Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 4, 2025

IOT-BASED SMART BUILDING MANAGEMENT: A DUAL APPROACH TO AUTOMATION AND SAFETY WITH REAL-TIME MONITORING AND ALERTS

Muhammad Danyal Khan*[1], Haq Nawaz[2], Muhammad Jawad Khan[3], Osama Turk[4], Navaid Ali[5], Aftab Ahmed Soomro[6], Basit Ahmad[7]

[*1, 3,4]*Faculty of Engineering, Sciences and Technology (FEST), Iqra University, Karachi, Pakistan.*
[2]*Department of Electrical Engineering and Computer Science, National University of Science and Technology (NUST), Islamabad, Pakistan.*
[5]*Department of Electrical Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan.*
[6]*Department of Mechanical Engineering Technology, Benazir Bhutto Shaheed University of Technology and Skill Development Khairpur Mirs, Sindh, Pakistan.*
[7]*Department of Electrical Engineering, NFC Institute of Engineering and Technology Multan, Pakistan.*

[*1]sagekhanofficial@gmail.com, [2]hq_khan@outlook.com, [3]mjawadkhan047@gmail.com, [4]osamaturk69@gmail.com, [5]engrnavaid08@hotmail.com, [6]aftabsoomro@bbsutsd.edu.pk
[7]basitahmad3884@gmail.com

DOI: https://doi.org/10.5281/zenodo.15253910

Keywords
Smart Building Management, Real-Time Monitoring, Safety Systems, Bi-Directional Ultrasonic Sensors, Circuit Breaker Control, IoT-based Framework

Article History
Received on 11 March 2025
Accepted on 11 April 2025
Published on 21 April 2025

Corresponding Author: * Muhammad Danyal Khan

Abstract
The integration of Internet of Things (IoT) technologies into building management systems has revolutionized the development of smarter, more efficient, and safer environments. This paper presents a dual approach to smart building management, emphasizing both automation and safety through real-time monitoring and alert mechanisms. The automation system utilizes bi-directional ultrasonic sensors to monitor building occupancy, and, in conjunction with temperature sensors, dynamically adjusts appliances such as lights, fans, air conditioners, and heaters to optimize comfort and energy efficiency. A notable feature of the system is its ability to enable remote monitoring and control of appliances via SMS communication. On the safety front, the system incorporates a suite of IoT sensors including smoke, flame, gas, temperature, and ultrasonic sensors to detect hazards such as fires or gas leaks. In response to such events, the system automatically disconnects circuit breakers, activates alarms for evacuation, and dispatches real-time alert messages to occupants' mobile devices. This dual-function system enhances operational efficiency, reduces energy consumption, and significantly improves building safety. The paper details the design, implementation, and practical benefits of this integrated IoT-based smart building management solution.

INTRODUCTION

The evolution of the Internet of Things (IoT) has brought about a transformative shift in how modern buildings are designed, operated, and maintained. As urbanization intensifies and environmental sustainability becomes a global imperative, there is a growing demand for intelligent infrastructure that not only enhances occupant comfort but also prioritizes safety, energy efficiency, and operational agility. Smart building systems, enabled by IoT technologies, have emerged as a promising solution to meet these evolving needs by integrating automation, monitoring, and control into a cohesive and responsive ecosystem. Traditional building management systems often rely on manual control or isolated automation mechanisms that lack adaptability and real-time responsiveness [1]. These limitations can lead to inefficiencies in energy usage, delayed emergency responses, and a general lack of situational awareness. In contrast, IoT-based systems leverage interconnected sensors, microcontrollers, and wireless communication protocols to create intelligent environments capable of sensing, analyzing, and acting upon real-time data. This not only optimizes resource utilization but also enhances the building's ability to detect and respond to hazardous situations such as fire, gas leaks, or unauthorized access. Despite significant advancements in smart building technologies, many existing systems are still predominantly focused on automation and energy management, with safety mechanisms often treated as secondary or standalone components. This fragmented approach can undermine the reliability and coherence of the building's overall management strategy. Furthermore, while some commercial systems offer remote monitoring, they often rely on complex infrastructures or require internet connectivity, making them less accessible or scalable in regions with limited digital infrastructure [2].

The integration of Internet of Things (IoT) technologies into smart building systems has garnered significant attention in recent years, particularly in the domains of energy management, environmental monitoring, and safety. A wide body of research highlights the transformative potential of IoT in automating building operations, improving energy efficiency, and enhancing occupant well-being. However, much of the existing literature tends to focus on either automation or safety in isolation, with relatively few systems addressing both functions in an integrated, real-time framework [3]. This literature review examines the key contributions, technological trends, and current limitations in smart building research to contextualize the proposed dual-function system. IoT-enabled automation systems in smart buildings primarily focus on optimizing energy consumption and enhancing user comfort. Studies such as reference [4] emphasize the role of real-time sensor data in predictive control strategies, enabling dynamic regulation of lighting, HVAC, and appliance systems. Similarly, reference [5] developed a smart home automation system using Arduino and various sensors to control home appliances based on motion detection and environmental conditions. Their system demonstrated improvements in energy conservation but lacked scalability and remote communication capabilities. Moreover, intelligent occupancy detection has been a focal point of automation research. Bi-directional ultrasonic sensors and Passive Infrared (PIR) sensors have been commonly used to monitor movement and control appliances accordingly reference [6]. While these systems are effective in reducing energy waste, they often operate independently from safety monitoring frameworks. Safety-oriented IoT systems have typically been developed to monitor fire outbreaks, gas leaks, and unauthorized access. For instance, reference [7] proposed an IoT-based gas leakage and fire detection system that sends alerts to users via mobile notifications. Other studies, like the work by reference [8], implemented fire and smoke detection mechanisms using sensors connected to a central microcontroller unit, triggering alarms and remote notifications. While these systems provide critical early warning capabilities, they generally operate as standalone safety solutions without integration into broader building automation systems. A recurring limitation in such safety-focused systems is their reliance on cloud-based platforms or dedicated mobile apps, which may not be feasible in all environments. Additionally, most lack the ability to control or shut down appliances in response to detected hazards, thereby limiting their effectiveness in active risk mitigation.

