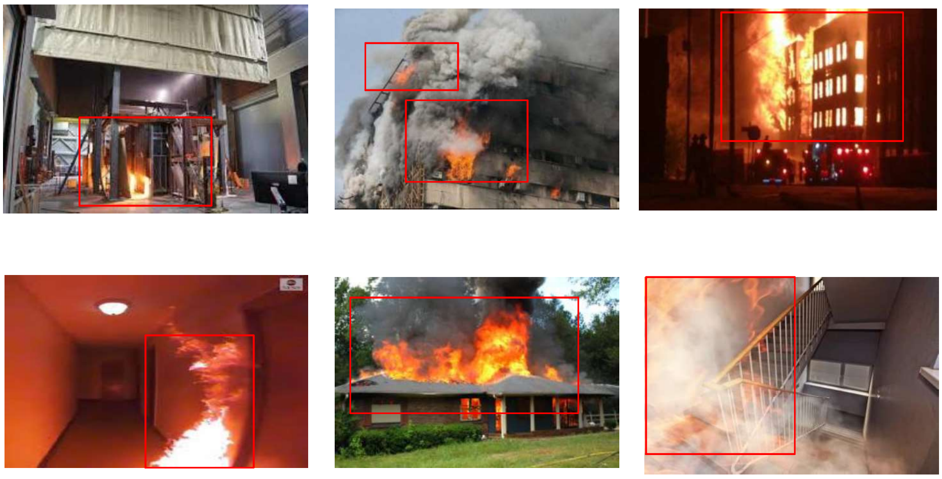


Figure 5.2 Training data for DNN Model used in Fire Detection

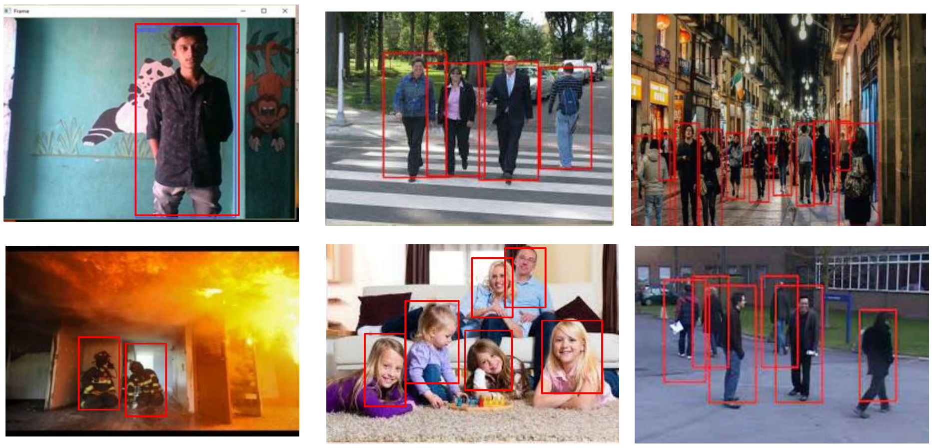


Figure 5.3 Training data for DNN Model used in People Detection

The model cannot be expected to perform well in real-world fire detection scenarios since the quantity and quality of data only from the video are not sufficient or adequate for proper training of the model. To improve efficiency, a diverse dataset was chosen by extracting relevant frames from fire breakage and smoke formation videos and obtaining pictures from the internet using web crawling. Our training set consists of photos of fire from Foggia's dataset as well as photographs from the internet. Several procedures were taken to diversity our dataset, including integrating smoke images from other web sources, collecting frames from movies, and randomly selecting photos from each one to produce our final dataset comprising of both fire breakage and smoke formation for use in this study. Figure 5.2 depicts an example fire detection training dataset. The same was gathered from a variety of sources, including the internet, live video, and so on. Because training the model on the Raspberry Pi is still problematic, this training was performed on a different system with a better configuration. Figure 5.3 depicts an example training dataset for person detection. For training, we utilized standard settings defined by previous investigations [114], as shown in Table 5.1 and Table 5.2

Table 5.1 Training configurations used for training the people counting model

Parameters	**Value**
Number of Test interval	10000
Number of a Test iteration	673
Gamma ratio value	0.5
Base Learning Rate	0.0005
Step interval value	20000
Max. iterations	120000
Weight decay value	0.00005
Learning Rate Policy	multistep

Table 5.2 Training configurations used for training the Fire Detection model

Parameters	**Value**
Number of Step size	100,000
Number of Iteration	150,000
Learning rate decay value	0.00001
Learning rate value	0.01
Weight decay value	0.00004
Pre-trained weight	ResNet-101
Batch size	256

5.2 Fire Breakage Detection and Stranded People Counting

In this part, we will discuss the approach used to detect fire and humans using a vision-based system. In addition, we give the method with a comprehensive flow diagram in this part. As illustrated in Figure 5.4, the functional block diagram is explained in order to accomplish fire detection and people counting. When a fire erupts, the vision node streams the scenario within the room to the web application in real-time. When a fire occurs, a camera linked to a Raspberry Pi captures the real-time image. The input for this functional block diagram is a real-time video. It is then divided into several frames for further processing. The functional block diagram is further divided into two sections fire detection and people counting. In the people counting section, frames are processed using DNN and a pre-trained model for detecting and counting people. In the fire detection section, image processing is done on the frames to detect fire events and their flow.

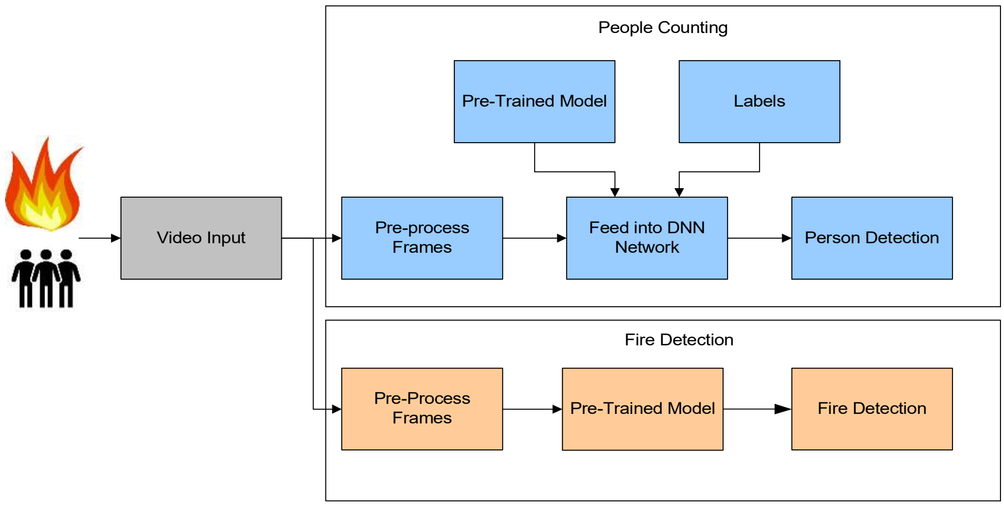


Figure 5.4 Functional Block Diagram of The System

5.2.1 DNN Model Fire Detection and People Counting

As illustrated in Figure 5.5, the DNN model-based comprehensive block design is described in order to accomplish fire detection and people counting. MobileNet SSD, a single shot detector, has been created utilizing transfer learning techniques for the identification and counting of human presence within a room. The knowledge in the current MobileNet SSD model was preserved in its initial twenty-four layers, and the additional 4 layers towards the output node are trained using photos acquired in our datasets that are more relevant to the settings and scenarios of the test application area. After the training is finished, we get a model file containing cumulative knowledge of the current MobileNet SSD model as well as pictures from our datasets, making it more trustworthy. ResNet101, one of the most effective neural network models that may be employed as the backbone for fire detection applications, was also used for fire detection. Furthermore, the last 15 levels of its total 101 layers are trained using the data repositories that we acquired from multiple sources utilizing transfer learning. Following the completion of the training, the model file was copied to and installed on the Raspberry Pi.

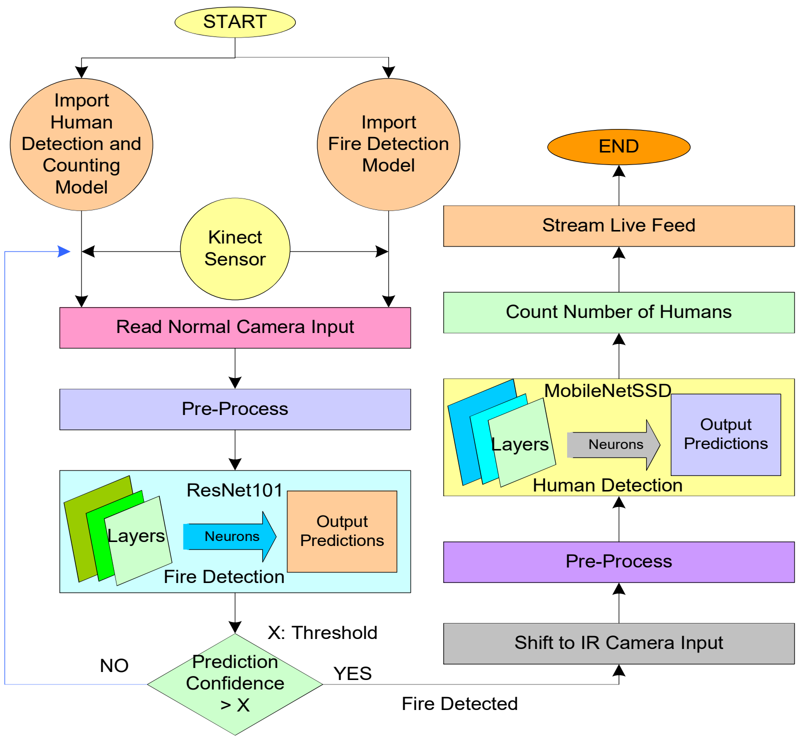


Figure 5.5 DNN Model Detecting Fire and Counting People

Once the system is enabled and powered up, it imports both the model and begins receiving the feed from the Kinect's generic camera feed and starts feeding it into the input layers of the ResNet101 model that was trained for performing fire breakage identification model after completing all the pre-processing procedures (e.g., scaling, formatting, etc.). Following that, the model then executes it and generates its projection regarding the detection of fire, as well as the forecast's confidence level. Our system's algorithm compares the model's confidence level to a predefined limit value. If the confidence is more than the predefined threshold value, the system deems the situation to be a detected fire and proceeds to the human detection and counting module of operation. In this case, the system changes the input source to the IR feed from the Kinect, which is then fed into the "MobileNet SSD model" after pre-processing for compatibility. The model then analyses the input feed after segmenting into frames to determine the count of stranded peoples present inside its field of view (FOV). The live feed from the cameras and the processed output of the model is then streamed to a network server and processed by an active application listening or pinging on the live-stream port. This stream may then be utilized by the appropriate officials to plan out the next steps and rescue operations.

5.2.2 Flowchart and Algorithm for Fire Detection and People Density Estimation

Figure 5.6 and Figure 5.7 show the process for detecting fires and estimating the number of individuals. According to Figure 5.6, the DNN is used to estimate the number of individuals following the training model. The following procedures are taken in order to recognize and count people: The previously trained object class recognition model with its class-defined labels is loaded first. When the camera takes a picture as an input feed, it is pre-processed and then fed into the DNN network. In this case, the network determines whether or not the item is known. If the thing is unknown, it begins photographing it. If the item is identified, it assigns an identification tag to it, draws bounding boxes around all identified object classes, and counts the total number of labels generated. At the end of a single process, the total count is displayed, and the procedure is repeated. Similarly, fire detection is done with DNN following the training model, as shown in Figure 5.7, and the sequential stages are as follows: The camera takes the picture as input in the first stage, and pre-processing is done to manipulate the image into a suitable format. The color picture is transformed to greyscale here, and the previously trained DNN model for fire breakage identification is loaded. Feed the input image to the DNN model, which determines whether or not the item in the image is a fire. If a fire is discovered as a consequence, the information is instantly sent to the web application. The parameters for the proposed system are shown in Table 5.3. Further, Table 5.4 describes the technique used for real-time fire detection. The parameters for the algorithm are shown in the table above. C_{IC}, Ppp, D_M, D_{OD}, and I_{LD} are the parameters used for fire detection. Furthermore, the suggested algorithm has five stages. Table 5.5 describes the technique used for people detection and counting. In the table below, the algorithm's parameters are listed. The parameters involved in the people identification and counting algorithm are B_{DB}, C_{IC}, I_{LD}, D_{OD}, D_M and Ppp. Furthermore, the suggested algorithm has five stages.

