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AI Based Fire Detection and Control System for an Indoor Positioning System

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Abstract: With the rapid advancement of the internet and the growth of the Internet of Things (IoT), buildings are becoming increasingly intelligent, utilizing advanced technological solutions for safety and efficiency. One significant application in this domain is emergency navigation through wireless sensor networks (WSNs), which can effectively respond to crises. In emergency situations, these networks play a crucial role by guiding occupants to the safest and quickest evacuation routes based on real-time threat detection. By continuously monitoring environmental conditions, sensors detect potential hazards and promptly relay evacuation instructions to prevent congestion and ensure a swift and organized response. This system is designed not only to direct people to safety but also to dynamically select the most efficient paths, mitigating the risk of crowding and enhancing the safety of occupants during emergencies.

The growing improvements in intelligent building systems, driven by advancements in AI and IoT, have opened new possibilities to make safety measures better. By using these technologies, emergency systems can now include smart tools to predict fire risks and ensure more effective safety actions. Additionally, the system's flexibility allows it to fit into different types of buildings, such as homes, offices, or factories, making it a practical solution for handling fire emergencies.

***Keywords**: Internet, IoT, Wireless Sensor Network, Emergency Navigation, Intelligent Buildings, Evacuation System.*

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I. INTRODUCTION

With the rapid advancement of technology, particularly the Internet of Things (IoT), buildings are becoming more intelligent, incorporating systems that enhance safety, security, and operational efficiency. One of the most critical applications in intelligent buildings is the use of Wireless Sensor Networks (WSNs) for emergency navigation. These networks can monitor real-time environmental conditions, detect threats, and provide dynamic evacuation instructions to guide occupants to safety during emergencies such as fires. By continuously assessing hazards and adjusting escape routes, WSNs can reduce congestion, prevent confusion, and ensure an organized, efficient response.

However, despite these advancements, traditional evacuation systems often rely on static routes and generalized instructions, which are not responsive to the constantly changing conditions of an emergency. During a recent visit to a mall, we found our-self trapped in a fire, unable to find a safe, efficient route to escape amid the confusion and chaos. The lack of real-time, personalized evacuation guidance made the situation more perilous, as the predefined routes failed to account for the rapidly changing environment and individual needs. This experience highlighted the gaps in current evacuation systems, which do not dynamically adjust to the real-time situation or consider individual factors like location, mobility, or the severity of the threat.

Motivated by this experience, we developed Smart Escape, a dynamic evacuation system that integrates mobile technology and wireless sensor networks to provide personalized, real-time escape routes based on an individual's location, physical condition, and the evolving fire conditions. Smart Escape aims to overcome the limitations of traditional evacuation systems by ensuring that every person can be guided to the safest and most efficient exit, reducing the risks associated with overcrowding and confusion. This project represents a significant step forward in emergency navigation, offering a more intelligent, responsive, and adaptive approach to evacuation in critical situations.

Adding IoT to smart buildings has brought a major change in how emergencies are handled by creating systems that react quickly to changing threats. These systems use advanced sensors and learning tools to improve safety and provide useful tips for managing buildings better. For example, they reduce false alarms, help locate threats faster, and guide people on the best way to leave the building based on the situation and their location.

II. MOTIVATION

Indoor fire incidents present significant threats to both life and property, often leading to devastating consequences if not managed swiftly and effectively. Timely and accurate fire detection is crucial for initiating emergency response systems that guide individuals safely out of hazardous areas. With advancements in AI and machine learning, we have the opportunity to significantly improve fire detection and evacuation strategies. These technologies enable the real-time analysis of various environmental factors, allowing for faster, more precise identification of fire hazards and dynamic, personalized evacuation routes. By leveraging AI’s ability to process vast amounts of data and predict patterns, we can not only detect fires more accurately but also enhance the overall safety and efficiency of evacuation efforts, minimizing risk and ensuring quicker responses in critical situations. Fires often happen quickly, giving people little time to act safely. According to reports, building fires in recent years have caused large amounts of damage and loss of life, showing the need for smarter systems. AI-powered tools can predict how fires will grow, test evacuation plans in advance, and give clear directions during an emergency. These tools make evacuations faster and safer while helping responders make better choices.