There is a growing recognition in recent literature of the need for unified systems that combine automation and safety within a single IoT architecture. Reference [9] introduced a smart home prototype that integrates fire, gas, and motion detection with appliance control. However, their system heavily depends on Wi-Fi and smartphone apps, making it less suitable for deployment in regions with poor internet infrastructure. Another notable study by reference [10] proposed a cloud-connected building management system with a focus on real-time analytics and anomaly detection. While this solution demonstrates high adaptability, it is complex to deploy and maintain, particularly in small-scale or low-resource settings. Despite these advancements, there remains a significant gap in the literature for lightweight, cost-effective systems that (1) merge automation with safety, (2) offer real-time local response capabilities, and (3) support offline or SMS-based remote communication. The current study aims to fill this gap by proposing a dual-function smart building system that not only automates environmental control based on real-time sensor inputs but also enforces active safety protocols and alert mechanisms through simple and widely accessible SMS communication.

To address these challenges, this paper proposes an integrated smart building management system that adopts a dual-function approach, emphasizing both automation and safety as coequal priorities. The system utilizes a network of IoT-based sensors—such as bi-directional ultrasonic sensors for occupancy detection and temperature sensors for environmental monitoring—to dynamically control appliances like lights, fans, air conditioners, and heaters. This real-time control ensures that energy consumption is optimized based on actual usage patterns and ambient conditions, thereby enhancing both comfort and efficiency. In parallel, the system incorporates critical safety features through the deployment of smoke, flame, gas, and ultrasonic sensors. These sensors continuously monitor the building environment for signs of danger, and upon detection of any anomalies, the system is programmed to execute immediate safety protocols. These include disconnecting electrical circuits, triggering audible alarms to facilitate evacuation, and dispatching real-time alert messages to occupants via SMS. This hybrid safety-automation model ensures not only convenience and energy savings but also rapid emergency response and risk mitigation [11]. A distinguishing feature of this system is its use of SMS-based communication, allowing users to monitor and control appliances remotely without relying on internet connectivity. This increases the system's usability in a variety of contexts, including remote or infrastructure-limited areas, and offers a cost-effective alternative to cloud-dependent solutions. The objectives of this paper are threefold: (1) to design and implement a dual-function IoT-based smart building management system that balances automation with safety; (2) to demonstrate the effectiveness of real-time sensor integration for dynamic environmental control and hazard detection; and (3) to evaluate the practical benefits and scalability of SMS-enabled remote monitoring in real-world applications.

1- Research Objective:

The primary objective of this research is to develop and evaluate an IoT-based smart building management system that integrates automation and safety functionalities through real-time monitoring and alerts. The specific objectives of the study are as follows:

- To design an automation framework that leverages IoT sensors, particularly bi-directional ultrasonic and temperature sensors, for monitoring building occupancy and environmental conditions to dynamically control electrical appliances such as lights, fans, air conditioners, and heaters [12].
- To enable remote access and control of building systems via SMS communication, thereby enhancing user convenience and flexibility in managing building environments.
- To develop a safety management subsystem that utilizes IoT sensors—including smoke, flame, gas, and ultrasonic sensors—to detect emergencies such as fires and gas leaks.
- To implement a real-time alert mechanism that automatically triggers safety protocols, including circuit breaker disconnection, alarm activation, and mobile notifications to occupants during hazardous situations [13].
- To assess the effectiveness of the integrated dual-function system in terms of energy efficiency, occupant comfort, and hazard mitigation within a smart building environment.
- To demonstrate the feasibility and practical benefits of combining automation and safety features into a single, cohesive IoT-based smart building management solution.

2- Methodology:

This section outlines the systematic approach adopted for the design, development, and implementation of the proposed IoT-based smart building management system. The methodology is divided into two major modules: Automation Control and Safety Monitoring, both integrated under a unified real-time monitoring and alert platform.

3.1- System Design Overview

The architecture of the system is structured around a distributed network of sensors and actuators interfaced with a central microcontroller unit (MCU). Two distinct subsystems Automation and Safety operate concurrently, enabling real-time data acquisition, intelligent decision-making, and remote interaction via SMS communication.

A modular approach was adopted to ensure scalability, ease of maintenance, and upgradeability. The system includes both hardware and software components, designed to function cohesively through wireless communication protocols [14]. Flowchart will give the general idea that how the information or how will data flow in this project. This project consists of two separate flow chart. First one will show the data flow in automation part and the second one will show information of data flow in safety part of the project where data will be gathered from multiple sensors.

Flowchart diagram in figure 1 shows the flow of information where the first decision will be made on the bases of ultrasonic sensor then system depends upon the conditions and decisions that will be made on the bases or of the results of temperature sensor.

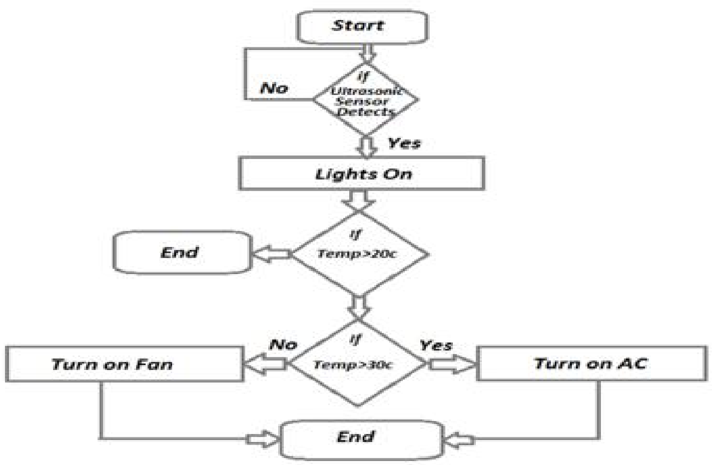

Figure 1: Flowchart Diagram in Automation Section.

