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AI-POWERED SMART BUILDING EVACUATION SYSTEM USING IOT

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ABSTRACT

Emergencies such as fires, gas leaks, and earthquakes often occur without warning and can lead to widespread panic, confusion, and casualties—especially in multi-storey or high-density buildings. During such situations, traditional static evacuation maps prove inadequate, particularly when routes are blocked or unsafe.

This paper proposes an AI-powered smart evacuation system that utilizes IoT sensors, real-time indoor data, and dynamic mapping to guide individuals during emergencies. The system is designed to detect threats such as heat, smoke, gas, or tremors using a network of smart sensors and track human movement via motion sensors or surveillance cameras. The collected data is processed using AI algorithms to generate the safest evacuation routes and display them to users through mobile applications or digital signage in the building.

Additionally, the system can send instant alerts to emergency services and building administrators. With future enhancements such as voice-assisted navigation, AR integration, and edge AI, the system aims to further reduce evacuation delays and enhance user experience. This research highlights the significance of real-time responsiveness, user empowerment, and multi-hazard adaptability in modern smart building safety frameworks.

I. INTRODUCTION

In recent years, there has been a notable increase in building-related emergencies across urban environments, including fires, toxic gas leaks, and seismic activities. Such incidents frequently result in chaos, injuries, and fatalities—especially in dense spaces like offices, shopping malls, hospitals, and educational institutions. A significant challenge during these crises is the lack of a responsive evacuation system capable of guiding people effectively in real-time.

According to the National Crime Records Bureau (NCRB), more than 7,500 fire-related deaths occurred in India during 2021 alone, primarily in residential and commercial buildings [10]. These incidents often become fatal due to delays in evacuation, unclear signage, or non-functional escape routes.

With the emergence of Internet of Things (IoT) and Artificial Intelligence (AI) technologies, there is a growing opportunity to develop intelligent, adaptive evacuation systems. Devices such as smoke detectors, gas sensors, heat sensors, and motion detectors can be deployed to monitor environmental variables in real time. These inputs can be processed by AI algorithms that assess the risk level and determine the safest escape path depending on live conditions.

Evacuation guidance can be presented to occupants through digital display boards, mobile alerts, or smart interfaces, while simultaneous notifications are sent to first responders and building authorities. In cases like earthquakes, the system can also monitor structural integrity and direct individuals away from compromised zones. The purpose of this research is to present a comprehensive system design that leverages real-time data, AI-based decision making, and smart communication to reduce panic and improve survival rates during emergencies.

II. LITERATURE REVIEW

A. IoT in Building Safety and Emergency Response

The Internet of Things (IoT) has been widely adopted for fire detection, gas leak alerts, and other building safety applications. Most current systems utilize smoke, temperature, or gas sensors to detect hazardous conditions and notify occupants through SMS alerts, buzzers, or alarms. For instance, a study by Sharma et al. [1] used NodeMCU integrated with gas sensors to detect early leakage and trigger alarms. However, such systems typically do not provide real-time evacuation assistance or incorporate dynamic pathfinding capabilities.

B. Static Evacuation Maps vs. Dynamic Routing

Conventional evacuation setups rely on static maps posted on walls, which do not adapt during emergencies when exits may be blocked by fire, smoke, or debris. Research by A. Rathi and V. Rao [2] highlighted the importance of real-time route updates using sensor-based data. Although their approach acknowledged the benefit of dynamic routing in reducing evacuation confusion, it lacked an AI-driven decision-making layer to adapt paths in real time.

C. Indoor Tracking and Crowd Management

Efforts to implement indoor tracking during emergencies have involved technologies like RFID, Bluetooth Low Energy (BLE), and Wi-Fi-based positioning systems. In a study by Kumar et al. [3], BLE tags were employed to monitor crowd flow in public buildings. Despite their utility, GPS-based solutions remain ineffective indoors due to signal degradation. Furthermore, most systems do not actively manage crowd congestion or provide alternate routing based on movement behavior.

D. AI-Based Path Optimization

Some studies have proposed using Artificial Intelligence (AI) for enhanced evacuation support. Singh and Patel [4] introduced an AI-powered fire escape model that used heat maps to guide users. However, this system was tailored for fire-specific scenarios only and did not consider multi-hazard conditions such as earthquakes or gas leaks. Additionally, the model lacked connectivity with external emergency services for wider disaster coordination.