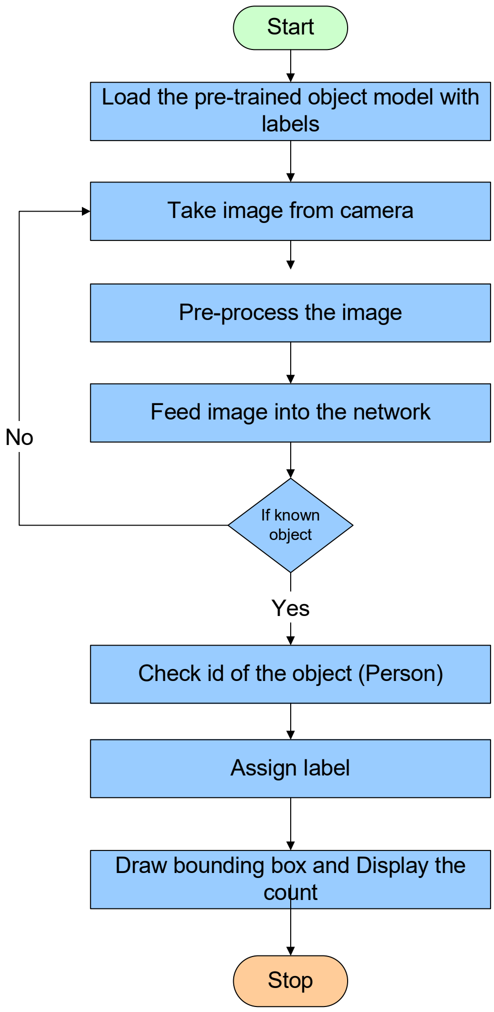


Figure 5.6 Flowchart of People Count Evaluation

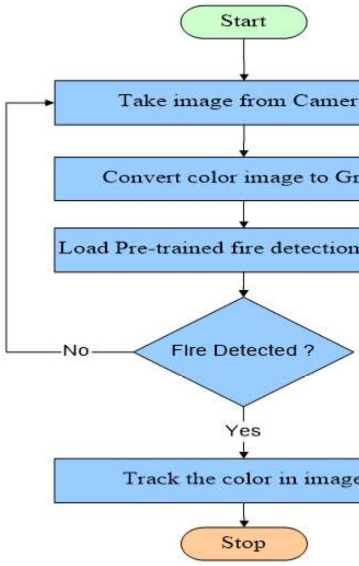


Figure 5.7 Flowchart of the Fire Detection method

Table 5.3 Parameter Description used in the Proposed System

P_{pp} → Pre-processing Image	D_{OD} → Deciding Object
I_{LD} → Loading pre-trained model	S_S → Status of detection
C_{IC} → Capturing Image	C_{CO} → Count object
D_M → Display Message	B_{DB} → Draw Bonding Box

Table 5.4 Real-time Fire breakage Identification Algorithm

Steps followed	Functions
Input: Real time video of object C_{IC} →Capture the image from input	cameraVar cap = cv2.VideoCapture(0)
P_{pp} → Apply pre-processing and formatting on input image i.e., convert a color image to gray.	grey = cv2.cvtColor(img,cv2.COLOR_BGR2GRAY)
I_{LD} → Load pre-trained model into the system for fire detection with DNN Network	fire_cascade = cv2.CascadeClassifier('fire_detection.xml')
D_{OD} → It is the decision variable which states whether the image has a known object (Fire) or not.	for (x,y,w,h) in fire: cv2.rectangle(img,(x,y),(x+w,y+h),(0,0,255),2) roi_gray = gray[y:y+h, x:x+w] roi_color = img[y:y+h, x:x+w]

D_M → Display text Once it finds an image and then tracks the color in the image.	cv2.putText(img, "Fire Detected", (40, 40), cv2.FONT_HERSHEY_SIMPLEX, 1, (0, 0, 255), 2) cv2.imshow('img',img)

Table 5.5 Algorithm for Detecting and Counting Stranded People in Real-Time

Steps followed	Functions
Input: Real-time video feed of the object I_{LD} → Load pre-trained model into the system for fire detection with DNN Network	net = v2.dnn.readNetFromCaffe("MobileNetSSD_deploy.prototxt.txt" , "MobileNetSSD_deploy.caffemodel")
C_{IC} →Capture the image feed/frame from the input	camera cap = cv2.VideoCapture(0)
P_{pp} → Apply pre-processing and formatting on input image	blob = cv2.dnn.blobFromImage(cv2.resize(frame, (300, 300)),0.007843, (300, 300), 127.5)
D_{OD} → Deciding identified Object (Person) and label it	label = CLASSES[idx]
B_{DB} → Draw Bonding Box over the Object identified (Person)	cv2.rectangle(frame, (startX, startY), (endX, endY),COLORS
D_M → Display the people count and repeat the process	if(label=='person'): count+=1 print("number of persons ",count)

5.3 Web Interface

The suggested system's primary goal is to function successfully in a situation such as a fire disaster. It is designed to deploy and thoroughly test the proposed system in real-time under diverse circumstances. To assess the proposed system's performance, we installed the vision node in a dummy environment or application area. In today's world, CCTV-based surveillance is common and may be utilized for fire detection. To record the real-time scenario, the vision node was installed in lieu of the current CCTV within the room. We developed a web-based application that would be deployed on a local server to collect real-time data from vision nodes in this system.

Figure 5.8 Admin Panel to Log Into the Portal

Figure 5.8 depicts the application's login window. The complete system can only be accessed by authorized people with the correct credentials. To activate the vision node, we must first log in to the online site. When we successfully join into the web portal, it will activate all of the vision nodes installed across the building that is connected via the internet.

Figure 5.9 Real-time People Detection and Visualization On Web Application

As shown in Figure 5.9, once connected, vision nodes begin providing live images as well as approximated statistics such as the condition of fire breakage identification and the number of stranded people as shown in Figure 5.10 depicts the many stages of end-to-end working.

Figure 5.10 Real-time Fire Detection and Visualization On Web Application

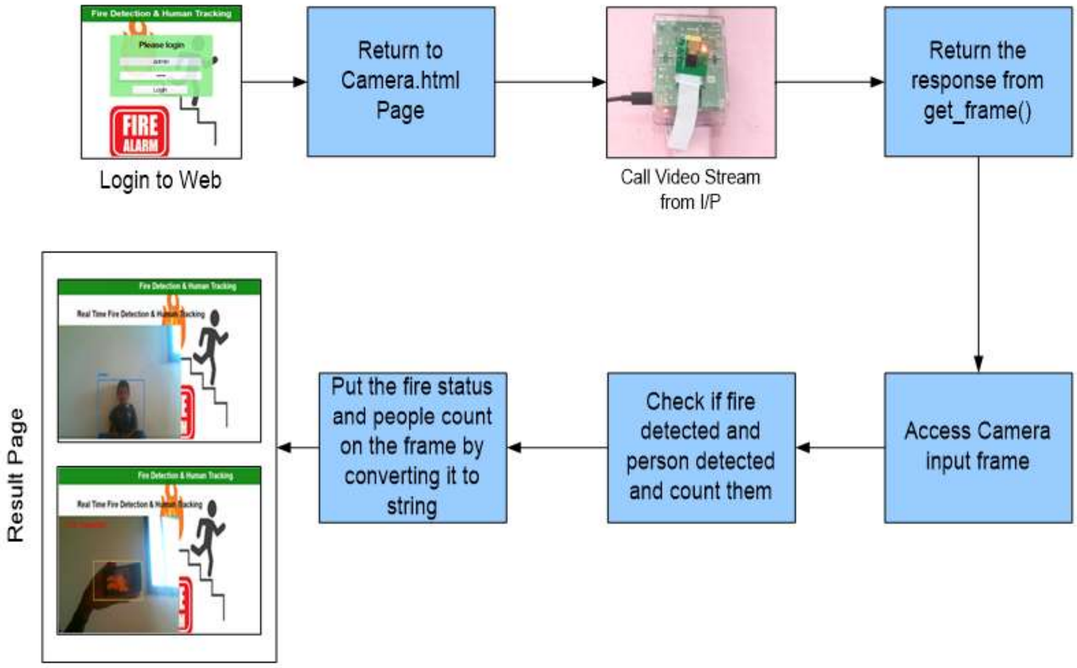


Figure 5.11 Stages Involved in The End-End Working of Vision Node

5.3.1 Web Interfacing for Fire Detection and People Tracking

This part provides a graphical user interface for Fire Detection and People Tracking, which will take the form of a seamless online application with all capabilities shown visually. Rendering to the sorts of entities with which they are associated, for example, adding an image, capturing an image, and transmitting an image from the camera to the database. The web interface was given special consideration, with the key idea being to achieve visual alignment with the least amount of effort necessary in terms of user activities.

As a consequence, each of these components is positioned as a connected container web control, with its contents and specifics accessible via a suitable tab menu at the top of each page's main section. The user selects a single tab based on their request. When appropriate, the contents of each tab are further split into parts based on a specific logical and functional grouping. When validation problems occur, they are shown in white at the top of the page.

Our system’s web modules are as follows:

Login Page

Login Page is having an entry for a user with secure credentials and access permissions for users.

Logout Page

Logout Page design proves the session is ended and you will be redirected to the home page.

Home Page

This page is the first page of our project which is having a camera visual picture interface and has detection interface of fire with the sensor.

Error page

In case of an application error, an error page is displayed describing the error that occurred.

5.4 Model Analysis

During our experiment, we examined our technology under a range of conditions. To establish the methodology for counting population density's precision and correctness, we analyzed The method is based on the distance between individuals and the camera, as well as the intensity of the light in the room. The system's precision with respect to the distance of individuals from the camera is shown in Table 5.6. To obtain the findings, the distance is divided into four separate sets. The distance from the camera was increased in each set by 5 feet. In case SET 1, a person is 5 feet away from the camera, and the system is 100 percent accurate. When the distance in SET 2 between a human and the camera is lowered to 10 feet, the system's accuracy stays constant, i.e., 100 percent. Similarly, in case of SET 3, the distance between the person and the camera is increased to 15 feet but the system's accuracy stays unchanged. However, in SET 4, the distance between a person and the camera is extended to 20 feet, but as a result, the accuracy has been lowered to 75%. The accuracy of the vision-based system is evaluated using the pictures below. We looked at pictures with varying numbers of individuals in them. Figure 5.12 depicts the system's ability to detect the number of individuals in pictures.

Table 5.6 System accuracy by changing distance between Camera and People

SET	Distance between People and Camera (In Feets)	Outcome of Vision node	Accuracy(in %)
1	5	Identified 4 out of 4 people	100
2	10	Identified 4 out of 4 people	100
3	15	Identified 4 out of 4 people	100
4	20	Identified 3 out of 4 people	75

Table 5.7 Image-Based Detection of the count of People

Source	Actual People count	People count by Vision Node	Accuracy(in %)
(a)	36	28	77.77
(b)	5	5	100
(c)	8	6	75
(d)	14	4	30

Figure 5.12 People detection and counting by vision node

The count of persons identified by the vision node is shown in Table 5.7. The real number of individuals present in Image 'a' is 36, and the vision node can detect the 28 persons with an accuracy of 77.77%. Because of the poor picture quality, the accuracy of image 'a' has been compromised. In the example of Image 'b,' there are 5 individuals there, and the vision node can recognize the 5 people with 100% accuracy in the example of Image 'c,' there are 8 individuals there, and the vision node can recognize the 6 people with 75% accuracy. In the example of Image 'd,' the real number of persons present is 14, and the vision node detects the 4 people with a 30% accuracy.

The accuracy has been compromised in this case due to unclear or distorted pictures, which hinder the system from detecting correct feature points. Based on the aforementioned results, it is determined that the accuracy is greater when the frame is more visible, as in the case of image 'a.' We obtain less accuracy when we use a fuzzy image than when we use Image 'd.' The higher the resolution of the picture, the more accurate the vision node fire breakage identification system will be.

The performance of the system corresponding to the intensity of light in the room is shown in Table 5.8. The findings are achieved by taking into account the light source to be 4 distinct light sources. During the performance evaluation of SET 1, the light intensity within the room is sunlight, and the corresponding system's accuracy was observed to be cent percent. When the amount of light that is present in the room is set to tube lighting in SET 2, then the system's accuracy remains the same, i.e., 100 percent. Similarly, in SET 3, the light intensity within the room is a partly dark room, and the system's accuracy is 50%. However, in SET 4, the light intensity within the room is decreased to 50% because there is no sunshine or tube light. When it comes to SET 3 and SET 4, we may include a thermal imaging or a night vision camera conjugated with the suggested vision node to increase the outcome and accuracy.

