

## DESIGN AND IMPLEMENTATION OF A VOICE-ENABLED IOT-BASED MULTI-HAZARD DETECTION AND AUTOMATED CONTROL SYSTEM WITH VOICE PROMPT

by

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### ABSTRACT

The increasing demand for intelligent safety and automation has accelerated the adoption of the Internet of Things in smart environments. This paper presents the design and implementation of a voice-enabled IoT-based multi-hazard detection and automated control system with cloud integration. The system employs multiple sensors to monitor critical conditions, including gas leakage, fire, water intrusion, and unauthorized motion. An embedded microcontroller processes sensor data and triggers automated responses such as alarm activation, gas shut-off, load isolation, and water pumping. A voice prompt module is integrated to provide real-time auditory alerts, enhancing situational awareness and enabling hands-free interaction during emergency scenarios. The system is further connected to the ThingSpeak cloud platform for real-time data transmission, visualization, and remote monitoring. Experimental evaluation demonstrates detection accuracy exceeding 90% and response latency below 3 seconds. The proposed system provides a unified framework that integrates multi-hazard detection, automation, voice interaction, and cloud connectivity, offering improved efficiency and usability over conventional IoT-based systems. It is suitable for deployment in smart homes and safety-critical applications.

**Keywords:** Internet of Things (IoT), Multi-Hazard Detection, Smart Home Automation, Voice-Enabled Systems, Cloud-Based Monitoring.

### 1. INTRODUCTION

The rapid advancement of the Internet of Things (IoT) has significantly transformed the way physical environments are monitored, controlled, and managed. IoT enables the interconnection of heterogeneous devices through the internet,

facilitating real-time data acquisition, intelligent decision-making, and remote system control across diverse application domains such as smart homes, industrial automation, healthcare, and environmental monitoring. This paradigm shift has enhanced operational efficiency, safety, and user convenience by enabling systems to respond autonomously to dynamic environmental conditions.

In recent years, the demand for intelligent safety and automation systems has increased due to rising concerns about environmental hazards, energy efficiency, and security. Conventional safety systems are typically designed to address isolated threats such as fire detection or gas leakage monitoring. However, these systems often operate independently, lack interoperability, and provide limited user interaction capabilities. Furthermore, many traditional systems require manual operation and do not support remote monitoring, thereby reducing their effectiveness in critical situations (Gupta & Shukla, 2019; Raja & Pavithra, 2020). IoT-based smart systems have emerged as a promising solution to these limitations by integrating multiple sensing, communication, and control functionalities into a unified platform. These systems utilize a combination of sensors, microcontrollers, and cloud-based services to enable continuous monitoring and automated responses to environmental changes. For instance, IoT-enabled detection systems can identify hazardous conditions such as gas leaks, fire outbreaks, water flooding, and unauthorized intrusions, while simultaneously triggering appropriate control actions such as alarms, shutdown mechanisms, and notifications (Chen et al., 2021; Mohsin et al., 2025).

Despite these advancements, a significant gap still exists in enhancing user interaction and accessibility within IoT systems. Many existing

solutions lack intuitive interfaces that allow users to interact with the system efficiently, particularly in emergency scenarios where manual control may be impractical. The integration of voice-enabled technologies, such as text-to-speech (TTS) and speech recognition, offers a viable approach to improving usability by enabling hands-free interaction and real-time auditory feedback. Voice prompts can provide immediate alerts and guidance, thereby enhancing situational awareness and response time (Lee et al., 2021; Sayeduzzaman et al; 2024).

In addition, the incorporation of cloud-based platforms, such as ThingSpeak, has further expanded the capabilities of IoT systems by enabling remote monitoring, data visualization, and scalable storage. Cloud integration allows users to access system data and control functionalities from any location, thereby improving flexibility and responsiveness. It also supports advanced data analytics, which can be used to identify patterns, predict potential hazards, and optimize system performance over time.

This study presents the design and implementation of a voice-enabled IoT-based multi-hazard detection and automated control system with cloud integration. The proposed system integrates multiple sensors for detecting environmental hazards, including gas leakage, fire, water intrusion, and unauthorized access. It employs an embedded microcontroller platform to process sensor data and execute control actions such as activating alarms, cutting off gas supply, and managing electrical loads. Additionally, the system incorporates a voice prompt module to provide real-time auditory feedback and utilizes a cloud-based IoT platform for remote monitoring and control.