E. Identified Gaps

Across the reviewed studies, a recurring limitation is the focus on hazard detection without offering active guidance or decision-making. Very few systems integrate IoT data collection, AI-based real-time analysis, and dynamic evacuation maps under a single framework. Moreover, most existing models are designed for a single hazard type, not multi-disaster scenarios. These gaps underline the need for a comprehensive evacuation solution that responds to various hazards in real time while enabling smart, human-aware guidance.

Understanding the Need for a Smart Building Evacuation System

3.A. What is the problem with current evacuation systems?

Most buildings still rely on static emergency maps, which are printed and placed on walls. These maps show fixed escape routes that do not change during real emergencies. In events like fire, gas leaks, or earthquakes, these maps can become ineffective. If the marked path is blocked by smoke, fire, or damaged structures, people may not know where else to go, leading to panic, bottlenecks, and potential casualties.

Additionally, current systems generally lack real-time guidance. Alarm systems can inform occupants of a danger but do not offer actionable information on which way to move. In large buildings like malls, hospitals, or corporate offices, this leads to crowding at familiar exits, causing delays and increasing the risk of injury. Thus, today's evacuation mechanisms are largely passive, non-adaptive, and not suited for complex or evolving emergencies.

C. How will the proposed system work?

1. Sensor Layer (IoT Integration)

This layer consists of **IoT-based sensors** installed at strategic locations across the building. These include:

- **Smoke and heat sensors** – detect fire
- **Gas sensors** – monitor for chemical or LPG leaks
- **Vibration sensors** – identify early tremors from earthquakes
- **Motion sensors / CCTV systems** – detect human movement and crowd patterns All these sensors collect **live environmental data** and send it to the AI-based processing unit [1].

2. Processing Layer (AI-Based Decision Engine)

This layer uses **Artificial Intelligence (AI)** to evaluate the data from sensors and generate **optimized evacuation paths**. It can:

- Detect blocked or unsafe exits
- Predict high-density zones and suggest alternate paths
- Update routes dynamically based on changing conditions

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The use of machine learning helps the system adapt over time, making it capable of handling multi-hazard conditions, such as a fire during a gas leak [2][3].

Communication Layer (User and Authority Interface)

Once a safe route is generated, the system communicates instructions through:

- **Mobile apps** connected to building networks
- **Digital displays** in hallways or rooms
- **Emergency voice broadcast systems**

Simultaneously, alerts are sent to **fire departments** and **building authorities**, ensuring a coordinated emergency response.

3.D. Where will this system be most useful?

The system is ideal for **densely populated indoor spaces**, where emergencies can lead to mass confusion. Use cases include:

- **Commercial complexes** like malls, office towers, and airports, where visitors may be unfamiliar with exit layouts [6].
- **Hospitals**, where quick, informed evacuation is essential, especially for non-ambulatory patients [7].
- **Schools and universities**, where structured evacuation is critical for young students and large campuses [8].

In such locations, **personalized and real-time guidance** can drastically reduce casualties, ease panic, and support emergency personnel.

F. Why is this research important right now?

Thousands of people die each year due to delayed evacuation in building-related disasters. As per **NCRB data**, over **7,500 deaths** occurred due to **fire incidents** in India alone during 2021, with many cases linked to **residential and commercial buildings** [11]. These statistics show a critical need for intelligent and adaptable safety systems.

This research emphasizes empowering people during emergencies through smart, timely decision-making. When users receive real-time, context-aware guidance, they can act faster and more confidently. This is especially impactful for elderly individuals, children, and people with disabilities.

By moving from passive detection to active evacuation support, the proposed system supports a future where buildings are responsive, inclusive, and life-protective, not just smart in name.

Proposed System Architecture

This section describes the functional layers and technical components of the smart evacuation system. It highlights how environmental data is collected, processed, and used to guide building occupants and support emergency teams during crises.

A. Layer 1 – Sensor Layer (Data Collection)

This is the data acquisition layer, responsible for detecting environmental hazards using IoT-enabled sensors. Devices in this layer include:

- Smoke sensors – identify signs of fire
- Gas sensors – detect leaks involving LPG, CO, or other toxic gases
- Temperature sensors – monitor overheating or sudden heat spikes
- Vibration sensors – recognize seismic activity from earthquakes
- Motion sensors / CCTV feeds – analyze human movement and crowd density

These sensors are strategically installed across corridors, exits, staircases, and high-risk zones, providing live data to the system [13].