Table 5.8 Result depending on the light intensity within the room

SET	Intensity type In Room	Identified Persons out of Total 4 Persons	Accuracy
1	In presence of sunlight	Identified 4 persons	100%
2	In presence of tube lighting	Identified 4 persons	100%
3	Partialy dull room	Identified 2 persons	50%
4	Without sunlight, under tube lighting	Identified 2 persons	50%

Furthermore, as part of our investigation, we conducted a variety of fire detection tests. Different frames collected by vision nodes in various circumstances were selected as taste instances and evaluated over time. When the intensity exceeds a certain threshold, say 0.6, the algorithm will anticipate that a fire has been spotted. In the first example, we fed the system frames with diminishing fire flames and obtained the result illustrated in Figure 5.13. In the second scenario, we have provided frames with increasing intensity of fire flame and received results as shown in Figure 5.14. In the third case, as shown in Figure 5.15 the system is tested with the frame of increasing and decreasing fire flames. At the last system is tested with frame of random fire flames intensity and we received results as shown in Figure 5.16.

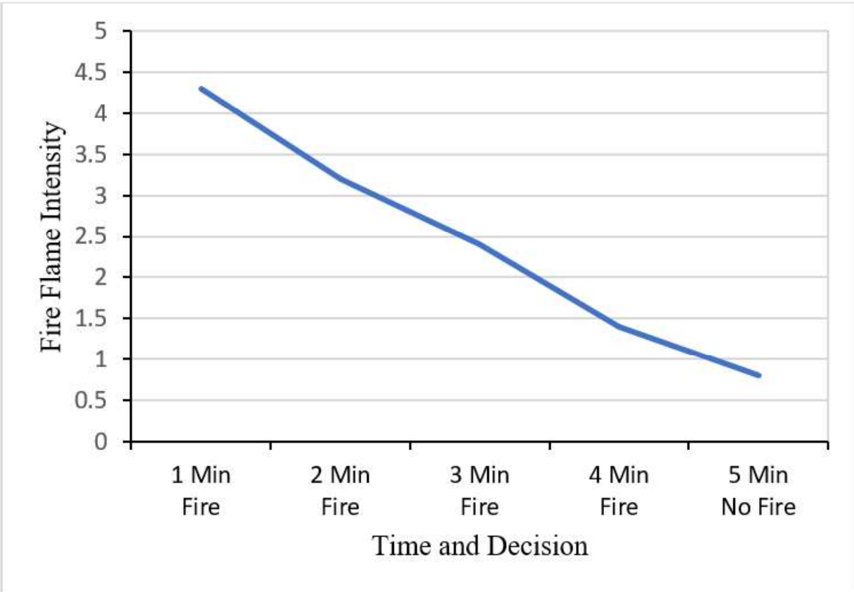


Figure 5.13 Decreasing fire flame vs Time

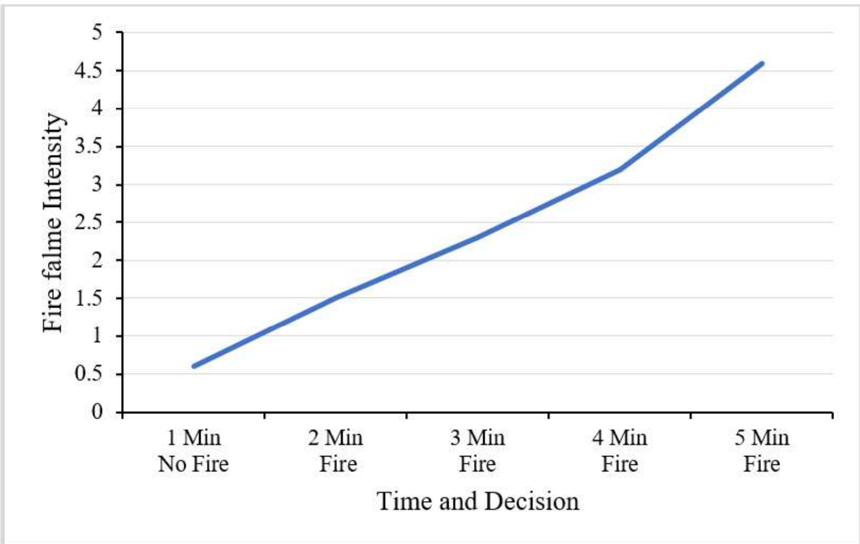


Figure 5.14 Increasing Fire Flame Vs Time

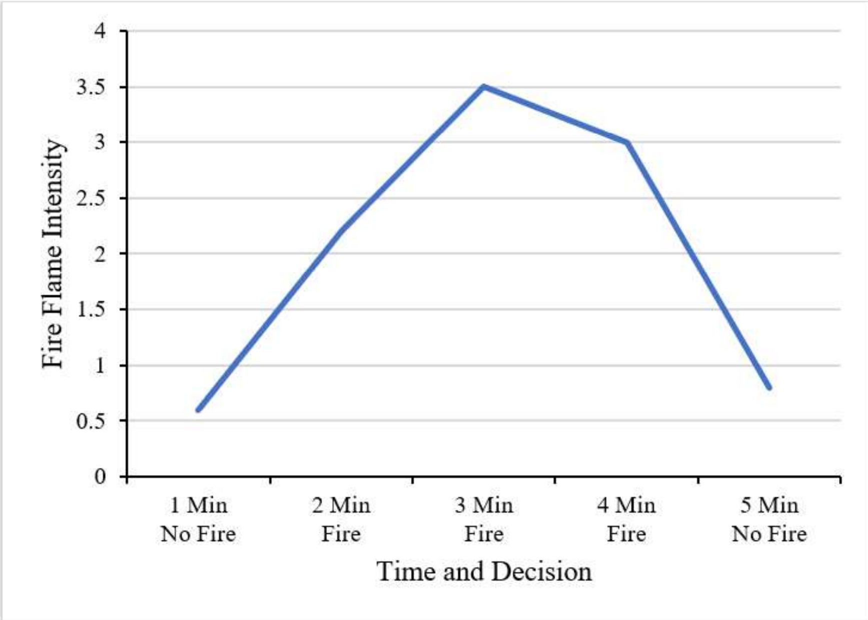


Figure 5.15 Increasing and Decreasing Fire Flame Vs Time

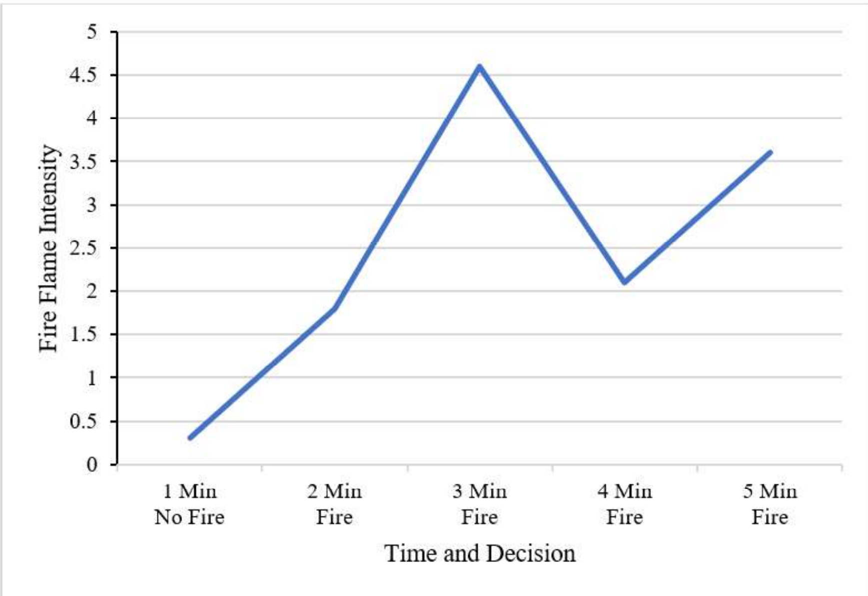


Figure 5.16 Random Fire Flame Vs Time

Table 5.9 shows a comparison of the proposed system to past research implemented for fire detection. The comparison is based on several factors, such as web interface, object detection method, Raspberry Pi, implementation in real-time, and CCTV retrofitting. Based on comparative assessment, it is observed that the proposed approach outperforms the past work in terms using Raspberry Pi for fire detection, and visualization through web interface. Here, a web interface is implemented for displaying the real time data acquired by the Raspberry Pi via the Kinect camera. Furthermore, CCTV retrofitting is also possible with the proposed system.

Table 5.9 Comparative analysis of vision node system with past work.

Reference	**Web Interface**	**Real-Time Implementation**	**Object Detection Method**	**Raspberry**	**CCTV Retrofitting**
[115]	No	Yes	DNN, CNN	No	Not realized
[116]	No	Yes	Image processing	No	Not realized
[117]	No	Yes	CNN	No	Not realized
Proposed work	Yes	Yes	DNN	Yes	Proposed a method

5.5 Correlation and Contribution of Vision Node in the System

As discussed in earlier sections and chapters, the system employs various systems in an interconnected network to detect unexpected fire breaks and aids in fast mitigations to minimize damage. However, when implementing such a system in a real-world setting, the system must be precise, efficient, and successful in all aspects. To help with this, the vision node in the system plays an important role. When the data collecting device delivers a signal of fire breakage, the vision node also transmits an information log confirming the same, which the coordinator uses as an additional layer of information for correlating and assessing the present condition and preventing false alarms. The vision node's onboard algorithm's capacity to examine the number of individuals trapped in the fireplace, the density of smoke, and other factors also assists the concerned authorities in thoroughly planning out future actions. Furthermore, the vision node assists authorities by giving a real-time video feed of the scenario, which is critical to preparing for the impending crisis ahead of time so that they may be better prepared for the event.

5.6 Chapter Summary

The chapter emphasizes the significance of vision node in the event of a fire. Based on observations, the suggested system outperforms prior research in terms of performing fire detection and people density estimates using a Raspberry Pi, a Kinect sensor, a DNN model, and a web interface. The system helps authorities and civilians in numerous ways to aid in rapid actions, mitigation strategies for limiting the damage and losses to the minimum. Furthermore, the suggested system allows for retrofitting with CCTV.

Chapter 6
Evacuation Guidance System

This chapter mainly focused on the design and implementation of a safe evacuation guidance system to assist the people stuck inside the building as well as to help the rescue team during a fire accident. Initially, it presents an exit path decision model using an improved shortest path algorithm and it is employed on hostel building for validation. The further part of the chapter presents an experimental model of the complete system with a detailed explanation and a working model with result visualization. The chapter ends with a discussion of overall power consumption individual nodes and systems in different stages of working.

6.1 Path Optimization

This section discusses a comprehensive decision model for current tall building rescue in compliance with the Fire Life and Safety Code 2005 and the National Building Code of India 2005. This decision model is based on an enhanced shortest path algorithm that was applied to a 3D map of the hostel building. Dijkstra's method is utilized as the shortest path algorithm in this study. It's a method for computing the shortest route between nodes in a graph, such as a network of data collecting nodes. The algorithm is available in a variety of versions. The original Dijkstra method states the shortest route between two nodes; however, A more frequent version assigns a single node to serve as the "source" node and calculates the shortest route from the source to all other nodes in the network, resulting in a shortest path tree.

The approach discovers the shortest route in the graph between a certain source node and each other node. It can also be used to evaluate the shortest routes between a single source and a single destination node, with the procedure terminating once the shortest path to the destinatio node is found. If the nodes of the graph reflect cities and the edge path costs indicate driving distances between two cities connected by a straight road, Dijkstra's approach can be used to determine the shortest route between them.

The Dijkstra method uses labels that are either positive integers or real numbers and completely ordered.. It can be extended to any partially ordered labels as long as the successive labels (which are generated when traversing an edge) are monotonically non-decreasing. The steps in Dijkstra's algorithm for finding the shortest path between a single source vertex and all other vertices in a graph are listed below.

Algorithm

- Create a set called sptSet (shortest path tree set) to keep records of the vertices in the shortest-path tree, or those whose shortest distance from the source has been computed and completed. This set begins with a blank slate.
- Each vertex of the input graph should be given a distance value. INFINITE should be set for all distance values. Assign the source vertex a distance of 0 to ensure that it is chosen first.
- Because sptSet does not contain all vertices...
  a) Select a vertex u that is not in sptSet and has the shortest distance.
  b) Add u to the sptSet.
  c) The distance between all of u's nearby vertices should be updated. Iterate through all nearby vertices to modify the distance values. If the entire distance value of u (from source) and the weight of edge u-v is less than the distance value of v for each neighbouring vertex v, update the distance value of v.

6.2 Decision Model

The decision model is prsenetd here is based on an enhanced shortest path algorithm applied to a 3D map of a residential structure as illustrated in Figure 6.1. It predicts the shortest exit path to the occupants stuck inside the building in real-time. Figure 6.2 illustrates the equivalent diagram of a hostel building, where bubbles are used in place of rooms, the staircase is replaced by jagged lines and the linear line used in place of straight path. Each entity is acting as nodes which are named as {E0, E1, …… E19}. In this case {E1, E2, …. E18} are source node and {E0 and E19} are destination node. The equivalent length of the channel is not the same due to the varied ease factors of evacuation routes under various road traffic conditions. When the equivalent distance is larger, the weighted graph's route weight increases.