The key contribution of this work lies in the development of a comprehensive and user-centric IoT solution that combines multi-hazard detection, automated response mechanisms, voice interaction, and cloud connectivity into a single integrated system. Unlike many existing systems that focus on isolated functionalities, the proposed approach enhances system intelligence, usability, and scalability, making it suitable for smart home and safety-critical applications.

## II. LITERATURE REVIEW

### 2.1 Overview of IoT-Based Smart Detection and Control Systems

The Internet of Things has enabled the development of intelligent systems capable of sensing, processing, and responding to environmental conditions in real time. In smart home environments, IoT systems integrate sensors, embedded processors, and communication networks to provide automation, monitoring, and control functionalities. These systems have been widely applied in areas such as home security, environmental monitoring, and energy management.

Recent studies have demonstrated the effectiveness of IoT in enhancing safety and automation. For instance, Chen (2024) and Kaur et al. (2022) developed a smart home system capable of detecting hazardous conditions such as fire and gas leakage while triggering alarm responses and enabling remote control. The system improved operational efficiency and reduced manual intervention through automation. Similarly, Taiwo (2021) and Aljumah et al. (2021) proposed a cloud-based IoT home control framework that supports remote monitoring and intelligent device interaction, highlighting the importance of cloud integration in modern smart systems.

In addition, IoT-driven security systems employing sensors such as Passive Infrared (PIR) detectors have been widely studied for intrusion detection and real-time alert generation. These systems improve safety and situational awareness but are often limited in terms of user interaction and adaptability.

### 2.2 Voice-Enabled IoT Systems

To improve user interaction, researchers have incorporated voice recognition technologies into IoT systems. Voice-enabled systems allow users to control devices using natural language commands, thereby enhancing accessibility and usability.

For example, Torad et al. (2022) and Akande et al. (2022) developed a voice-controlled IoT home automation system using natural language processing (NLP), enabling users to control appliances via speech commands. The system demonstrated improved convenience and efficiency in smart home environments.

Similarly, Herlian et al. (2025) implemented a smart home system integrated with Google Nest, where voice commands were used to control lighting and surveillance systems, improving user experience and accessibility.

More recent work has explored lightweight machine learning approaches such as TinyML for voice recognition in IoT devices. Malche (2025) proposed a system that enables keyword-based voice control on resource-constrained devices, addressing challenges related to computational limitations in embedded systems. Despite these advancements, many voice-enabled IoT systems are primarily focused on device control (e.g., lighting, appliances) and do not extend to comprehensive hazard detection or automated safety response.

### 2.2.1 Multi-Hazard Detection Systems in IoT

Several studies have focused on IoT-based hazard detection systems that monitor environmental parameters such as gas concentration, temperature, humidity, and motion.

For instance, IoT-based systems have been developed for gas leak detection, fire monitoring, and intrusion detection using combinations of sensors such as MQ-series gas sensors, temperature sensors, and PIR sensors (Ali et al., 2025). These systems typically trigger alarms and notifications when abnormal conditions are detected (reddy et al., 2024)

Other research has explored integrated smart home systems capable of detecting multiple hazards simultaneously (Shah et al., 2019). However, such systems often lack advanced interaction mechanisms and are limited to basic

alert systems (e.g., buzzers or mobile notifications). Additionally, many implementations rely on isolated functionalities rather than a unified architecture that combines detection, control, and user interaction.

### 2.2.2 Cloud Integration and Remote Monitoring

Cloud platforms play a critical role in modern IoT systems by enabling data storage, visualization, and remote access. Platforms such as ThingSpeak allow real-time data streaming, analytics, and remote control of connected devices.

Studies have shown that cloud-based IoT systems enhance scalability and enable users to monitor their environments remotely (Hao et al., 2015). However, challenges such as network dependency, latency, and data security remain significant concerns in cloud-integrated systems (Herlian et al., 2025).

Furthermore, literature on smart homes highlights growing concerns regarding privacy, security, and unauthorized access, particularly in systems that transmit sensitive data over the internet (Buil-Gil et al., 2022; Zhang et al., 2025).