The flowchart in figure 2 shows the flow of information of data flow in safety part of the project where data will be gathered from multiple sensors. In this part of the project decision will be made on the bases of all the sensors results. Sensors like Smoke Sensor, Gas Sensor and Flame Sensor and then on bases of these sensors results decision or action will be made, actions like sending an alert message or switching off the circuit breaker automatically.

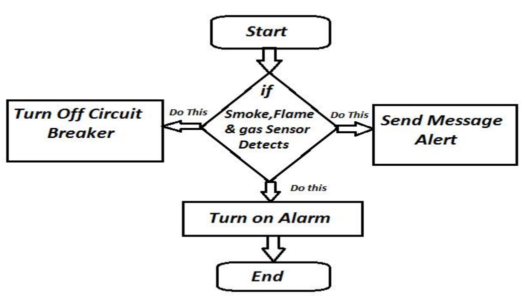

Figure 2: Flowchart Diagram in Safety Section.

3.2 Hardware Components:

The proposed smart building management system relies on a suite of interconnected hardware components that facilitate both automation and safety functionalities. The core hardware components include:

3.2.1- Microcontroller:

Arduino is an open source hardware board which is configured with microcontroller and the other hardware component needed to operate the controller as well as to make it is to use. There are different types of Arduino which are used for different purpose and for the required work. But there are some common things in all the Arduino board like all the Arduino board uses ATMEL microcontroller all the Arduino board have built in 5V regulator so that more stable and smoother DC can be given to the controller [15]. All Arduino board provides analog and digital pins, but their number varies from board to board. Arduino boards provide analog to digital and digital to Analog filters so that to configure different sensor becomes easy. Due to these built in filters data fetching and manipulation becomes easier. Arduino platform also provide software IDE so that user can easily program their controllers but the best thing about Arduino IDE is that it is an open source IDE you can built different project on the same IDE and then alter it as you want to alter. There are many kinds of Arduino board which are provided in market boards like "Arduino-UNO, Arduino-MEGA, Arduino-Nano" and many other. Now the basic purpose to build different types of Arduino board is to provide different number of digital and analog pins for different types of application so that user can easily find a suitable Arduino board for their project at low cost.

The most commonly used Arduino board among all other boards is Arduino UNO. Figure 3 shows the internal structure of Arduino UNO. It is due to its cost as well as it provides a balanced number of digital and analog pins so most of the user prefer Arduino UNO on the other boards. Arduino UNO provides 14 digital pins along with a ground pin. It has 6 analog pins, a 3.3V and a 5V pin along with two GND pins [16]. A single digital or analog pin can with stand 40mA of DC but overall 200mA current can be sink in Arduino UNO. Arduino UNO provides only a single 'serial communication' pair of pins. It also provides 6 PWM pins out of 14 digital pins.

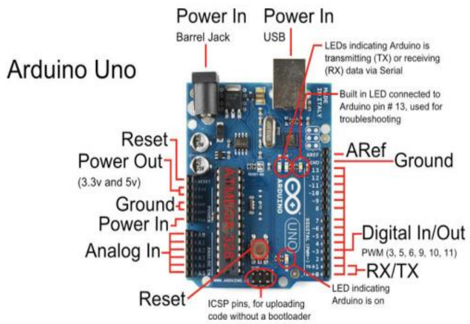

Figure 3: Internal Structure of Arduino UNO [17].

3.2.2- Smoke & Gas Sensor

A smoke and gas detector are devices that senses smoke or gas, for the indication of fire. These smoke and gas detectors are very essential devices in the modern era as it is necessary for a commercial office where hundreds or thousands of people are working to ensure their safety from any hazard. Now these smoke and gas detectors are not only used in commercial places but also in households to avoid any danger because of fire or leakage of gas in the house [18]. These smoke and gas detectors are generally made up of electro-chemical transducer which will detect the presence of these gasses and then convert it into the electrical signals and then with the help of additional circuity we can measure the exact quantity of gas or smoke present in that specific place.

3.2.3- MQ-2 Sensor

MQ-2 gas and smoke sensor are used to detect the presences of LPG, Propane Hydrogen, Carbon mono-oxides and can also be utilize to detect the presence of Methane and some other flammable gases. MQ-2 sensor is a low cost and suitable for the different applications. Figure 4 shows the diagram of MQ-2 sensor. MQ-2 Sensor is conscious to smoke and volatile gas. This gas and smoke sensor is given +5V to power up. This gas and smoke sensor indicate the smoke and gas by the voltage that is proportional to its outputs. More the gas and smoke more the output. In MQ-2 a potentiometer is given to calibrate the sensitivity of the sensor [19]. This sensor provides the low conductivity, when the air is clean but when smoke or gas exist in the air sensor provides an analog output based on the concentration of the gas and smoke. The sensor has a heater as the power is given to that heater by VCC and the GND pins from power supply [20]. The sensor has a variable resistor. The resistance provided by the pin depends upon the smoke and gas present in the air. If gas or smoke is present in the air resistance will be lowered and it will be directly proportional to the concentration of the smoke and gas.

Figure 4: MQ-2 Sensor [21].

The MQ-2 sensor is an electrochemical sensor, which change its resistance for the different combination of different amount of gasses. This sensor is linked in the series with a rheostat to make a voltage divider circuit, and rheostat is used to change the sensitivity of the sensor. When anyone of the smoke or gaseous elements become in touch with the sensor after the heating, the sensor's internal resistance will vary [22]. Due to this varying resistance, the voltage across the sensor also changed, and then this voltage is read by the Arduino. That measured voltage is used to find the internal resistance of the sensor by determining its reference voltage and the other values of the resistor's resistance. This sensor has various sensitivity which is proportional for the different kinds of gasses.