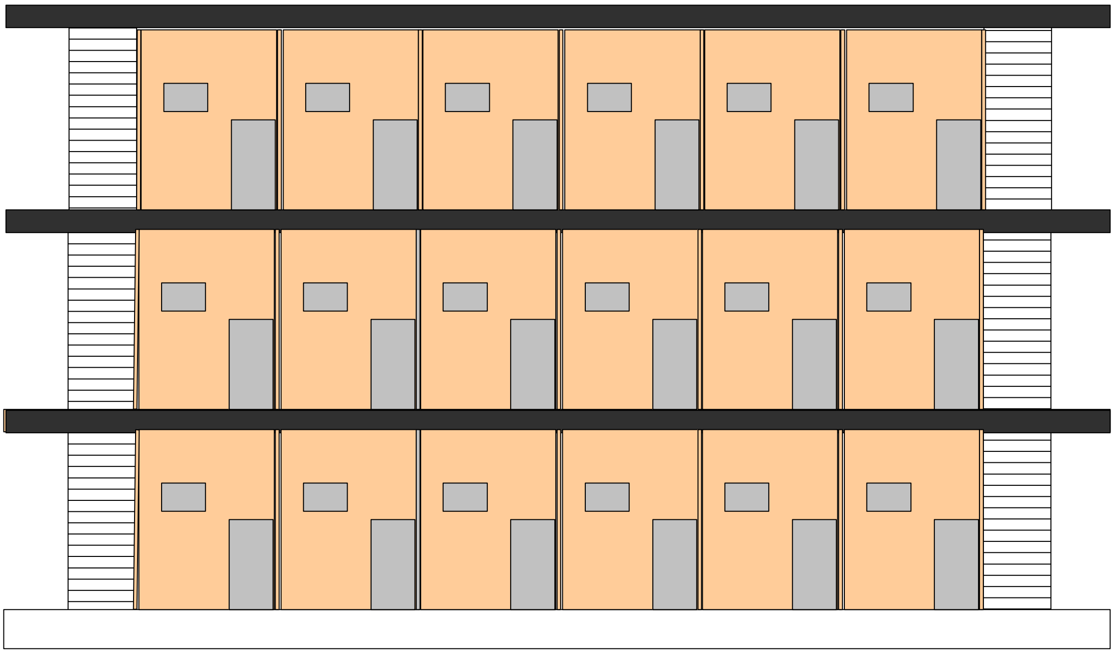


Figure 6.1 Architecture of Hostel Building for case study

6.2.1 Case 1: No fire

Under the situation of no fire hazards, it gives the conclusion that the shortest route from transit node E18 to exit E0 is {E18, E12, E1, E0} after using the improved Dijkstra algorithm, and middle nodes are E1, E12, length is 14m.

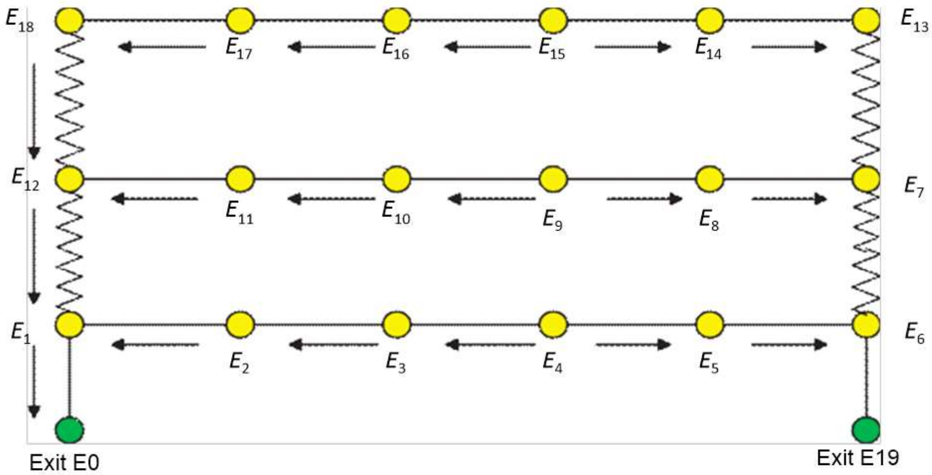


Figure 6.2 Equivalent schematic of hostel building when there is no Fire detected

The shortest route from transit node E18 to exit E19 is {E18, E17, E16, E15, E14, E13, E7, E6, E19}, and middle nodes are E6, E7, E13, E14, E15, E16, E17, length is 51.5m. In this, as distance from node E18 to reach exit node E0 is comparatively less hence it should select the exit E0 as its exit, and the ultimate path to exit is {E18, E12, E1, E0}. Based on this analysis, Table 6.1 shows the shortest route between source and destination node when there is no Fire.

Table 6.1 Shortest route between source and destination node when there is no Fire

Source Node	Exit	Exit Path	Distance
E1	E0	E1→E0	7.0m
E2		E2→E1→E0	14.5m
E3		E3→E2→E1→E0	21.0m
E10		E10→E11→E12→E1→E0	29.0m
E11		E11→E12→E1→E0	21.5m
E12		E12→E1→E0	14.0m
E16		E16→E17→E18→E12→E1→E0	36.0m
E17		E17→E18→E12→E1→E0	28.5m
E18		E18→E12→E1→E0	21.0m
E4	E19	E4→E5→E6→E19	21.0m
E5		E5→E6→E19	14.5m
E6		E6→E19	7.0m
E7		E7→E6→E19	14.0m
E8		E8→E7→E6→E19	21.5m
E9		E9→E8→E7→E6→E19	29.0m
E13		E13→E7→E6→E19	21.0m
E14		E14→E13→E7→E6→E19	28.5m
E15		E15→E14→E13→E7→E6→E19	36.0m

When a fire strikes, evacuation routes must be developed in line with the concept of rapid and secure design, depending on the varied scenarios and building types. The evacuation route directions should be kept away from the fire to prevent the evacuation action from being harmed by the smoke spreading process. To ensure the overall efficiency of the safety and evacuation, the subsequent fire alarm should not change the completed emergency evacuation route instructions to avoid when staff is evacuated by emergency evacuation routes, evacuation routes change direction suddenly causing panic or counter.

6.2.2 Case 2: Fire at E12 Node

If the sensor nodes of a source node detects a fire event, and the source node is closest to the transit node E12, the source node is triggered. The channel E18, E12 gets highly polluted by the smoke stream in a relatively short period of time, thus evacuees are unable to choose it in practice. Figure 6.3 depicts the corresponding schematic of hostel building when Fire detected at E12 Node.

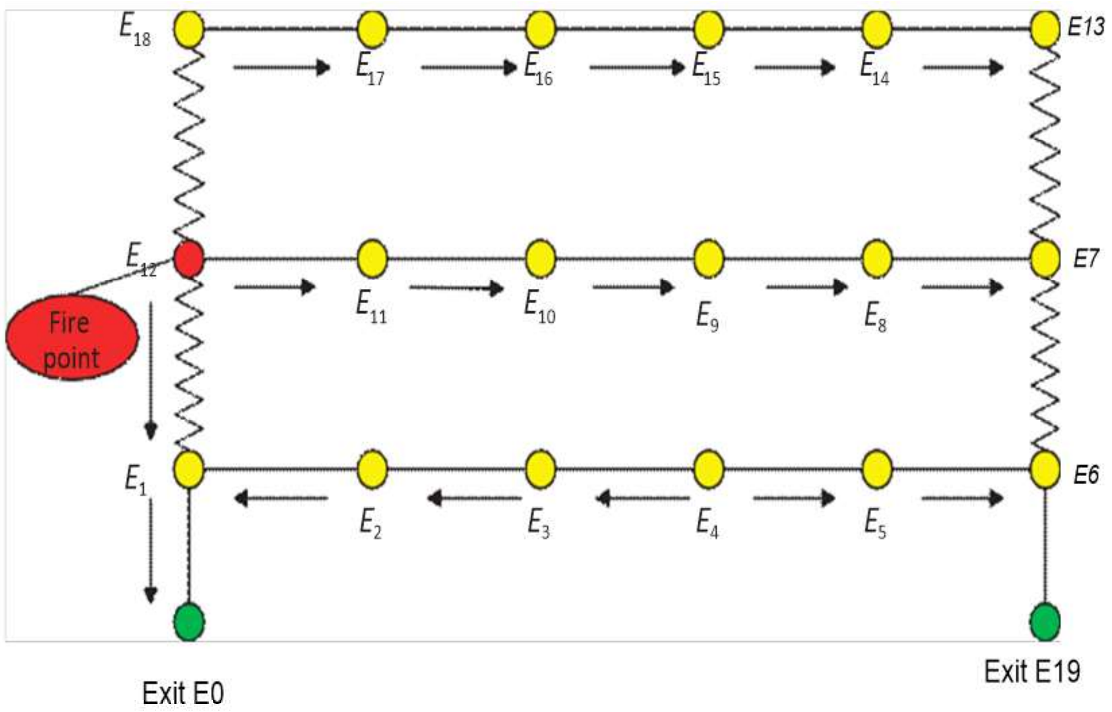


Figure 6.3 Equivalent schematic of hostel building when Fire detected at E12 Node

Currently, the calculated evacuation route based on the shortest distance is ineffective, so it cannot be used as a guide for the evacuation plan's safety. To address this issue improved Dijkstra algorithm is presented and with this evacuee can obtain the optimal path of exit output from respective transmission nodes as shown in Table 6.2.

Table 6.2 Improved escape route between Source and Destination node when Fire detected at E12 Node

Source Node	Exit Node	Exit Path	Distance
E1	E0	E1→E0	7.0m
E2		E2→E1→E0	14.5m
E3		E3→E2→E1→E0	21.0m
E12		E12→E1→E0	14.0m
E4	E19	E4→E5→E6→E19	21.0m
E5		E5→E6→E19	14.5m
E6		E6→E19	7.0m
E7		E7→E6→E19	14.0m
E8		E8→E7→E6→E19	21.5m
E9		E9→E8→E7→E6→E19	29.0m
E10		E10→E9→E8→E7→E6→E19	36.5m
E11		E11→E10→E9→E8→E7→E6→E19	44.0m
E13		E13→E7→E6→E19	21.0m
E14		E14→E13→E7→E6→E19	28.5m
E15		E15→E14→E13→E7→E6→E19	36.0m
E16		E16→E15→E14→E13→E7→E6→E19	43.5m
E17		E17→E16→E15→E14→E13→E7→E6 →E19	51.0m
E18		E18→E17→E16→E15→E14→E13→E7 →E6→E19	58.5m

The routes of nodes E10, E11, E16, E17, and E18 to exit altered when compared to the output path in the absence of a fire threat. For an instance, the shortest but safest route from node E18 to exit way is shifted to the optimal route of E18, E17, E16, E15, E14, E13, E7, E6, E19 from the generic shortest route of E18, E12, E1, E0 because the path passes node E12, which is covered by fire.

6.2.3 Case 3: Fire at E15 and E16 Node

If the sensor nodes of a source node detects a fire event, and the source node is closest to the transit node E16 and E15, the source node is triggered. The channel E15, E16 gets highly polluted by the smoke stream in a comparatively in less time, thus evacuees are unable to choose it in practice. Figure 6.4 depicts the corresponding schematic of hostel building when Fire detected at E15 and E16 Node.

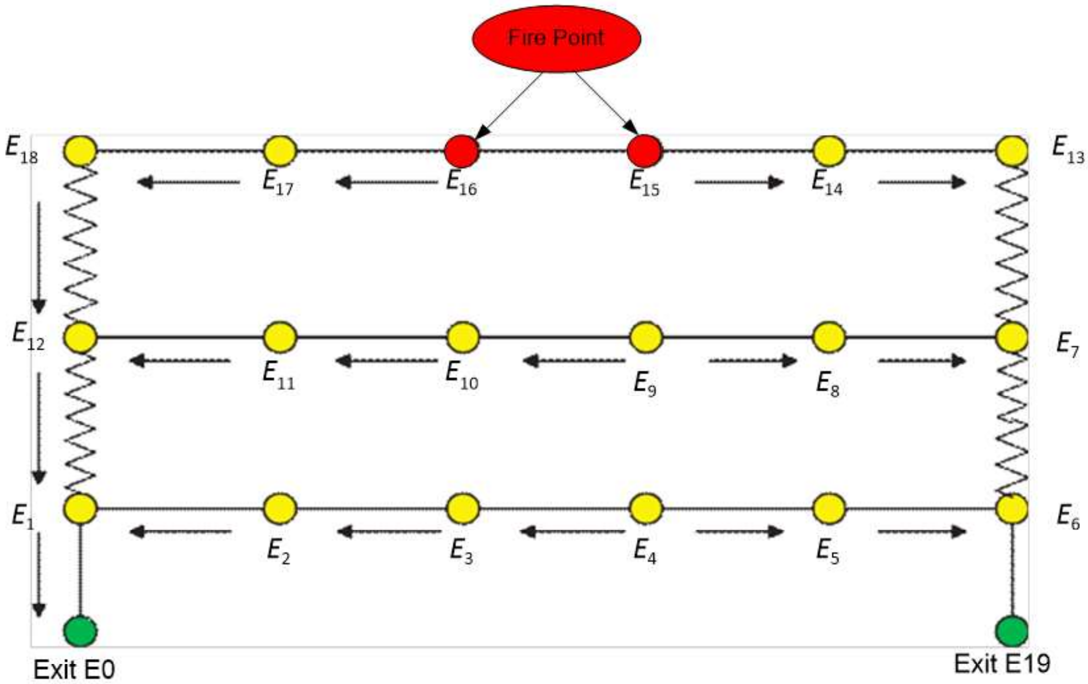


Figure 6.4 Equivalent schematic of hostel building when Fire detected at E15 and E16 Node

The optimal exit path from each node for case 3 presented in Table 6.3. The routes of nodes E15 to exit altered when compared to the output path in the absence of a fire threat. For an instance, the shortest but safest route from node E15 to exit way is shifted to the optimal route of E15, E14, E13, E7, E6, E19 from the generic shortest route of E15, E16, E17, E18, E12, E1, E0 because the path passes node E16, is covered by fire.