### 2.3 Comparative Analysis of Reviewed IoT-Based Systems

Table 1 present a comparative evaluation of existing IoT-based smart detection and control systems based on key features such as hazard detection capability, voice interaction, cloud integration, automation, and system scope

Table 1: Comparison of Existing IoT-Based Smart Detection and Control Systems

Author(s)	System Focus	Multi-Hazard Detection	Voice Interaction	Cloud Integration	Automated Control	Key Limitations
Gupta & Shukla (2019)	Smart home security system	Partial (security-focused)	✓ (Voice alerts)	✗	Partial	No cloud integration; limited hazard scope
Chen et al. (2021)	Environmental monitoring system	✓ (gas, temperature)	✓ (voice interaction)	✓	✗	Lacks automated control actions
Lee et al.	Voice-enabled	✗	✓	Partial	✓	No hazard

Author(s)	System Focus	Multi-Hazard Detection	Voice Interaction	Cloud Integration	Automated Control	Key Limitations
(2021)	smart home control					detection capability
Taiwo (2021)	IoT smart home control system	×	×	✓	✓	No voice interaction; limited safety features
Torad et al. (2022)	Voice-controlled home automation	×	✓	Partial	✓	Focuses only on appliance control
Netinant (2024)	IoT security monitoring system	Partial (intrusion detection)	×	✓	Partial	No voice interaction; limited automation
Malche (2025)	TinyML-based voice IoT system	×	✓	Partial	✓	No hazard detection; limited system integration
Herlian et al. (2025)	Smart home with voice assistant	Partial (security + lighting)	✓	✓	✓	Limited hazard detection scope
<b>Proposed System</b>	Multi-hazard detection & control	✓ (gas, fire, water, intrusion)	✓ (voice prompts)	✓ (ThingSpeak)	✓ (automated response)	— (addresses identified gaps)

### 2.4 Identified Research Gaps

Despite the significant progress in IoT-based smart systems, several critical gaps remain in the literature:

#### 1. Lack of Integrated Multi-Hazard and Voice Interaction Systems

Most existing systems focus either on: Hazard detection without user-friendly interaction, or voice control without comprehensive environmental sensing. Furthermore, very few systems effectively combine multi-hazard detection with voice-enabled feedback and control in a unified architecture.

#### 2. Limited User-Centric Design

Although voice control has been introduced in some studies, many systems still rely on mobile applications and manual interfaces. This limits usability in emergency situations where hands-free interaction is essential.

#### 3. Inadequate Automated Response Mechanisms

Many IoT systems provide alerts but lack: automated control actions (e.g., gas cut-off, load isolation) and intelligent decision-making capabilities. This reduces their effectiveness in mitigating hazards in real time.

#### 4. Fragmented System Architectures

Existing solutions are often designed as standalone subsystems (e.g., security, fire detection, or automation), rather than as fully integrated smart safety systems.

#### 5. Challenges in Resource-Constrained Environments

Advanced techniques such as AI and voice processing often require high computational resources, making them difficult to deploy on embedded systems with limited memory and processing power.

## 2.5 Contribution of the Present Study

To address these gaps, this study proposes a comprehensive IoT-based system that integrates: Multi-hazard detection (gas, fire, water, intrusion), Automated control mechanisms (alarm activation, gas cut-off, load control), Voice prompt feedback for real-time user interaction and Cloud-based monitoring and remote access.

Unlike previous works, this system combines detection, control, voice interaction, and cloud integration into a single unified framework,

thereby enhancing safety, usability, and system intelligence.

## III. MATERIALS AND METHODS

### 3.1 Materials

The design and implementation of the proposed voice-enabled IoT-based multi-hazard detection and automated control system require a combination of hardware (see Table 1) and software components (see Table 2). These materials were carefully selected to ensure system reliability, scalability, cost-effectiveness, and ease of integration.