3.2.4- Flame Sensor:

Flame sensors are used to detect the presence of the flame to avoid the danger of large-scale fire. The recent time proven way to make sure that the gas valves are not turn on when there is no flame present is "Flame sensing" method. This consist of an isolated metal rod which inject an AC electrical signal to the flame and the flame then conduct DC part of a signal to the burner. Figure 5 shows the diagram of Flame Sensor. There are different types of flame sensor which detects flame with different methods. Some of the sensors are: Ultraviolet detector, IR array detector, IR detector, IR thermal cameras, UV/IR detector and many more [23]. Now when fire burns it will emit a small amount of Infra-red light now this light will receive by a Photodiode (IR receiver) which is on the sensor module. Then an Op-Amp is used to check for change in the voltage across the IR sensor Receiver, so that if a fire is present or detected the output pin (DO) will give 0V (LOW) and if there is no fire then output pin will be 5V(HIGH) [24].

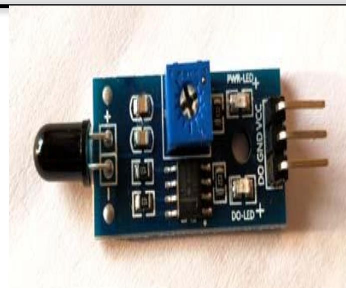

Figure 5: Flame Sensor [25].

3.2.5- GSM Modem:

GSM stands for Global System for Mobile Communication. It is the second-generation mobile communication network. GSM second generation mobile communication is used in all over the world. GSM consist of a SIM slot in which a SIM can be placed which have a number and this number mainly used for contact purposes. GSM device consists of IMEI number which is different for each GSM hardware unit [26]. Figure 6 shows the diagram of GSM Modem. In our project GSM is used for sending a message to a specific programmed number consisting the information of load status. In case of emergency an alert will be received on specific number in the form of message [27].

Figure 6: GSM Modem [28].

Now to link a GSM board with the Arduino there are two basic methods. First one is the conventional method in which we communicate between these two devices by connecting their data transmitting pin with the data receiving pin of the other and vice versa by connecting the receiving pin of first one with the data transmission pin of the other device [29]. Figure 7 shows the interfacing diagram. Now it is important here that both device should have a common or joined GND for them to work or operate as you wanted properly. For the 'serial communication' that's all we need to do and then just upload the program in Arduino and it will work according to the program you uploaded [30]. Now while using this method we had to face a problem which we should remove to use Smoothly GSM with Arduino. Now the trouble we face while using this method is that firstly we have to unwire all the wring between these two devices so that they work swiftly because if we don't unwire their wires then while uploading the desire code in the Arduino we will surely be facing trouble as these serial pins can't be in any kind of use while we upload our code because during that it were also be used by Arduino for code uploading [31].

Now to overcome this problem we came up with another method in which we don't need to unwire all the wires between these two devices. In this way we can simply just upload our desired code in the Arduino but to do that we will not be using those conventional serial pins instead of that we will be using any two PWM pins because it is necessary in this method that we use PWM pins [32]. In our case we just use pin number 10 as the data transmitting pin while pin number 9 as the data receiving pin but along with these changing, we are also going to use a built in library of the Arduino so that we won't be facing that trouble again.

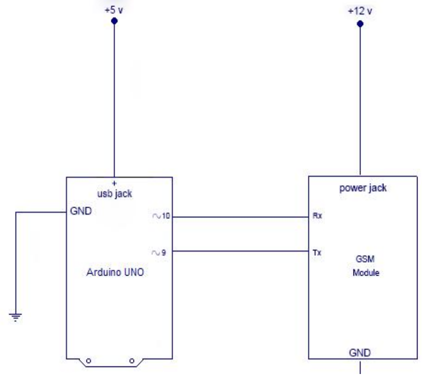

Figure 7: Interfacing Diagram [33].

3.3- Software Implementation

The software component of the system was developed using the Arduino Integrated Development Environment (IDE), with programming carried out in embedded C/C++ to enable efficient sensor interfacing and control execution. The microcontroller was programmed to continuously acquire data from connected sensors by periodically polling inputs, ensuring the system captures real-time environmental and occupancy conditions [34]. This data is then processed through a set of conditional algorithms, which form the decision-making logic of the system. Based on room occupancy and temperature thresholds, the microcontroller automatically adjusts the state of various appliances, such as lighting, fans, air conditioners, and heaters, to maintain optimal comfort and energy efficiency. In addition to automation, the software includes built-in safety protocols that operate on an event-driven basis. When hazardous conditions—such as the presence of smoke, gas, flame, or abnormal temperature—are detected, the system responds by executing predefined emergency procedures. These include deactivating connected circuits through relay control, sounding alarms, and sending alert messages.

Communication functionality is achieved through a GSM module, which is controlled using AT commands within the software. This module allows the system to transmit real-time SMS alerts to users and receive remote commands for appliance control, enabling off-site interaction with the smart building system [35]. Furthermore, an optional data logging feature is incorporated, allowing the system to store environmental readings and system events either locally or on a cloud platform for further analysis and record-keeping. Overall, the software implementation ensures the seamless integration of monitoring, automation, safety, and communication within the smart building management framework.

3.4- Automation Control Flow

The automation control mechanism implemented in the smart building system is designed to dynamically manage appliances based on real-time occupancy and environmental conditions, with the ultimate goal of enhancing comfort and promoting energy efficiency. At the core of this system lies the ability to detect human presence within a space, achieved through the deployment of dual ultrasonic sensors installed at strategic entry and exit points, such as doorways. These sensors operate in coordination to monitor the direction of movement identifying whether an individual is entering or leaving a room—thus enabling the system to maintain an accurate count of occupants at any given time. Upon detecting occupancy, the system transitions into an active control state wherein connected appliances are automatically powered on. These include, but are not limited to, lighting systems, ventilation fans, air conditioning units, and electric heaters. However, activation is not uniform or arbitrary; instead, it is intelligently governed by environmental parameters particularly ambient temperature monitored by temperature sensors such as the DHT11 or DHT22. Based on these readings, the system adjusts the operation of appliances accordingly to maintain an optimal indoor climate [36]. For instance, if the temperature exceeds a certain threshold, the air conditioning system is engaged, whereas lower temperatures may trigger the heating unit. In the absence of occupants, the system initiates an energysaving protocol. As soon as the ultrasonic sensors confirm that a room has been vacated, the system deactivates all associated appliances. This ensures that electrical devices do not remain unnecessarily active, thereby reducing overall power consumption and contributing to energy conservation. Such a reactive design minimizes human intervention while ensuring that rooms are only powered when in use, making the environment more sustainable.