B. Layer 2 – Processing Layer (AI Decision Engine)

This layer is the computational core of the system. It uses AI algorithms to interpret sensor data and make real-time decisions. Key functions include:

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- Threat analysis – detects fire, gas, or quake indicators
- Path optimization – identifies the most viable escape routes
- Crowd flow prediction – reroutes based on congestion levels
- Multi-hazard detection – enables system response to compound risks (e.g., gas leak during fire or tremor)

The system continuously updates path suggestions based on real-time changes, ensuring adaptability and reliability during emergencies [14].

C. Layer 3 – Communication Layer (User + Emergency Interface)

This layer manages information delivery to both building occupants and emergency authorities. It includes:

- Mobile applications – display dynamic exit maps and safety alerts
- Digital signage – visual cues for safe paths inside the building
- Voice guidance – for visually impaired users or crowded zones
- Emergency service dashboard – sends real-time alerts with maps and hazard data to responders

This ensures occupants receive timely, understandable directions, while first responders are well-informed of the building's risk profile [15].

III. ADVANTAGES AND USE CASES

This section outlines the benefits of the proposed system and illustrates practical implementation scenarios where it offers significant value.

A. Key Advantages

- Real-Time Evacuation Support – Enables safe, quick exits based on live building data
- Multi-Hazard Response – Manages fire, gas, and seismic threats through one unified system
- Dynamic Route Mapping – Continuously adjusts exit suggestions as conditions evolve
- Crowd Management – Minimizes overcrowding by recommending alternate paths
- Inclusive Safety – Supports vulnerable individuals with voice and visual aids
- Faster Emergency Response – Sends alerts and building data to rescue teams for improved coordination

B. Practical Use Cases

- Shopping Malls – Directs large crowds safely in real time during panic events
- Hospitals – Assists staff and patients with adaptive evacuation in complex buildings
- Schools & Universities – Reduces chaos and ensures orderly evacuation of students and staff
- Offices & Corporate Buildings – Promotes quick, controlled response during unexpected threats
- Residential Complexes – Enhances resident safety, especially in high-rise buildings with limited escape routes

IV. FUTURE SCOPE

The proposed system demonstrates considerable potential for future development, especially as smart infrastructure, urban digitization, and IoT capabilities continue to advance. The following technological extensions can enhance the system's efficiency and inclusivity:

- Edge Computing – Shifting AI processing closer to the sensors (i.e., at the network edge) will improve system response time and reduce reliance on external internet connectivity during critical situations [16].
- Augmented Reality (AR) – AR overlays via smart glasses or mobile apps can guide users visually through safe exit paths in real time, improving clarity during evacuation.
- Facial Recognition Integration – Enables the system to identify and track missing or vulnerable individuals, especially in schools, malls, or during large-scale evacuations.
- Voice-Activated Alerts – Allows occupants to interact with the system using voice commands for assistance, especially beneficial for differently-abled or visually impaired users.
- Data Analytics Dashboard – Aggregated data from past events can be used to train predictive evacuation models, enhance compliance reports, and simulate drills for preparedness.
- Smart City Integration – Connecting the system with broader city infrastructure will enable coordinated responses across multiple buildings or zones during regional disasters [17].

V. CONCLUSION

This research proposes a comprehensive AI-powered smart evacuation system that integrates IoT-based sensor networks with real-time decision-making algorithms. Designed for emergencies such as fires, gas leaks, and earthquakes, the system dynamically generates and communicates safe exit routes to building occupants.

Unlike conventional static systems, this solution provides personalized evacuation guidance, live monitoring, and multi-hazard adaptability, making it highly relevant in today's evolving urban spaces. It addresses a wide range of use cases, from commercial complexes to healthcare centers and educational institutions, where structured evacuation is crucial.

By offering real-time support, inclusive safety features, and automated emergency coordination, the system serves as a scalable, future-ready safety model. As technologies like edge computing, AR, and smart city frameworks evolve, this platform can further transform building safety into a proactive, life-saving solution.

Ultimately, this work supports the global vision of creating resilient, intelligent, and people-centric smart environments where technology acts swiftly to protect lives when it matters most.

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