## A. Hardware Components

Table 1: Summary of System Components and Functions

Component	Description	Function(s)
<b>Microcontroller Unit (MCU)</b>	Arduino Nano (ATmega328P)	Sensor data acquisition, signal processing, control execution, interfacing with communication and output modules
<b>Gas Sensor (MQ-2)</b>	Semiconductor gas sensor	Detects combustible gases (methane, propane, smoke)
<b>Flame Sensor (LM393)</b>	Infrared flame detection sensor	Detects presence of fire/flame
<b>Water Level Sensor</b>	Conductive/analog sensor	Detects water presence or flooding conditions
<b>Intruder Sensor (PIR/LDR)</b>	Motion/light detection sensor	Detects movement or unauthorized access
<b>Communication Module</b>	GPRS module	Enables wireless data transmission, remote monitoring, and alert notifications
<b>Cloud Platform</b>	ThingSpeak	Provides real-time data visualization, storage, and remote access
<b>Voice Module (APR9600)</b>	Voice recording/playback IC	Generates audio alerts and emergency voice prompts
<b>Relay Module</b>	Electromechanical switching device	Controls electrical loads and isolates circuits during hazards
<b>Solenoid Valve</b>	Electrically actuated valve	Automatically shuts off gas supply
<b>Buzzer/Alarm</b>	Audible alert device	Provides sound-based warning signals
<b>LED Indicators</b>	Visual indicators	Displays system status and alerts
<b>Power Supply Unit</b>	12V/2A SMPS + 7805 regulator	Provides stable 5V and 12V power to system components

## B. Software Components

Table 2: Software Components and Communication Protocol

Category	Component/Protocol	Description	Function(s)
<b>IoT Data Processing &amp; Visualization</b>	ThingSpeak	Cloud-based IoT platform	Enables real-time data logging, graphical visualization of sensor data, and remote system monitoring
<b>Communication Protocol</b>	HTTP	Application layer protocol	Facilitates data transmission between the system and cloud server
<b>Communication Protocol</b>	UART	Serial communication protocol	Enables communication between microcontroller and GPRS module
<b>Interface Protocols</b>	Digital/Analog I/O	Hardware interfacing methods	Supports sensor data acquisition and control signal transmission

## IV. METHODOLOGY

This study adopts a hardware–software co-design methodology for the development of a voice-enabled IoT-based multi-hazard detection and automated control system, integrating embedded system design, sensor interfacing, communication networking, and cloud-based analytics into a unified framework. A waterfall development model was utilized, comprising requirement analysis, system design, hardware implementation, software development, system integration, and testing/validation. This structured approach ensures system modularity, traceability, and reproducibility.

### 4.1 System Architecture

The system is structured into four layers: sensing (gas, flame, water, and motion sensors), processing (microcontroller unit), communication (GPRS module), and application (ThingSpeak cloud platform and user interface). The architecture adopts a sense–process–act–communicate paradigm, where sensor data is continuously acquired, processed, and utilized to initiate automated responses and real-time cloud updates.

### 4.2 Hardware Implementation Procedure

#### Step 1: Circuit Implementation

The hardware implementation was carried out on a Vero board/PCB with all system components interfaced to the microcontroller. The gas sensor was connected to analog input A0, while the water sensor was interfaced through analog input A1. Digital input pins D2 and D3 were used for the flame sensor and intruder detection sensor (PIR/LDR), respectively. Output control was achieved using digital pins D8–D10 for relay modules and D11 for the buzzer unit. The LCD display was interfaced via digital pins D4–D7 along with control lines (RS and EN). Communication with the GPRS module was established through UART (TX/RX) pins, and the voice module was triggered using dedicated digital output pins. Power distribution was achieved using a regulated 5V supply for the microcontroller and sensor units, while a 12V supply was provided for high-power components such as relays and solenoid valves.

#### Step 2: Power Supply Configuration

A 12V/2A switched-mode power supply (SMPS) was regulated to 5V using a 7805 voltage regulator to meet the requirements of the microcontroller and sensor units. A common ground was maintained across all components to

minimize noise and ensure stable system operation.

### 4.3 Software Development

#### A. Firmware Design

The embedded firmware was developed using the Arduino IDE and organized into modular components, including sensor acquisition, hazard detection (decision-making), control execution, communication, and voice prompt modules.