Table 6.3 Improved escape route between Source and Destination node when Fire detected at E15 and E16 Node

Source Node	Exit Node	Exit Path	Distance
E1	E0	E1→E0	7.0m
E2		E2→E1→E0	14.5m
E3		E3→E2→E1→E0	21.0m
E10		E10→E11→E12→E1→E0	29.0m
E11		E11→E12→E1→E0	21.5m
E12		E12→E1→E0	14.0m
E16		E16→E17→E18→E12→E1→E0	36.0m
E17		E17→E18→E12→E1→E0	28.5m
E18		E18→E12→E1→E0	21.0m
E4	E19	E4→E5→E6→E19	21.0m
E5		E5→E6→E19	14.5m
E6		E6→E19	7.0m
E7		E7→E6→E19	14.0m
E8		E8→E7→E6→E19	21.5m
E9		E9→E8→E7→E6→E19	29.0m
E13		E13→E7→E6→E19	21.0m
E14		E14→E13→E7→E6→E19	28.5m
E15		E15→E14→E13→E7→E6→E19	36.0m

6.2.4 Case 4: Fire at E7 and E8 Node

If the sensor nodes of a source node detects a fire event, and the source node is closest to the transit node E7 and E8, the source node is triggered. The channel E7, E8 gets highly polluted by the smoke stream in a relatively short period of time, thus evacuees are unable to choose it in practice. Figure 6.5 depicts the corresponding schematic of hostel building when Fire detected at E7 and E8 Node.

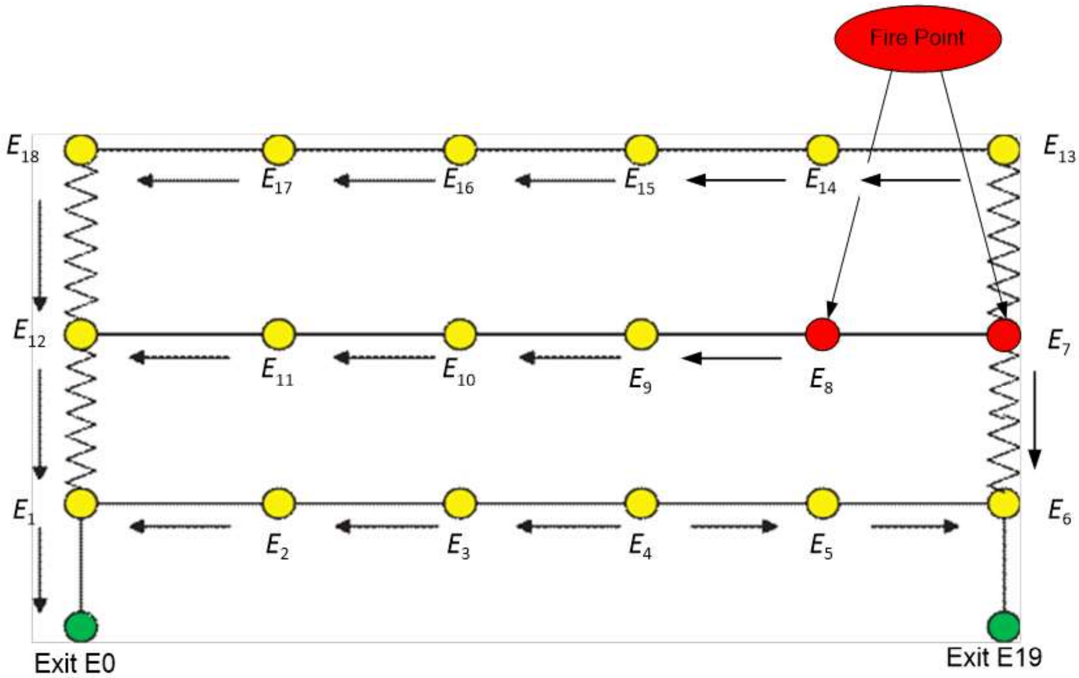


Figure 6.5 Equivalent schematic of hostel building when Fire detected at E7 and E8 Node

The optimal exit path from each node for case 4 presented in Table 6.3. The routes of nodes E13, E14, E15, E8 and E9 to exit altered when compared to the output path in the absence of a fire threat. For an instance, the shortest but safest route from node E13, E14 and E15 to exit way is shifted from the generic shortest route of E15, E14, E13, E7, E6, E19 to the optimal route of E13, E14, E15, E16, E17, E18, E12, E1, E0 because the path passes node E7, is covered by fire. Also generic shorets route for E8 is shifted from E8, E7, E6, E19 to safe route E8, E9, E10, E11, E12, E1, E0 as nearest node E7 is covered by fire.

Table 6.4 Improved escape route between Source and Destination node when Fire detected at E7 and E8 Node

Source Node	Exit Node	Exit Plan	Distance
E1	E0	E1→E0	7.0m
E2		E2→E1→E0	14.5m
E3		E3→E2→E1→E0	21.0m
E8		E8→E9→E10→E11→E12→E1→E0	44.0m
E10		E10→E11→E12→E1→E0	29.0m
E11		E11→E12→E1→E0	21.5m
E12		E12→E1→E0	14.0m
E13		E13→E14→E15→E16→E17→E18→E12→E1→E0	58.5m
E14		E14→E15→E16→E17→E18→E12→E1→E0	51.0m
E16		E16→E17→E18→E12→E1→E0	36.0m
E17		E17→E18→E12→E1→E0	28.5m
E18		E18→E12→E1→E0	21.0m
E4	E19	E4→E5→E6→E19	21.0m
E5		E5→E6→E19	14.5m
E6		E6→E19	7.0m
E7		E7→E6→E19	14.0m
E8		E8→E7→E6→E19	21.5m
E9		E9→E8→E7→E6→E19	29.0m
E13		E13→E7→E6→E19	21.0m
E14		E14→E13→E7→E6→E19	28.5m
E15		E15→E14→E13→E7→E6→E19	36.0m

The optimal evacuation path based on the imrpoved algorithm, while having a longer commuting distance than the shortest route, has a higher level of security, allowing people to safely evacuate while avoiding the way fire as a result of unforeseen damage. In the event of a actaul evacuation, a congested evacuation route caused by personnel can cause the evacuation time to be extended.

The best method is to divert a portion of the audience to a safe and relatively open path, which will make it convenient to use an alternate route and confirm that everyone gets to a safe exit in a timely manner. In this case the distance between each node to the destination node is worked out using coordinator module that collect sensor data from all the nodes wirelessly and compute, optimal evacuation path using an enhanced algorithm. The evacuation information evaluated by coordinator node will then be linked to a dynamic exit display, which will show that lights are flashing and validate that the appropriate direction is being produced. The proposed decision model is employed to design the hardware of the exit display. Initially, sensor nodes sense the environmental values out of the deployed position and share them wirelessly to coordinator nodes. After that, the coordinator node creates a complete decision following the model as discussed earlier and activates the evacuation display.

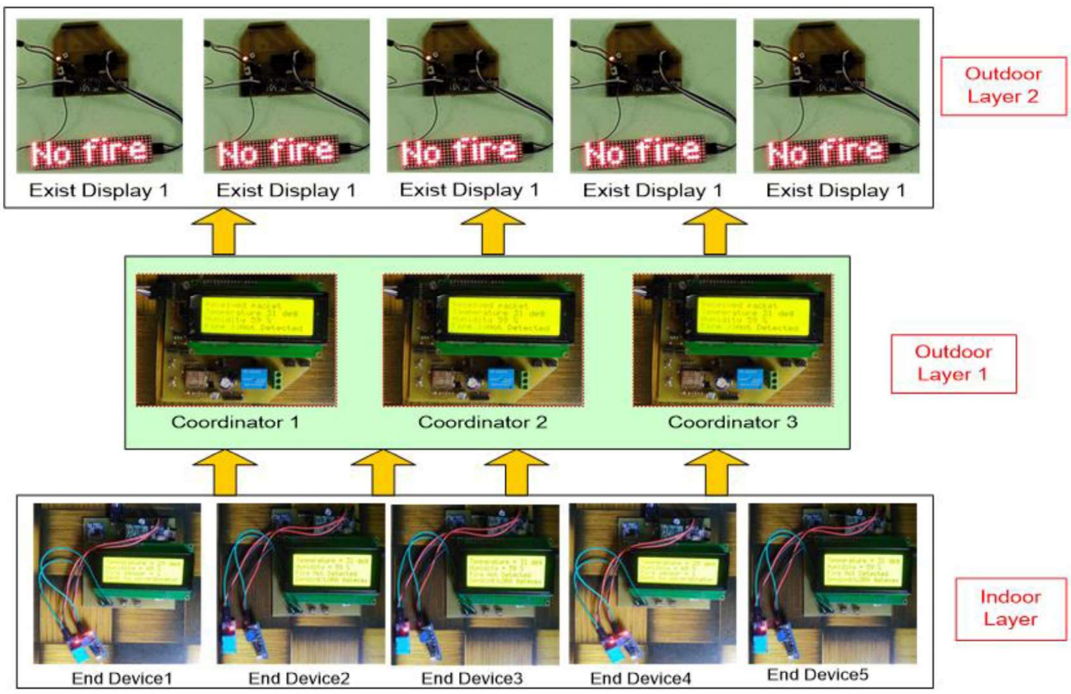


Figure 6.6 Functional Model for Evacuation display during normal condiation

In case of normal condition, end devices will not send any fire signals. Here coordinator communicates a signal to exit display module to indicate no fire message or normal direction. The working model of evacuation guidance system under no fire situation is depicted in Figure 6.6. If end device detects a fire signal, then the coordinator communicates a signal to the exit display module which will display exit path as per the decision model providing an safe and optimal exit path for evacuees. The working model of the evacuation assistance system under fire events is illustrated as shown in Figure 6.7.

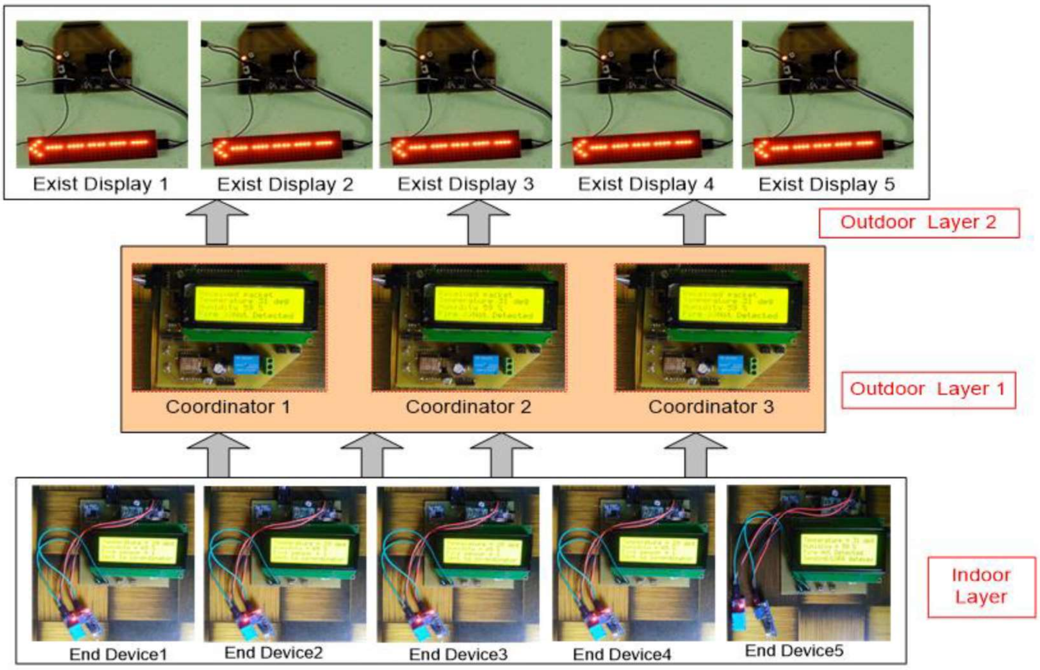


Figure 6.7 Functional Model for Evacuation display during fire emergency

During fire, the situation inside the building becomes clutter high anxiety, unfamiliar surroundings, and with low visibility, thus exit guidance signs are extremely important for evacuees to exit safely from the building. To predict safe and optimized exit path various algorithms have been proposed by existing work. Table 4.3 illustrates comparative analysis of algorithms used in existing work. This comparison is made based on parameter of consideration and findings of each.