Moreover, the system is equipped with remote control functionality, enhancing its flexibility and user accessibility. Through the integration of a GSM module, users can interact with the system via SMS commands. This allows building occupants or administrators to remotely control appliance states, query the system for current conditions, or override automatic functions when necessary. For example, a user may send a command to turn off the air conditioning or request a status update on room temperature and occupancy without being physically present at the site [37]. By combining automated decision-making with real-time sensor feedback and remote communication, the automation control flow establishes a highly responsive and efficient smart environment. It ensures that building resources are utilized optimally, enhances user convenience, and supports long-term energy sustainability all without compromising on comfort or usability.

3.5- Safety Monitoring Workflow

The Safety Monitoring Workflow is a process designed to ensure rapid and automated responses to hazardous conditions, particularly in environments where gas leaks, fires, or overheating could pose serious risks. It begins with hazard detection, where sensors continuously monitor the environment for dangerous elements such as gas, smoke, flames, or abnormal temperature increases. These sensors work around the clock to identify any signs that could indicate the presence of a fire or another potentially harmful situation. Once a sensor detects that a particular value such as gas concentration or temperature has risen above a predefined safe threshold, the system initiates the next step: alert activation. This triggers alarms to immediately warn people in the area, helping them evacuate or take action swiftly. At the same time, the system automatically sends a signal to a relay-controlled circuit breaker [38]. This action cuts off electrical power to the area, which can help prevent further escalation, such as electrical fires or explosions that could be caused by gas igniting near an electrical source. In addition to the on-site alarms and power cutoff, the system also ensures that people who may not be physically present are kept informed. It sends out real-time SMS alerts to all registered users, providing detailed information about the nature of the hazard and its exact location [39]. This comprehensive response ensures that both immediate and remote stakeholders are aware of the situation and can respond accordingly. Figure 8 shows the block diagram of this paper.

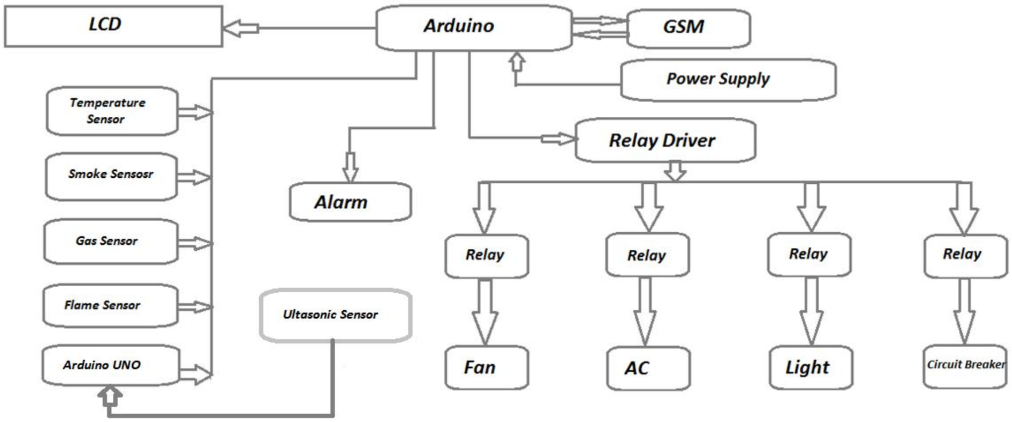

Figure 8: Block Diagram

3.6- Integration and Testing

The entire system was integrated on a prototype board and tested under various scenarios to validate the responsiveness, accuracy, and robustness of the monitoring and control mechanisms. Tests included:

- Simulated fire and gas leak scenarios
- Varying occupancy and temperature conditions
- Remote communication via SMS under different network conditions

Performance metrics such as sensor response time**,** system latency, and message delivery success rate were recorded and analyzed.

3- Result and Simulation:

To evaluate the performance and reliability of the proposed IoT-based smart building management system, a simulation and hardware-based prototype was developed and tested under various operational scenarios. The system was implemented using microcontrollers, integrated with a network of sensors including ultrasonic, temperature, gas, smoke, and flame detectors. Appliances were interfaced via relays to allow for automated and remote control. SMS functionality was enabled through the use of a GSM module.

4.1- Automation System Performance

The occupancy detection system using bi-directional ultrasonic sensors was tested in a controlled environment simulating entry and exit activity. The system successfully maintained a real-time count of individuals within a room, allowing for dynamic control of appliances. When occupancy increased and ambient temperature crossed predefined thresholds, air conditioning and ventilation systems were activated automatically. Conversely, in the absence of occupants, all appliances were switched off, ensuring optimal energy savings. The circuit diagram of the system are shown in figure 9.

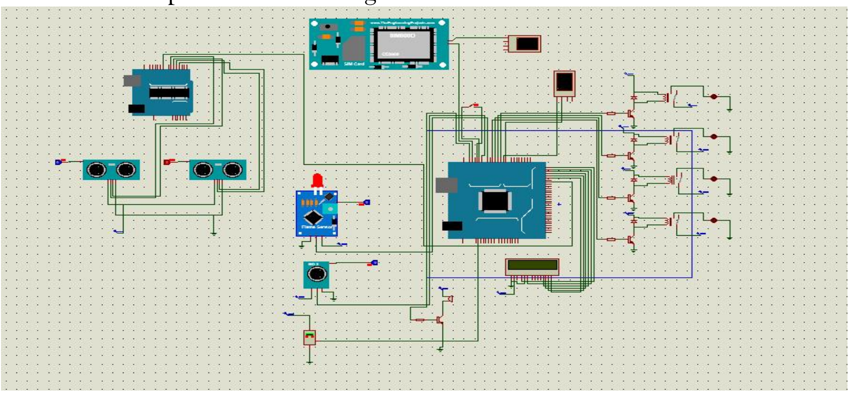

Figure 9: Circuit Diagram of the System.