#### B. Hazard Detection Logic

Hazard detection is based on predefined threshold conditions for each sensor. A hazard is identified when the sensor output exceeds its specified threshold: gas leakage is detected when the MQ-2 analog reading surpasses a preset limit; fire is detected when the flame sensor outputs a digital HIGH signal; water intrusion is identified when the analog value exceeds a defined moisture threshold; and intrusion is detected when the motion sensor produces a HIGH signal.

#### 4.4 Mathematical Modeling of Detection

The detection mechanism is based on threshold comparison:

$$H_i = \begin{cases} 1 & \text{if } S_i \geq T_i \\ 0 & \text{if } S_i < T_i \end{cases}$$

(1)

Where,  $H_i = Hazard\ State(1 = Detected, 0 = Not\ Detected)$ ,  $S_i = Sensor\ reading$ ,  $T_i = Threshold\ Value$

#### 4.5 Control and Autonomy Strategy

Once a hazard is detected, the system executes predefined control actions in Table 3:

Table 3: Hazard Type and Control Action for the System

Hazard Type	Control Action
Gas leakage	Activate alarm + shut gas valve
Fire detection	Activate alarm + cut power supply
Water flood	Activate water pump + alarm
Intruder detection	Activate alarm + send alert

#### 4.6 Voice Prompt Implementation

The voice module (APR9600) stores pre-recorded messages. Each hazard condition triggers a corresponding voice output: “Gas leak detected”, “Fire detected”, “Intruder detected”, “Water level rising”

Digital output pins from the microcontroller activate the appropriate voice channel.

#### 4.7 Cloud Integration Procedure

The system interfaces with the ThingSpeak cloud platform via a GPRS module. The communication process involves configuring the API key, establishing a GPRS connection using AT commands, transmitting sensor data through HTTP POST requests, and updating cloud fields for real-time visualization. Data transmission is performed at fixed intervals, typically between 15 and 30 seconds.

#### 4.8 Algorithm for System Operation

**Algorithm 1:** IoT-Based Hazard Detection and Control

**BEGIN**

Initialize system components

Connect to IoT platform

**WHILE** system is ON **DO**

Read gas sensor value

Read flame sensor value

Read water sensor value

Read motion sensor value

**IF** gas detected **THEN**

Activate alarm

Shut gas valve

Play voice prompt

**ENDIF**

**IF** fire detected **THEN**

Activate alarm

Cut power supply

Play voice prompt

**ENDIF**

**IF** water detected **THEN**

Activate pump

Activate alarm

Play voice prompt

**ENDIF**

**IF** intruder detected **THEN**

Activate alarm

Play voice prompt

**ENDIF**

Send data to cloud

**ENDWHILE**  
**END**

#### 4.9 Experimental Validation

The system was evaluated under controlled conditions through simulated hazard scenarios, including gas leakage using a gas source, fire detection using a flame source, water intrusion via controlled spillage, and intrusion detection through human movement. Performance assessment was based on key metrics, including detection accuracy, response time, system reliability, and consistency of cloud data transmission.

### V. RESULT AND DISCUSSION

#### 5.1 System Testing Overview

The developed system was assessed through controlled experiments to evaluate its capability for accurate hazard detection, automated response execution, and reliable cloud communication. The evaluation considered four primary hazard scenarios: gas leakage, fire/flame detection, water/flood detection, and intrusion detection. Each scenario was replicated under controlled laboratory conditions to ensure consistency and repeatability of the results.

#### 5.2 Hazard Detection Performance

##### A. Gas Leakage Detection

The MQ-2 gas sensor was exposed to a controlled gas source to evaluate system performance. When the gas concentration exceeded the predefined threshold, the system successfully initiated multiple responses, including activation of the alarm (buzzer),

automatic shutdown of the gas valve, generation of a voice alert, and transmission of data to the cloud platform. The near-instantaneous response demonstrates the system's effectiveness in real-time hazard detection and mitigation.

##### B. Fire Detection

The flame sensor was evaluated using a controlled flame source, where it detected infrared radiation indicative of fire. Upon detection, the system activated the alarm, disconnected the electrical load via relay, triggered a voice alert, and updated the cloud platform. The results demonstrate high sensitivity and reliable performance in fire detection.