Table 4.3 Comparative analysis of Algorithms used in Existing work

Ref.	Algorithm Used	Parameter of Consideration	Findings
[47]	Dijkstra algorithm	Shortest path prediction	• Proposed topological model to evacuate people in fire as soon as possible • It can be further extended to elevator evcuation as well as larger scale evacuation network.
[48]	ant colony algorithm	Shortest path, prediction by controlling LEDs	• Ant colony Algorithm is applied for computing shortest evacuation path to control lights with dynamic instruction • Further work can be done on redcution of coputation time and node
[50]	Detour algorithm	Shortest travel distance	• Tested with real time building and • this algorithm uses Graph data structure to find the shortest travel distance with improved Floor field model • Tested for limited exit direction
[52]	Bee Colony Optimization Algorithm	To improve total evacuation time and prediction of exit route	• Clearance and total evacuation time is reduced • Need to validate using real human experiments
Propoased	Improved Dijkstra algorithm	Safe and Optimized evacuation path	• Tested for hostel building with different cases • Validated through hardware implementation

6.3 Chapter Summary

According to existing fire protection regulations, every building should have predefined escape routes that users can use in the event of natural or man-made disasters such as fire, earthquake, etc. To address this problem, the current chapter presented decision models based on the shortest path algorithm and its implementation with customer-specific hardware devices. The shortest path algorithm is logged in the hardware and validated in real-time.

Chapter 7
Conclusions and Future Work

Technological developments are enormous in the twenty-first century, and they are being utilized to tackle some of the most crucial challenges in human civilization. Progress in the realm of fire safety and mitigation is equally noteworthy. According to the literature study, a combination of technologies such as IoT, embedded systems, wireless sensor networks, and AI can be revolutionary for early detection, fast mitigation, and rescue operations in the event of a fire break out in a variety of locations. Deployment of IoT-based smart systems can be extremely beneficial, but it remains an open research issue owing to the sensitivity of the operations, which include time constraints, harsh environments, mid-operation device failure, and life risk due to erroneous system judgments. The system to be deployed for this cause needs to be highly accurate, reliable, and fail-safe because its improper performance can lead to huge losses in human health and wealth.

In the first objective, a suitable and reliable framework is proposed for accurate identification of fire breakage, performing early mitigation procedures, and autonomously aiding in the evacuation or rescue procedures. The system architecture was proposed to be established using a merger of interconnected systems i.e., data collection device, vision node, safety operation controller, evacuation display system, coordinators, gateway, and IoT server. The system's data flow starts from the first layer being the data collection devices that are deployed to sense the environmental parameters like gas, smoke, fire, temperature and share the same using the RF module with the coordinator after formulating those into suitable and secure packets. Similarly, the vision node sends to the coordinator the information about identifying any fire breakage and the number of stranded people at the fireplace. Once the data is received by the coordinator, it analyses to extract and correlate the data trends and then use its onboard algorithms to generate a decision i.e., if a fire is detected and verified both by the data collection device and vision node, it sends wakeup command to the safety operation controller and the evacuation path display system. The wake-up command from the coordinator comprises the data about the intensity and interval for the safety operation controller to control the sprinkler and the ID and direction for the evacuation path display system to illuminate referential direction for the safe path.

In the second objective, customized design, and development of all the nodes of the system were carried out where the individual nodes were customized keeping in mind factors such as the components to be used, protocols to be enabled, etc. depending upon the node's application area, responsibility, and deployment condition. In the nodes, Atmega328p and esp8266 were used as the computing units for executing specific tasks as defined through the onboard algorithms, 2.4 GHz RF transceiver modules were used for communication between the internal nodes and the coordinator, Sx1278 LoRa transceiver module was used for the communication between coordinators and gateway, Voltage regulating and distribution circuitries were used to supply multiple voltage ranges as required along with a direct facility to power up the boards with 12v DC adapter, and liquid crystal displays were used for displaying any important information as and when needed. Additionally, the customized node's prime boot configurable pins were removed to prevent any tampering with the code. The final circuit design of the boards was made as compact and form factor efficient as possible to make it more effective for deployment in confined spaces. Along with this, the system also includes an implementation of the vision node that hosts intelligent DNN algorithms to identify fire breakage at any place and then accurately count the number of stranded people in the vicinity. This data is shared with the authorities at the gateway to planning out the rescue operations more effectively.

In the third objective, the network architecture was designed using reliable RF-based protocols for the internal communication between the individual nodes. A 2.4 GHz RF-based network was used for the communication between the internal nodes and the assigned coordinator. On the other hand, a Longe Range RF communication protocol i.e., LoRa was used for the communication between the coordinators and the gateway. Several extensive methodologies were incorporated within the system to make its communication architecture safe, secure, and fail-proof including (i) prevention of point-to-point communication amongst the internal nodes i.e., no nodes can communicate with each other autonomously. and routing all the communications through the coordinator only, that prevents unnecessary interference and any unwanted breaches into the network by an intruder. (ii) accessibility control configuration in all the nodes to control their communication with the assigned coordinators only. (iii) Multi origin AES encryption to allow explicit encryptions for all the individual communications in the system. The data received at the gateway is then logged into the cloud server using the integrated WiFi/GSM module through a secured HTTPS connection and JWT authentication.

Contextual to the advantages availed from using a hybrid RF based network architecture includes: (i) Data communication over long distances was easily achieved using the hybrid architecture, (ii) reduced recurring costs for the network mantainance, (iii) RF network is more robust to be used at such intended disaster conditions, (iv) Severe dependancies over the internet is eliminated (v) Reduced interference of internal nodes with long range data communication nodes because of the frequency deviation between them.

In the fourth objective, the design and development of the evacuation path display system were carried out where on receipt of data from the data collection and vision nodes, the coordinator uses its onboard algorithms to first analyze the sections of the building where the fire broke and then correlates it with the data comprising of the pathways available in the building. After analysis, the coordinator routes a suitable path from the building to let the stranded people get out safely. Following that, the coordinator identifies the evacuation display systems that are present in the routed path and generates a final output array comprising of the ID and direction, which is then sent to the evacuation display systems. The evacuation display systems receive the data and use their onboard algorithms to extract the direction in which they need to illuminate the led matrix. At last, the corresponding LEDs in the matrix are illuminated by the evacuation display system to direct the people stranded inside the building safely in the specific direction.

The present research work is having opportunities that can be enhanced in future work for delivering effective and reliable solutions in fire detection and building evacuation. The following are the future work of the current research, and it is as follows:

a. Robots for immediate mitigation procedures

The suggested system's efficacy can be increased by employing mobile yet sturdy robots to execute rapid mitigating operations. In the event of an extreme fire breakage in a confined space, the authorities' options for rescuing or controlling the fire breakage become quite limited. In such cases, the proposed system, through its internal nodes, can direct or command the robots to perform any desired tasks as and when needed, with much greater efficiency and less risk to human health and wealth.

b. CCTV as a Vision Node

The vision node in this study is created with a Raspberry Pi and a DNN model. It detects fire occurrences and assists in determining the number of individuals within a room during a fire. Furthermore, it provides real-time pictures to a website, where a responsible authority can accelerate rescue activities. As we all know, most buildings are now outfitted with CCTV cameras for monitoring and security purposes. Within the same budget and avoiding any critical architectural changes, we may expand our study into combining CCTV with vision node intelligence and provide more benefits to end-users.

c. Energy Harvesting

In order to fulfill the specified objectives, we employed various nodes, Coordinators, and Gateways in the current study. Rechargeable and long-lasting batteries power these components/devices. This creates a reliability concern if a certain gadget fails to work owing to a low battery during a fire. As a result, these gadgets must constantly have enough battery charge. Future research may be conducted to overcome this issue by gathering energy from nearby energy sources and making devices energy independent.

Bibliography

[1] N. N. Brushlinsky, M. Ahrens, S. V Sokolov, and P. Wagner, “World fire statistics. International Association of Fire and Rescue Services,” *Cent. Fire Stat. checked*, vol. 10, no. 8, p. 2019, 2017.

[2] “World Fire Statistics Bulletin No. 29 | Geneva Association.” .

[3] V. Kodur, P. Kumar, and M. M. Rafi, “Fire hazard in buildings: review, assessment and strategies for improving fire safety,” *PSU Res. Rev.*, vol. 4, no. 1, pp. 1–23, 2019, doi: 10.1108/prr-12-2018-0033.

[4] C. Maluk, M. Woodrow, and J. L. Torero, “The potential of integrating fire safety in modern building design,” *Fire Saf. J.*, vol. 88, pp. 104–112, 2017.

[5] A. Cowlard, A. Bittern, C. Abecassis-Empis, and J. Torero, “Fire safety design for tall buildings,” *Procedia Eng.*, vol. 62, pp. 169–181, 2013.

[6] P. Navitas, “Improving Resilience against Urban Fire Hazards through Environmental Design in Dense Urban Areas in Surabaya, Indonesia,” *Procedia - Soc. Behav. Sci.*, vol. 135, pp. 178–183, 2014, doi: 10.1016/j.sbspro.2014.07.344.

[7] M. T. Davidson, I. E. Harik, and D. B. Davis, “Fire Impact and Passive Fire Protection of Infrastructure: State of the Art,” *J. Perform. Constr. Facil.*, vol. 27, no. 2, pp. 135–143, Apr. 2013, doi: 10.1061/(ASCE)CF.1943-5509.0000295.

[8] S. Kerber, “Analysis of One and Two-Story Single Family Home Fire Dynamics and the Impact of Firefighter Horizontal Ventilation,” *Fire Technol.*, vol. 49, no. 4, pp. 857–889, 2013, doi: 10.1007/s10694-012-0294-5.

[9] E. C. Fischer, A. H. Varma, and A. Agarwal, “Performance-Based Structural Fire Engineering of Steel Building Structures: Design-Basis Compartment Fires,” *J. Struct. Eng.*, vol. 145, no. 9, p. 04019090, Jul. 2019, doi: 10.1061/(ASCE)ST.1943-541X.0002370.

[10] J. Gehandler, “The theoretical framework of fire safety design: Reflections and alternatives,” *Fire Saf. J.*, vol. 91, pp. 973–981, 2017, doi: https://doi.org/10.1016/j.firesaf.2017.03.034.

[11] E. Rangel, A. R. S. Queiroz, and M. F. De Oliveira, “The importance of

inspections on electrical installations in hazardous locations," *IEEE Trans. Ind. Appl.*, vol. 52, no. 1, pp. 589–595, 2016, doi: 10.1109/TIA.2015.2461181.

[12] J. Aronstein and D. W. Carrier, "Molded case circuit breakers -some holes in the electrical safety net," *IEEE Access*, vol. 6, pp. 10062–10068, 2018, doi: 10.1109/ACCESS.2018.2803298.

[13] U. Rüppel and K. Schatz, "Designing a BIM-based serious game for fire safety evacuation simulations," *Adv. Eng. Informatics*, vol. 25, no. 4, pp. 600–611, 2011, doi: 10.1016/j.aei.2011.08.001.

[14] M. Kobes, I. Helsloot, B. de Vries, and J. G. Post, "Building safety and human behaviour in fire: A literature review," *Fire Saf. J.*, vol. 45, no. 1, pp. 1–11, 2010, doi: https://doi.org/10.1016/j.firesaf.2009.08.005.

[15] G. L. Nelson, "Carbon monoxide and fire toxicity: A review and analysis of recent work," *Fire Technol.*, vol. 34, no. 1, pp. 39–58, 1998, doi: 10.1023/A:1015308915032.

[16] Y. Alarie, "Toxicity of Fire Smoke," *Crit. Rev. Toxicol.*, vol. 32, no. 4, pp. 259–289, Jan. 2002, doi: 10.1080/20024091064246.

[17] "NFPA - Reporter's Guide: The consequences of fire." .

[18] D. Han and B. Lee, "Flame and smoke detection method for early real-time detection of a tunnel fire," *Fire Saf. J.*, vol. 44, no. 7, pp. 951–961, 2009.