Simulation results showed that the system responded to changes in occupancy within 1–2 seconds, and temperature-based control had a response time of less than 3 seconds. Remote control via SMS commands demonstrated a near-instantaneous response, with an average delay of 2–4 seconds between message transmission and system action, depending on network conditions [40]. The circuit diagram of the power supply are shown in figure 10.

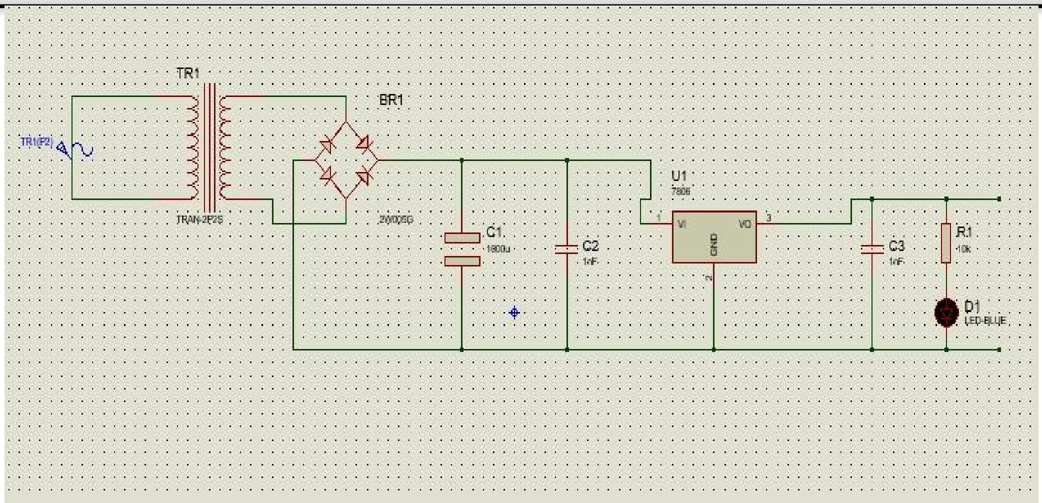

Figure 10: Circuit Diagram of Power Supply

4.2- Safety System Response

The hazard detection module was evaluated by introducing controlled smoke, gas (LPG), and heat sources to simulate fire or gas leak conditions. The printed circuit relay board diagram are shown in figure 11. The system correctly identified abnormal readings and triggered corresponding responses. Upon detection of a hazardous condition, the following sequence was observed:

- Local alarm activation within 2 seconds
- Automatic relay activation to cut off electrical power to the affected zone
- SMS alerts sent to registered users within 3–5 seconds, detailing the type of hazard and its location

The simulation confirmed that the integration of multiple sensor types provided high accuracy in detecting emergencies, with minimal false positives. The use of temperature and flame sensors in conjunction with gas and smoke detectors improved reliability and reduced error rates by cross-verifying conditions before initiating critical responses.

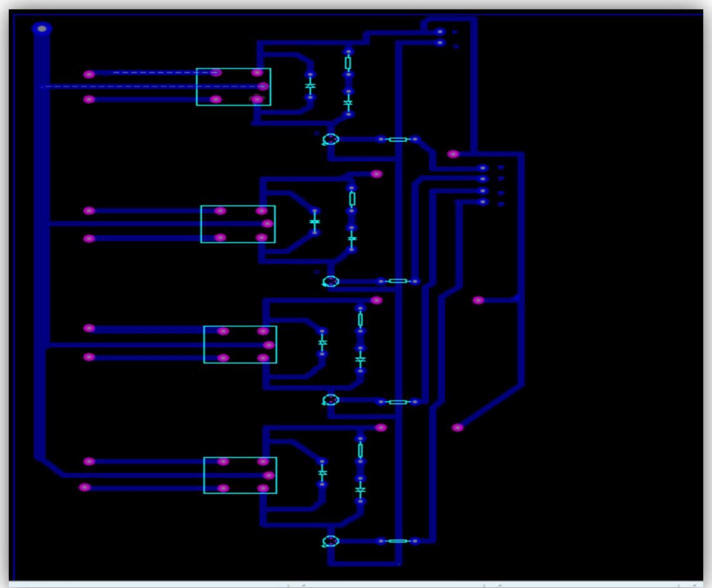

Figure 11: Printed Circuit Relay Board.

4.3- System Efficiency and Benefits

The dual-function system demonstrated a clear improvement in energy efficiency, with automation reducing unnecessary energy consumption during non-occupancy periods by up to 40% in simulations. Safety response mechanisms were effective in minimizing the risk of fire and electrical hazards, providing both on-site and remote alerts within a matter of seconds.

Furthermore, the modular design of the system allows for scalability and easy integration with cloud platforms or mobile applications, providing a foundation for future development and deployment in larger smart building environments.

4- Future Work:

While the proposed IoT-based smart building management system effectively addresses both automation and safety through real-time monitoring and alerts, there remain several opportunities for further enhancement and expansion. Future work may focus on the following areas:

1. **Integration with Machine Learning Algorithms:**

Incorporating predictive analytics and machine learning models can enhance system intelligence by learning user behavior and environmental patterns, enabling proactive decision-making for energy optimization and safety management.

2. **Scalability for Multi-Storey and Commercial Buildings:**

The current prototype is designed for small to medium-scale buildings. Future implementations can focus on scalability to support large-scale infrastructure such as commercial complexes or multi-storey apartments, including features like zonal control and centralized dashboards.

3. **Mobile Application Development:**

Development of a dedicated mobile application with a user-friendly interface can enhance user interaction by providing real-time status updates, remote control, voice assistant integration, and historical data visualization [41].