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III. SYSTEM ARCHITECTURE

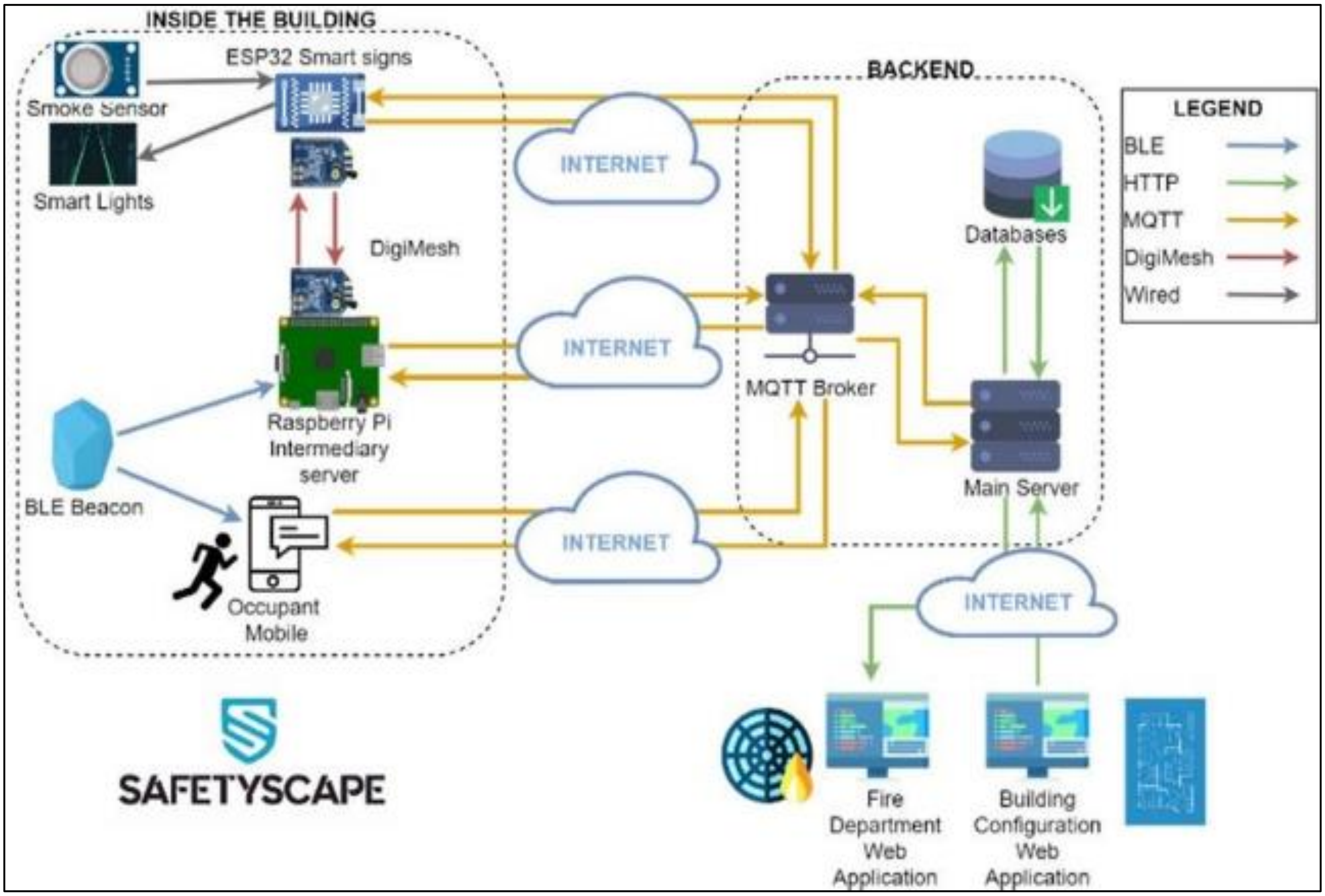

Fig 1 System Architecture

This system is built with parts that are designed to work together smoothly and reliably. Sensors like heat cameras and smoke detectors collect real-time data. This data is then processed by small computers that use AI to figure out where the fire is and suggest the safest routes. Wireless communication devices, such as Bluetooth beacons, ensure a strong connection so the system can guide people even if some parts fail. Backup power and extra safety measures are added to keep everything working during emergencies.

IV. REVIEW OF LITERATURE

“WhereArtThou: A WiFi-RTT-Based Indoor Positioning System" by Rebal Jurdi, Hao Chen, and Yuming Zhu, published in 2024, discusses an indoor positioning system that utilizes WiFi Round-Trip Time (RTT) measurements to estimate distances accurately. This approach is particularly beneficial in environments where GPS signals are ineffective, as it provides precise location information indoors by calculating distances based on RTT data.

"LEDPOS: Indoor Visible Light Positioning Based on LED as Sensor and Machine Learning"** by Christian Fragner and Christian Krutzler, also published in 2024, investigates an innovative indoor positioning system that combines visible light communication (VLC) technology with machine learning techniques. In this system, LEDs are used as sensors to determine the location of users or objects by analyzing the intensity and characteristics of the light signals. This approach offers a novel solution for indoor positioning using visible light, enhanced by machine learning for accuracy.

"Indoor Positioning System: A Review" by N. Syazwani C.J, Keng Yinn Wong, and Yichiet Aun, published in 2022, provides a comprehensive review of various indoor positioning technologies, including WiFi, Bluetooth, RFID, and VLC. The paper highlights the advantages and limitations of various technologies used in indoor positioning systems and identifies potential directions for future research in this domain, offering valuable insights into the evolving landscape of indoor navigation solutions.