[19] H. K. Patil and T. M. Chen, "Wireless Sensor Network Security," in *Computer and Information Security Handbook*, Elsevier, 2017, pp. 317–337.

[20] S. E. Díaz, J. C. Pérez, A. C. Mateos, M.-C. Marinescu, and B. B. Guerra, "A novel methodology for the monitoring of the agricultural production process based on wireless sensor networks," *Comput. Electron. Agric.*, vol. 76, no. 2, pp. 252–265, 2011.

[21] M. Carlos-Mancilla, E. López-Mellado, and M. Siller, "Wireless sensor networks formation: Approaches and techniques," *Journal of Sensors*, vol. 2016. Hindawi Limited, 2016, doi: 10.1155/2016/2081902.

[22] M. S. Manshahia, "Wireless sensor networks: a survey," *Int. J. Sci. Eng. Res.*, vol. 7, no. 4, pp. 710–716, 2016.

[23] T. Arampatzis, J. Lygeros, and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," in *Proceedings of the 2005 IEEE*

International Symposium on, Mediterrean Conference on Control and Automation Intelligent Control, 2005., 2005, pp. 719–724.

[24] P. Lopez, D. Fernandez, A. J. Jara, and A. F. Skarmeta, "Survey of internet of things technologies for clinical environments," *Proc. - 27th Int. Conf. Adv. Inf. Netw. Appl. Work. WAINA 2013*, pp. 1349–1354, 2013, doi: 10.1109/WAINA.2013.255.

[25] G. Pottie and M. Ý. Srivastava, "INSTRUMENTING THE WORLD WITH WIRELESS SENSOR NETWORKS Department of Computer Science email : destrin , girod @ cs . ucla . edu Department of Electrical Engineering email : mbs , pottie @ ee . ucla . edu," *Electr. Eng.*

[26] C. T. Yang, S. T. Chen, C. H. Chang, W. Den, and C. C. Wu, "Implementation of an Environmental Quality and Harmful Gases Monitoring System in Cloud," *J. Med. Biol. Eng.*, vol. 39, no. 4, pp. 456–469, 2019, doi: 10.1007/s40846-018-0383-0.

[27] A. Koubaa, M. Alves, and E. Tovar, "IEEE 802.15.4: a federating communication protocol for time-sensitive wireless sensor networks," *IPP-Hurray*, no. February, 2006.

[28] R. S. Sinha, Y. Wei, and S.-H. Hwang, "A survey on LPWA technology: LoRa and NB-IoT," *Ict Express*, vol. 3, no. 1, pp. 14–21, 2017.

[29] S.-R. Moon and J.-H. Cho, "Study on IoT-based Map Inside the Building and Fire Perception System," *J. Digit. Converg.*, vol. 17, no. 1, pp. 85–90, 2019.

[30] BUREAU OF INDIAN STANDARDS (IS 2189 : 2008), *SELECTION, INSTALLATION AND MAINTENANCE OF AUTOMATIC FIRE· DETECTION AND ALARM SYSTEMCODE OF PRACTICE*. 2008.

[31] BUREAU OF INDIAN STANDARDS (IS 12456 : 2004), *FIRE PROTECTION OF ELECTRONIC DATA PROCESSING INSTALLATION — CODE OF PRACTICE*. 2004.

[32] V. Adjiski, D. Mirakovski, Z. Despodov, and S. Mijalkovski, "Simulation and optimization of evacuation routes in case of fire in underground mines," *J. Sustain. Min.*, vol. 14, no. 3, pp. 133–143, 2015, doi: 10.1016/j.jsm.2015.10.001.

[33] P. Yang, C. Li, and D. Chen, "Fire emergency evacuation simulation based on integrated fire-evacuation model with discrete design method," *Adv. Eng. Softw.*,

vol. 65, pp. 101–111, 2013, doi: 10.1016/j.advengsoft.2013.06.007.

[34] M. Seike, N. Kawabata, and M. Hasegawa, “Quantitative assessment method for road tunnel fire safety: Development of an evacuation simulation method using CFD-derived smoke behavior,” *Saf. Sci.*, vol. 94, pp. 116–127, 2017, doi: 10.1016/j.ssci.2017.01.005.

[35] J. M. Czerniak, H. Zarzycki, A. Apiecionek, W. B. Palczewski, and P. Kardasz, “A cellular automata-based simulation tool for real fire accident prevention,” *Math. Probl. Eng.*, vol. 2018, 2018, doi: 10.1155/2018/3058241.

[36] H. Bi, A. Desmet, and E. Gelenbe, “Routing emergency evacuees with cognitive packet networks,” in *Information Sciences and Systems 2013*, Springer, 2013, pp. 295–303.

[37] A. Morales, R. Alcarria, D. Martin, and T. Robles, “Enhancing evacuation plans with a situation awareness system based on end-user knowledge provision,” *Sensors (Switzerland)*, vol. 14, no. 6, pp. 11153–11178, 2014, doi: 10.3390/s140611153.

[38] Z. C. Zou, H. Leng, K. L. Wu, and W. Q. Su, “Intelligent Space for Building Fire Detection and Evacuation Decision Support,” no. Eame, pp. 365–368, 2015, doi: 10.2991/eame-15.2015.101.

[39] M. Ghazal, S. Ali, M. Al Halabi, N. Ali, and Y. Al Khalil, “Smart mobile-based emergency management and notification system,” in *2016 IEEE 4th International Conference on Future Internet of Things and Cloud Workshops (FiCloudW)*, 2016, pp. 282–287.

[40] M. H. Nguyen, T. V. Ho, and J. D. Zucker, “Integration of smoke effect and blind evacuation atrategy (SEBES) within fire evacuation simulation,” *Simul. Model. Pract. Theory*, vol. 36, pp. 44–59, 2013, doi: 10.1016/j.simpat.2013.04.001.

[41] G. Zhang, D. Huang, G. Zhu, and G. Yuan, “Probabilistic model for safe evacuation under the effect of uncertain factors in fire,” *Saf. Sci.*, vol. 93, pp. 222–229, 2017, doi: 10.1016/j.ssci.2016.12.008.

[42] Y. Lim *et al.*, “A fire detection and rescue support framework with wireless sensor networks,” in *2007 International Conference on Convergence Information Technology (ICCIT 2007)*, 2007, pp. 135–138.

[43] H. Soliman, K. Sudan, and A. Mishra, "A smart forest-fire early detection sensory system: Another approach of utilizing wireless sensor and neural networks," in *SENSORS, 2010 IEEE*, 2010, pp. 1900–1904.

[44] K. B. Deve, A. Kumar, and G. P. Hancke, "Smart fire detection system based on the IEEE 802.15. 4 standard for smart buildings," in *2014 International Conference on Network Security and Communication Engineering (NSCE 2014)*, 2015, pp. 649–652.

[45] W. Zheng and Q. Cai, "Implementation of intelligent fire evacuation route based on Internet of things," *Proc. 2015 IEEE Adv. Inf. Technol. Electron. Autom. Control Conf. IAEAC 2015*, vol. 1, pp. 934–938, 2016, doi: 10.1109/IAEAC.2015.7428693.

[46] C. Ahn, J. Kim, and S. Lee, "An Analysis of Evacuation under Fire Situation in Complex Shopping Center Using Evacuation Simulation Modeling," *Procedia - Soc. Behav. Sci.*, vol. 218, pp. 24–34, 2016, doi: 10.1016/j.sbspro.2016.04.007.

[47] J. J. Li and H. Y. Zhu, "A Risk-based Model of Evacuation Route Optimization under Fire," *Procedia Eng.*, vol. 211, pp. 365–371, 2018, doi: 10.1016/j.proeng.2017.12.024.

[48] J. Yang, M. Shi, and Z. Han, "Research Intelligent Fire Evacuation System Based on Ant Colony Algorithm and MapX," *Proc. - 2014 7th Int. Symp. Comput. Intell. Des. Isc. 2014*, vol. 2, pp. 100–103, 2015, doi: 10.1109/ISCID.2014.35.

[49] Y. Zheng, B. Jia, X. G. Li, and R. Jiang, "Evacuation dynamics considering pedestrians' movement behavior change with fire and smoke spreading," *Saf. Sci.*, vol. 92, pp. 180–189, 2017, doi: 10.1016/j.ssci.2016.10.009.

[50] J. Lee, M. Lee, and C. Jun, "Fire evacuation simulation considering the movement of pedestrian according to fire spread," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.*, vol. 42, no. 4/W9, pp. 273–281, 2018, doi: 10.5194/isprs-archives-XLII-4-W9-273-2018.

[51] Y. Zheng, B. Jia, X. G. Li, and N. Zhu, "Evacuation dynamics with fire spreading based on cellular automaton," *Phys. A Stat. Mech. its Appl.*, vol. 390, no. 18–19, pp. 3147–3156, 2011, doi: 10.1016/j.physa.2011.04.011.

[52] C. Wang, L. C. Wood, H. Li, Z. Aw, and A. Keshavarzsaleh, "Applied Artificial

Bee Colony Optimization Algorithm in Fire Evacuation Routing System," *J. Appl. Math.*, vol. 2018, 2018, doi: 10.1155/2018/7962952.

[53] C. Caliendo, P. Ciambelli, M. L. De Guglielmo, M. G. Meo, and P. Russo, "Computational analysis of fire and people evacuation for different positions of burning vehicles in a road tunnel with emergency exits," *Cogent Eng.*, vol. 5, no. 1, p. 1530834, 2018.

[54] T.-H. Chen, Y.-H. Yin, S.-F. Huang, and Y.-T. Ye, "The smoke detection for early fire-alarming system base on video processing," in *2006 international conference on intelligent information hiding and multimedia*, 2006, pp. 427–430.

[55] X. Chen and Y. Li, "Geometry-based virtual simulation for fire escape in emergency environment," in *2013 Fourth International Conference on Networking and Distributed Computing*, 2013, pp. 56–59.

[56] J. Huixian and Z. Shaoping, "Design of intelligent fire-fighting system of a big public building emergency evacuation navigation system for mobile terminal," *13th Int. Conf. Comput. Sci. Educ. ICCSE 2018*, no. Iccse, pp. 90–95, 2018, doi: 10.1109/ICCSE.2018.8468780.

[57] C.-S. Ryu, "Iot-based intelligent for fire emergency response systems," *Int. J. Smart Home*, vol. 9, no. 3, pp. 161–168, 2015.

[58] Z. Nauman, S. Iqbal, M. I. Khan, and M. Tahir, "WSN-based fire detection and escape system with multi-modal feedback," in *International Conference on Multimedia Communications, Services and Security*, 2011, pp. 251–260.

[59] F. Saeed, A. Paul, A. Rehman, W. H. Hong, and H. Seo, "IoT-Based intelligent modeling of smart home environment for fire prevention and safety," *J. Sens. Actuator Networks*, vol. 7, no. 1, 2018, doi: 10.3390/jsan7010011.

[60] P. V. K. Borges and E. Izquierdo, "A probabilistic approach for vision-based fire detection in videos," *IEEE Trans. circuits Syst. video Technol.*, vol. 20, no. 5, pp. 721–731, 2010.

[61] C.-B. Liu and N. Ahuja, "Vision based fire detection," in *Proceedings of the 17th International Conference on Pattern Recognition, 2004. ICPR 2004.*, 2004, vol. 4, pp. 134–137.

[62] Y. Guan, Z. Fang, and T. Wang, "Fire risk assessment and daily maintenance management of cultural relic buildings based on ZigBee technology," *Procedia*

Eng., vol. 211, pp. 192–198, 2018.

[63] N. Johnsaida, L. V Rahul, and T. Shalini, "IOT Based Smart Fire Emergency Response System," *2017 3rd Int. Conf. Appl. Theor. Comput. Commun. Technol.*, vol. 3, pp. 194–199, 2018.

[64] J.-S. Chou, M.-Y. Cheng, Y.-M. Hsieh, I.-T. Yang, and H.-T. Hsu, "Optimal path planning in real time for dynamic building fire rescue operations using wireless sensors and visual guidance," *Autom. Constr.*, vol. 99, pp. 1–17, 2019.

[65] Y. Chen, P. Gao, and Z. Li, "Design of Security Alarm System Based on LoRa Technology," in *International Conference on Geo-Informatics in Sustainable Ecosystem and Society*, 2018, pp. 280–288.

[66] A. Kumar, A. Singh, A. Kumar, M. K. Singh, P. Mahanta, and S. C. Mukhopadhyay, "Sensing Technologies for Monitoring Intelligent Buildings: A Review," *IEEE Sens. J.*, vol. 18, no. 12, pp. 4847–4860, 2018, doi: 10.1109/JSEN.2018.2829268.