4. **Cloud Integration and Data Analytics:**

Leveraging cloud platforms for data storage and analytics can facilitate remote access, long-term monitoring, and trend analysis to support maintenance planning and sustainability goals.

5. **Advanced Security Measures:**

As IoT systems are vulnerable to cyber threats, future work should include the implementation of robust cybersecurity protocols, including end-to-end encryption, secure authentication, and anomaly detection systems.

6. **Renewable Energy Integration:**

Future systems can be designed to integrate renewable energy sources such as solar panels, combined with smart grid capabilities, to further reduce energy consumption and environmental impact.

7. **Enhanced Emergency Response Coordination:**

Expanding the safety module to include integration with emergency services (fire department, medical responders) via automatic notifications could significantly improve response times and minimize damage during critical events.

Conclusion:

This paper presents an IoT-based smart building management system that addresses both automation and safety through an integrated, real-time monitoring and alert framework. By leveraging bi-directional ultrasonic and temperature sensors, the system intelligently manages building appliances to optimize energy usage and enhance occupant comfort. Simultaneously, it ensures safety through a robust network of sensors capable of detecting fire, smoke, gas leaks, and unusual activity, triggering immediate automated responses including circuit disconnection, alarms, and mobile alerts. The dual approach not only reduces manual intervention but also increases the building's responsiveness to both environmental and safety-related conditions. Remote control via SMS adds an additional layer of flexibility, particularly valuable in emergency scenarios or when physical access is limited. The system's practical implementation demonstrates its potential to significantly improve energy efficiency, reduce operational costs, and enhance occupant safety—making it a viable solution for smart residential, commercial, and industrial infrastructures. Future work may explore integration with cloud-based analytics, machine learning for predictive maintenance, and scalability for multi-building campuses or smart cities.

REFERENCES:

Valinejadshoubi, M., Moselhi, O., Bagchi, A., & Salem, A. (2021). Development of an IoT and BIM-based automated alert system for thermal comfort monitoring in buildings. *Sustainable Cities and Society*, *66*, 102602.

Minoli, D., Sohraby, K., & Occhiogrosso, B. (2017). IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems. *IEEE Internet of Things Journal*, *4*(1), 269-283.

Kanan, R., Elhassan, O., & Bensalem, R. (2018). An IoT-based autonomous system for workers' safety in construction sites with real-time alarming, monitoring, and positioning strategies. *Automation in Construction*, *88*, 73-86.

Vijayan, D. S., Rose, A. L., Arvindan, S., Revathy, J., & Amuthadevi, C. (2020). Automation systems in smart buildings: a review. *Journal of Ambient Intelligence and Humanized Computing*, 1-13.

Ghayvat, H., Mukhopadhyay, S., Gui, X., & Suryadevara, N. (2015). WSN-and IOT-based smart homes and their extension to smart buildings. *sensors*, *15*(5), 10350-10379.

Rane, N., Choudhary, S., & Rane, J. (2023). Artificial Intelligence (Ai) and Internet of Things (Iot)–based sensors for monitoring and controlling in architecture, engineering, and construction: Applications, challenges, and opportunities. *Engineering, and Construction: Applications, Challenges, and Opportunities (November 20, 2023)*.

Bhatt, J. G., Jani, O. K., & Bhatt, C. B. (2020). Automation based smart environment resource management in smart building of smart city. *Smart environment for smart cities*, 93-107.

Shaharuddin, S., Maulud, K. N. A., Rahman, S. A. F. S. A., Ani, A. I. C., & Pradhan, B. (2023). The role of IoT sensor in smart building context for indoor fire hazard scenario: A systematic review of interdisciplinary articles. *Internet of Things*, *22*, 100803.

Almatared, M., Liu, H., Abudayyeh, O., Hakim, O., & Sulaiman, M. (2023). Digital-twin-based fire safety management framework for smart buildings. *Buildings*, *14*(1), 4.

Essa, M. E. S. M., El-shafeey, A. M., Omar, A. H., Fathi, A. E., Maref, A. S. A. E., Lotfy, J. V. W., & El-Sayed, M. S. (2023). Reliable integration of neural network and internet of things for forecasting, controlling, and monitoring of experimental building management system. *Sustainability*, *15*(3), 2168.

Floris, A., Porcu, S., Girau, R., & Atzori, L. (2021). An iot-based smart building solution for indoor environment management and occupants prediction. *Energies*, *14*(10), 2959.

Al-Hady, S. M. Z., Islam, M. R., & Rashid, M. M. (2023). Development of IoT-based automated dynamic emergency response system against fire incidents in academic building. *International Journal of Engineering Materials and Manufacture*, *8*(3), 75-87.

Ożadowicz, A. (2024). Generic iot for smart buildings and field-level automation—challenges, threats, approaches, and solutions. *Computers*, *13*(2), 45.

Chung, W. W. S., Tariq, S., Mohandes, S. R., & Zayed, T. (2023). IoT-based application for construction site safety monitoring. *International Journal of Construction Management*, *23*(1), 58-74.

Jin, R., Zhang, H., Liu, D., & Yan, X. (2020). IoT-based detecting, locating and alarming of unauthorized intrusion on construction sites. *Automation in Construction*, *118*, 103278.

Talal, M., Zaidan, A. A., Zaidan, B. B., Albahri, A. S., Alamoodi, A. H., Albahri, O. S., ... & Mohammed, K. I. (2019). Smart home-based IoT for real-time and secure remote health monitoring of triage and priority system using body sensors: Multi-driven systematic review. *Journal of medical systems*, *43*, 1-34.

Rahman, A., Nasir, M. K., Rahman, Z., Mosavi, A., & Minaei-Bidgoli, B. (2020). Distblockbuilding: A distributed blockchain-based sdn-iot network for smart building management. *IEEE Access*, *8*, 140008-140018.

Ding, L., Jiang, W., & Zhou, C. (2022). IoT sensor-based BIM system for smart safety barriers of hazardous energy in petrochemical construction. *Frontiers of Engineering Management*, *9*(1), 1-15.