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"Simulation Research on Fire Evacuation of Large Public Buildings Based on Building Information Modeling" by Fuyu Wang, Xiao Xu, and Mengkai Chen, published in 2021, explores fire evacuation strategies in large public buildings. The study utilizes Building Information Modeling (BIM) along with Fire Dynamics Simulator (FDS) software to simulate different evacuation strategies. It compares the effectiveness of various approaches, such as using only stairs versus combining stairs and fire elevators, in ensuring safe evacuation during fire emergencies in complex indoor environments.

"Development of Fire Detection Systems in Intelligent Buildings" by Z.G. Liu, J.M. Makar, and A.K. Kim, introduces a smart building fire detection system that leverages IoT sensors, machine learning models, and image processing methods. The proposed system incorporates smoke, temperature, and gas sensors for real-time monitoring and uses both supervised and unsupervised machine learning algorithms, including Support Vector Machines (SVM) and Neural Networks, to detect anomalies. Additionally, image processing methods such as edge detection and color segmentation are applied to recognize smoke and flames from a dataset containing 10,000 images of various fire scenarios. The system's performance is assessed through key metrics like LPIPS (Learned Perceptual Image Patch Similarity), FID (Fréchet Inception Distance), PSNR (Peak Signal-to-Noise Ratio), SSIM (Structural Similarity Index), and IS (Inception Score).

"Efficient and Secure IoT Based Smart Home Automation Using Multi-Model Learning and Blockchain Technology" by Nazik Alturki et al., the authors propose a smart home automation system that leverages multi-model learning, blockchain, and IoT integration. The system combines machine learning models, such as decision trees and neural networks, for predictive analytics, and uses blockchain to ensure data integrity and security. IoT devices provide real-time monitoring and control of smart home systems. Evaluated with a dataset of 5,000 smart home device records, the system's performance is measured by accuracy, latency, security metrics, and throughput.

"SMART HOME AUTOMATION SYSTEM BASED ON IoT" by Mandeep Singh et al., proposes an IoT-based automation system that integrates sensors, actuators, and internet connectivity for remote management of home devices. The system features a mobile/web interface for controlling lighting, HVAC, and security, using Wi-Fi for communication. Though no specific dataset was used, the paper discusses a general IoT setup framework. The performance metrics focus on energy efficiency, security, and control latency, with identified gaps in security, scalability, real-world testing, and interoperability among devices.

"The Security of Smart Buildings: A Systematic Literature Review"** by Pierre Ciholas et al., conducts a systematic literature review on smart building security, examining security protocols such as BACNet, KNX, and ZigBee. It categorizes research into threats, privacy issues, and defenses, while focusing on vulnerabilities introduced by IoT integration. The review covers over 90 papers and evaluates security threats, protocol resilience, and study robustness, identifying gaps in empirical testing, non-technical factors, and the need for protocol standardization.

"Enhancing Security of Smart Buildings using Internet of Things" by Zahra Alisha and Scott Gordon, proposes an agent-based IoT system for smart building security, using a multi-layered approach to manage tasks and coordinate security responses. The system operates with decentralized control, tested with simulated intrusion data. Performance metrics include response time, reliability, and flexibility. Research gaps include real-world validation, integration challenges, advanced threat detection, and scalability.

V. OPEN ISSUES

The primary goal of this thesis is to enhance the performance of object detection and tracking by contributing novel improvements to two key areas: (a) motion segmentation and (b) object tracking. Automated object tracking has many practical applications, and having an accurate, reliable tracking system is crucial for developing advanced vision-based systems. However, object tracking presents several challenges due to the unpredictable behavior of objects, variations in their movement, and the complexities involved in capturing images or video. The aim of video tracking is to maintain continuity by linking target objects across consecutive frames. This process involves identifying and tracking objects as they move independently against a stationary background. Four key scenarios are considered in this work: a single camera tracking a single object, a single camera tracking multiple objects, multiple cameras tracking a single object, and multiple cameras tracking multiple objects. As reviewed earlier, many difficulties arise in object detection, tracking, and recognition when using fixed camera networks. Therefore, the objective of this work is to create an automatic system for segmenting and tracking moving objects in videos recorded by stationary cameras. This system can provide a foundation for higher-level analysis and applications, while also improving commonly used algorithms. The final objective is to demonstrate a method for detecting and tracking moving objects based on their motion in footage from fixed cameras. Specifically, the study focuses on understanding how segmentation techniques can help identify objects and examining different tracking approaches for following one or more objects. Even with recent progress, there are still important challenges to solve. One issue is the heavy workload on the system when processing large amounts of data quickly, which can slow it down. Another problem is making sure different IoT devices work together without trouble. There are also privacy concerns, as monitoring systems collect a lot of data, raising questions about how to protect people's information. Future work should focus on creating simpler tools and setting common rules to ensure these systems are easy to use and secure.

VI. CONCLUSION

AI-Based Fire Detection and Control System for Indoor Positioning Systems enhances emergency response by integrating real-time fire detection with indoor positioning. Utilizing sensors, BLE beacons, and efficient pathfinding algorithms, the system provides users with safe, dynamic evacuation routes, minimizing exposure to hazardous areas. This solution significantly improves indoor safety, enabling quicker, more informed evacuation decisions and helping protect lives in fire emergencies.

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