[67] S. Gokceli, N. Zhmurov, G. K. Kurt, and B. Ors, "IoT in Action: Design and Implementation of a Building Evacuation Service," *J. Comput. Networks Commun.*, vol. 2017, 2017, doi: 10.1155/2017/8595404.

[68] A. S. Angel and R. Jayaparvathy, "Design and implementation of an intelligent emergency evacuation system," *6th Int. Conf. Comput. Power, Energy, Inf. Commun. ICCPEIC 2017*, vol. 2018-Janua, pp. 13–17, 2018, doi: 10.1109/ICCPEIC.2017.8290331.

[69] K.-M. Yu *et al.*, "Intelligent evacuation system integrated with image recognition technology," in *2015 8th International Conference on Ubi-Media Computing (UMEDIA)*, 2015, pp. 23–28.

[70] N.-E. Chung *et al.*, "An effectiveness study of an intelligent emergency evacuation system using field verification techniques," in *2017 Sixth International Conference on Future Generation Communication Technologies (FGCT)*, 2017, pp. 1–6.

[71] H. P. Hsu, K. M. Yu, S. T. Chine, S. T. Cheng, M. Y. Lei, and N. Tsai, "Emergency evacuation base on intelligent digital signage systems," *Proc. - 2014 7th Int. Conf. Ubi-Media Comput. Work. U-MEDIA 2014*, pp. 243–247, 2014, doi: 10.1109/U-MEDIA.2014.31.

[72] K. M. Yu *et al.*, "Intelligent evacuation system integrated with image recognition technology," *2015 8th Int. Conf. Ubi-Media Comput. UMEDIA 2015 - Conf. Proceeedings*, pp. 23–28, 2015, doi: 10.1109/UMEDIA.2015.7297422.

[73] D. Lee *et al.*, "Environment Adaptive Emergency Evacuation Route GUIDE through Digital Signage Systems," *Int. J. Adv. Cult. Technol.*, vol. 5, no. 1, pp. 90–97, 2017.

[74] K. Xie, Z. Liu, L. Fu, and B. Liang, "Internet of Things-based intelligent evacuation protocol in libraries," *Libr. Hi Tech*, 2019.

[75] H. M. Poy and B. Duffy, "A Cloud-Enabled Building and Fire Emergency Evacuation Application," *IEEE Cloud Comput.*, vol. 1, no. 4, pp. 40–49, 2014, doi: 10.1109/MCC.2014.67.

[76] S. Majumder, S. O'Neil, and R. Kennedy, "Smart apparatus for fire evacuation—An IoT based fire emergency monitoring and evacuation system," in *2017 IEEE MIT Undergraduate Research Technology Conference (URTC)*, 2017, pp. 1–4.

[77] Z. Han, W. Weng, Q. Zhao, X. Ma, Q. Liu, and Q. Huang, "Investigation on an integrated evacuation route planning method based on real-time data acquisition for high-rise building fire," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 2, pp. 782–795, 2013, doi: 10.1109/TITS.2012.2237398.

[78] L. Chu and S.-J. Wu, "An integrated building fire evacuation system with RFID and cloud computing," in *2011 Seventh International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 2011, pp. 17–20.

[79] S. J. Liu and G. Q. Zhu, "The application of GIS and IOT technology on building fire evacuation," *Procedia Eng.*, vol. 71, pp. 577–582, 2014, doi: 10.1016/j.proeng.2014.04.082.

[80] P. Annadata, W. Eltarjaman, and R. Thurimella, "Person detection techniques for an IoT based emergency evacuation assistance system," *ACM Int. Conf. Proceeding Ser.*, vol. 28-Novembe, pp. 77–82, 2016, doi: 10.1145/3004010.3004019.

[81] K. Katayama, H. Takahashi, S. Yokoyama, K. Gäfvert, and T. Kinoshita, "Evacuation guidance support using cooperative agent-based IoT devices," in *2017 IEEE 6th Global Conference on Consumer Electronics (GCCE)*, 2017, pp. 1–2.

[82] X. Xu, L. Zhang, S. Sotiriadis, E. Asimakopoulou, M. Li, and N. Bessis, “CLOTHO: A Large-Scale Internet of Things-Based Crowd Evacuation Planning System for Disaster Management,” *IEEE Internet Things J.*, vol. 5, no. 5, pp. 3559–3568, 2018, doi: 10.1109/JIOT.2018.2818885.

[83] L.-W. Chen and J.-J. Chung, “Mobility-aware and congestion-relieved dedicated path planning for group-based emergency guiding based on internet of things technologies,” *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 9, pp. 2453–2466, 2017.

[84] O. Khalid, M. U. S. Khan, Y. Huang, S. U. Khan, and A. Zomaya, “EvacSys: A cloud-based service for emergency evacuation,” *IEEE Cloud Comput.*, vol. 3, no. 1, pp. 60–68, 2016.

[85] N. Al-Nabhan, N. Al-Aboody, and A. B. M. A. Al Islam, “A hybrid IoT-based approach for emergency evacuation,” *Comput. Networks*, vol. 155, pp. 87–97, 2019.

[86] L.-W. Chen and J.-X. Liu, “EasyGO: A rapid indoor navigation and evacuation system using smartphones through Internet of Things technologies,” in *Proceedings of the 24th Annual International Conference on Mobile Computing and Networking*, 2018, pp. 835–837.

[87] S. Spinsante *et al.*, “A LoRa enabled building automation architecture based on MQTT,” in *2017 AEIT international annual conference*, 2017, pp. 1–5.

[88] S. Majumder, S. O’Neil, and R. Kennedy, “Smart apparatus for fire evacuation - An IoT based fire emergency monitoring and evacuation system,” *2017 IEEE MIT Undergrad. Res. Technol. Conf. URTC 2017*, vol. 2018-Janua, pp. 1–4, 2018, doi: 10.1109/URTC.2017.8284186.

[89] L. Chittaro and D. Nadalutti, “A mobile RFID-based system for supporting evacuation of buildings,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 5424 LNCS, pp. 22–31, 2009, doi: 10.1007/978-3-642-00440-7_3.

[90] N. E. Chung *et al.*, “An effectiveness study of an intelligent emergency evacuation system using field verification techniques,” *2017 6th Int. Conf. Futur. Gener. Commun. Technol. FGCT 2017*, pp. 78–83, 2017, doi: 10.1109/FGCT.2017.8103735.

[91] B. Wang, H. Li, Y. Rezgui, A. Bradley, and H. N. Ong, "BIM based virtual environment for fire emergency evacuation," *Sci. World J.*, vol. 2014, 2014, doi: 10.1155/2014/589016.

[92] L. Chu and S. J. Wu, "An integrated building fire evacuation system with RFID and cloud computing," *Proc. - 7th Int. Conf. Intell. Inf. Hiding Multimed. Signal Process. IIHMSP 2011*, pp. 17–20, 2011, doi: 10.1109/IIHMSP.2011.65.

[93] Y. C. Zhang and J. Yu, "A study on the fire IOT development strategy," *Procedia Eng.*, vol. 52, pp. 314–319, 2013, doi: 10.1016/j.proeng.2013.02.146.

[94] V. Gajjar, Y. Khandhediya, and A. Gurnani, "Human detection and tracking for video surveillance: A cognitive science approach," *Proc. - 2017 IEEE Int. Conf. Comput. Vis. Work. ICCVW 2017*, vol. 2018-Janua, pp. 2805–2809, 2017, doi: 10.1109/ICCVW.2017.330.

[95] S. S. A. Abbas, M. Anitha, and X. V. Jaini, "Realization of multiple human head detection and direction movement using Raspberry Pi," in *2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, 2017, pp. 1160–1164.

[96] T. Parthornratt, N. Burapanonte, and W. Gunjarueg, "People identification and counting system using raspberry Pi (AU-PiCC: Raspberry Pi customer counter)," in *2016 International Conference on Electronics, Information, and Communications (ICEIC)*, Jan. 2016, pp. 1–5, doi: 10.1109/ELINFOCOM.2016.7563020.

[97] C. Singh and M. Sohani, "Estimation of crowd density by counting objects," in *2017 International Conference on Trends in Electronics and Informatics (ICEI)*, 2017, pp. 235–238.

[98] T. Surasak, I. Takahiro, C. H. Cheng, C. E. Wang, and P. Y. Sheng, "Histogram of oriented gradients for human detection in video," in *Proceedings of 2018 5th International Conference on Business and Industrial Research: Smart Technology for Next Generation of Information, Engineering, Business and Social Science, ICBIR 2018*, 2018, doi: 10.1109/ICBIR.2018.8391187.

[99] M. S. Bin Bahrudin, R. A. Kassim, and N. Buniyamin, "Development of Fire alarm system using Raspberry Pi and Arduino Uno," *2013 Int. Conf. Electr. Electron. Syst. Eng. ICEESE 2013*, pp. 43–48, 2013, doi:

10.1109/ICEESE.2013.6895040.

[100] H. C. Bheemul, G. Lu, and Y. Yan, "Three-dimensional visualization and quantitative characterization of gaseous flames," *Meas. Sci. Technol.*, vol. 13, no. 10, p. 1643, 2002.

[101] Q. Jiang and Q. Wang, "Large space fire image processing of improving canny edge detector based on adaptive smoothing," in *2010 International Conference on Innovative Computing and Communication and 2010 Asia-Pacific Conference on Information Technology and Ocean Engineering*, 2010, pp. 264–267.

[102] Z. Zhang, J. Zhao, D. Zhang, C. Qu, Y. Ke, and B. Cai, "Contour based forest fire detection using FFT and wavelet," in *2008 International conference on computer science and software engineering*, 2008, vol. 1, pp. 760–763.

[103] S. Ma, Y. Zhang, J. Xin, Y. Yi, D. Liu, and H. Liu, "An early forest fire detection method based on unmanned aerial vehicle vision," in *2018 Chinese Control And Decision Conference (CCDC)*, 2018, pp. 6344–6349.

[104] C. E. Premal and S. S. Vinsley, "Image processing based forest fire detection using YCbCr colour model," in *2014 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014]*, 2014, pp. 1229–1237.

[105] V. K. Vijaylaxmi and S. C. Sajjan, "Fire Detection using YCbCr Color Model." IJSRSET, 2016.

[106] Z.-G. Liu, Y. Yang, and X.-H. Ji, "Flame detection algorithm based on a saliency detection technique and the uniform local binary pattern in the YCbCr color space," *Signal, Image Video Process.*, vol. 10, no. 2, pp. 277–284, 2016.

[107] G. Sathyakala, V. Kirthika, and B. Aishwarya, "Computer Vision Based Fire Detection with a Video Alert System," in *2018 International Conference on Communication and Signal Processing (ICCSP)*, 2018, pp. 725–727.

[108] L.-W. Kang, I.-S. Wang, K.-L. Chou, S.-Y. Chen, and C.-Y. Chang, "Image-based real-time fire detection using deep learning with data augmentation for vision-based surveillance applications," in *2019 16th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS)*, 2019, pp. 1–4.

[109] R. A. Khan, J. Uddin, S. Corraya, and J. Kim, "Machine vision based indoor fire

detection using static and dynamic features," *Int. J. Control Autom.*, vol. 11, no. 6, pp. 87–98, 2018.

[110] H. Wu, D. Wu, and J. Zhao, "An intelligent fire detection approach through cameras based on computer vision methods," *Process Saf. Environ. Prot.*, vol. 127, pp. 245–256, 2019.

[111] J. Xin and C. Huang, "Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management," *Fire Saf. J.*, vol. 62, pp. 72–78, 2013.

[112] G. Xu *et al.*, "Video smoke detection based on deep saliency network," *Fire Saf. J.*, vol. 105, pp. 277–285, 2019.

[113] G. Xu, Y. Zhang, Q. Zhang, G. Lin, and J. Wang, "Deep domain adaptation based video smoke detection using synthetic smoke images," *Fire Saf. J.*, vol. 93, pp. 53–59, 2017.

[114] M. Padmashini, R. Manjusha, and L. Parameswaran, "Vision based algorithm for people counting using deep learning," *Int. J. Eng. Technol.*, vol. 7, no. 3, pp. 74–80, 2018, doi: 10.14419/ijet.v7i3.6.14942.

[115] B. Kim and J. Lee, "A video-based fire detection using deep learning models," *Appl. Sci.*, vol. 9, no. 14, 2019, doi: 10.3390/app9142862.

[116] P. Foggia, A. Saggese, and M. Vento, "Real-Time Fire Detection for Video-Surveillance Applications Using a Combination of Experts Based on Color, Shape, and Motion," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 25, no. 9, pp. 1545–1556, 2015, doi: 10.1109/TCSVT.2015.2392531.

[117] Y. Valikhujaev, A. Abdusalomov, and Y. Im Cho, "Automatic fire and smoke detection method for surveillance systems based on dilated cnns," *Atmosphere (Basel).*, vol. 11, no. 11, pp. 1–15, 2020, doi: 10.3390/atmos11111241.