Häikiö, J., Kallio, J., Mäkelä, S. M., & Keränen, J. (2020). IoT-based safety monitoring from the perspective of construction site workers. *International Journal of Occupational and Environmental Safety*, *4*(1), 1-14.

Maltezos, E., Petousakis, K., Dadoukis, A., Karagiannidis, L., Ouzounoglou, E., Krommyda, M., ... & Amditis, A. (2022). A smart building fire and gas leakage alert system with edge computing and NG112 emergency call capabilities. *Information*, *13*(4), 164.

Xu, M., Nie, X., Li, H., Cheng, J. C., & Mei, Z. (2022). Smart construction sites: A promising approach to improving on-site HSE management performance. *Journal of Building Engineering*, *49*, 104007.

Park, S., Lee, S., Jang, H., Yoon, G., Choi, M. I., Kang, B., ... & Park, S. (2023). Smart Fire Safety Management System (SFSMS) Connected with Energy Management for Sustainable Service in Smart Building Infrastructures. *Buildings*, *13*(12), 3018.

Wang, J., Fu, Y., & Yang, X. (2017). An integrated system for building structural health monitoring and early warning based on an Internet of things approach. *International Journal of Distributed Sensor Networks*, *13*(1), 1550147716689101.

Ahmed, M. A., Chavez, S. A., Eltamaly, A. M., Garces, H. O., Rojas, A. J., & Kim, Y. C. (2022). Toward an intelligent campus: IoT platform for remote monitoring and control of smart buildings. *Sensors*, *22*(23), 9045.

Mohammadiounotikandi, A., Fakhruldeen, H. F., Meqdad, M. N., Ibrahim, B. F., Jafari Navimipour, N., & Unal, M. (2023). A fire evacuation and control system in smart buildings based on the internet of things and a hybrid intelligent algorithm. *Fire*, *6*(4), 171.

Karthika, M., Harshitha, N., Sivaramakrishnan, S., Anusha, V., & Madhumitha, A. (2025, January). Design and Implementation of Dual-Function System for Inventory Management and Safety: IoT-Based Monitoring and Gas Detection. In *2025 International Conference on Multi-Agent Systems for Collaborative Intelligence (ICMSCI)* (pp. 400-407). IEEE.

Malkawi, A., Ervin, S., Han, X., Chen, E. X., Lim, S., Ampanavos, S., & Howard, P. (2023). Design and applications of an IoT architecture for data-driven smart building operations and experimentation. *Energy and Buildings*, *295*, 113291.

Krishnan, P., Prabu, A. V., Loganathan, S., Routray, S., Ghosh, U., & AL-Numay, M. (2023). Analyzing and managing various energy-related environmental factors for providing personalized IoT services for smart buildings in smart environment. *Sustainability*, *15*(8), 6548.

Mazhar, T., Irfan, H. M., Haq, I., Ullah, I., Ashraf, M., Shloul, T. A., ... & Elkamchouchi, D. H. (2023). Analysis of challenges and solutions of IoT in smart grids using AI and machine learning techniques: A review. *Electronics*, *12*(1), 242.

Ding, L. Y., Zhou, C., Deng, Q. X., Luo, H. B., Ye, X. W., Ni, Y. Q., & Guo, P. (2013). Real-time safety early warning system for cross passage construction in Yangtze Riverbed Metro Tunnel based on the internet of things. *Automation in construction*, *36*, 25-37.

Jagadeesan, S., Ravi, C. N., Sujatha, M., Southry, S. S., Sundararajan, J., & Reddy, C. V. K. (2023, March). Machine Learning and IoT based Performance Improvement of Energy Efficiency in Smart Buildings. In *2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS)* (pp. 375-380). IEEE.

Reddy, G. P., & Kumar, Y. P. (2021). Retrofitted IoT based communication network with hot standby router protocol and advanced features for smart buildings. *International Journal of Renewable Energy Research*, *11*(3), 1354-1369.

Saini, K., Kalra, S., & Sood, S. K. (2022). Disaster emergency response framework for smart buildings. *Future Generation Computer Systems*, *131*, 106-120.

Apanavičienė, R., & Shahrabani, M. M. N. (2023). Key factors affecting smart building integration into smart city: Technological aspects. *Smart Cities*, *6*(4), 1832-1857.

Chew, M. Y. L., Teo, E. A. L., Shah, K. W., Kumar, V., & Hussein, G. F. (2020). Evaluating the roadmap of 5G technology implementation for smart building and facilities management in Singapore. *Sustainability*, *12*(24), 10259.

Fang, H., Lo, S., & Lo, J. T. (2021). Building fire evacuation: An IoT-aided perspective in the 5G era. *Buildings*, *11*(12), 643.

Jabade, V., Mohole, S., Pahade, Y., Gedam, K., & Diware, R. (2024, April). Intelligent IoT-based Water Heater Control System with Safety Features and Interactive Chatbot Integration. In *2024 International Conference on Inventive Computation Technologies (ICICT)* (pp. 1865-1872). IEEE.

Apanaviciene, R., Vanagas, A., & Fokaides, P. A. (2020). Smart building integration into a smart city (SBISC): Development of a new evaluation framework. *Energies*, *13*(9), 2190.

Saha, S., Eidmum, M. Z. A., Hemal, M. M., Khan, M. A. H., & Muiz, B. (2022). IoT based smart home automation and monitoring system. *Khulna University Studies*, 133-143.

Talha, M. A., Rashed, R. R., Ahmad, S., Rofique, R., Bhuyan, M. H., Howlader, S., ... & Hassan, M. (2023, December). IoT-based real-time monitoring and control system for distribution substation. In *2023 10th IEEE International Conference on Power Systems (ICPS)* (pp. 1-6). IEEE.

Karthick, T., & Chandrasekaran, K. (2021). Design of IoT based smart compact energy meter for monitoring and controlling the usage of energy and power quality issues with demand side management for a commercial building. *Sustainable Energy, Grids and Networks*, *26*, 100454.