##### C. Intruder Detection

Intrusion was simulated by introducing motion within the sensor's detection range. Upon detection, the system activated the alarm, generated a voice alert, and recorded the event on the cloud platform. The system exhibited reliable performance with minimal false positives.

##### D. Water/Flood Detection

Water presence was simulated through controlled spillage within the sensing area. Upon detection, the system activated the alarm, initiated the water pump, generated a voice alert, and updated the cloud platform. The system demonstrated effective and reliable performance in detecting and mitigating water-related hazards.

#### 5.3. System Response Time Analysis

The response time of the system was measured from hazard detection to action execution in Table 4.

Table 4: System Response Time

Hazard Type	Detection Time (s)	Response Time (s)	Total Delay (s)
Gas Leakage	1.2	0.8	2.0
Fire Detection	0.9	0.7	1.6
Water Detection	1.5	1.0	2.5
Intruder Detection	0.7	0.6	1.3

The system demonstrates low latency (< 3 seconds) across all hazard scenarios, making it suitable for real time safety applications

### 5.4 System Accuracy Evaluation

The system accuracy was evaluated by comparing successful detections against total test cases in Table 5.

Table 5: Detection Accuracy

Hazard Type	Test Cases	Correct Detections	Accuracy (%)
Gas Leakage	20	19	95%
Fire Detection	20	20	100%
Water Detection	20	18	90%
Intruder Detection	20	19	95%

From Table 5, results show the following: High accuracy was achieved across all sensors, slight variation in water detection due to environmental factors and overall system reliability exceeds 90% accuracy.

### 5.5 Cloud Integration Performance

The system was integrated with the ThingSpeak cloud platform for remote monitoring. Experimental observations indicate that data was successfully transmitted at regular intervals of 15–30 seconds, enabling real-time visualization. The remote monitoring process was stable and consistent throughout the evaluation. These results demonstrate the system's capability to support remote awareness, facilitate data logging and analysis, and enhance overall scalability.

### 5.6 Voice Prompt Evaluation

The voice module was evaluated in terms of clarity and responsiveness. The results indicate that the audio alerts were clear and sufficiently audible, with response timing synchronized with hazard detection events. This functionality significantly enhanced user awareness and responsiveness during emergency situations.

### 5.7 Comparative Result

Table 6: Comparative evaluation with other systems

Feature	Existing Systems	Proposed System
Multi-hazard detection	Limited	✓ Comprehensive
Voice interaction	Partial	✓ Integrated
Automated control	Limited	✓ Full automation
Cloud integration	Partial	✓ Fully integrated

As illustrated in Table 6, the proposed system demonstrates superior integration and functionality, addressing major gaps identified in the literature.

### 5.8 Implication of the Results

The results demonstrate that the system enables real-time hazard detection and response, improves user safety and situational awareness, supports remote monitoring through IoT integration, and enhances usability via voice-

based interaction. Consequently, the system is well-suited for deployment in smart homes, industrial safety environments, and environmental monitoring applications.

### 5.9 System Limitation

Despite its effective performance, the system exhibits certain limitations, including susceptibility of sensor accuracy to environmental variations, reliance on network connectivity for cloud communication, constrained processing capability of the microcontroller, and considerations related to power consumption.

## VI. CONCLUSION

This study presented the design and implementation of a voice-enabled IoT-based multi-hazard detection and automated control system with integrated cloud functionality. The proposed system combines multi-sensor data acquisition, embedded processing, automated actuation, voice-based feedback, and cloud-enabled monitoring within a unified architecture. Experimental evaluation indicates that the system achieves detection accuracy exceeding 90% with response latency below 3 seconds, enabling efficient real-time mitigation of hazards such as gas leakage, fire, water intrusion, and unauthorized access. Automated control operations, including gas shut-off, alarm activation, and load isolation, were performed reliably without manual intervention. Integration with ThingSpeak facilitates real-time data transmission, remote monitoring, and scalability, while the voice prompt module improves situational awareness through immediate auditory notifications. Compared to conventional systems, the proposed approach offers a more comprehensive and efficient solution by integrating multi-hazard detection, automation, voice interaction, and cloud connectivity. Although certain limitations exist, particularly in sensor sensitivity and network dependence, the system demonstrates strong applicability for deployment in smart homes and safety-critical environments.

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