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SMS-Based Remote Monitoring and Alarm System for Flame and Gas Leak Detection: A Low-Cost Embedded Approach Using Arduino and GSM Technology

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SMS-Based Remote Monitoring and Alarm System for Flame and Gas Leak Detection: A Low-Cost Embedded Approach Using Arduino and GSM Technology

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Abstract

Domestic and industrial accidents involving gas leaks and fires continue to be significant causes of fatalities worldwide, especially in low- and middle-income countries where affordable safety infrastructure is scarce. Existing commercial alarm systems either lack remote notification capability or rely on internet connectivity, rendering them unusable in areas without broadband access. This paper presents the design, implementation, and experimental evaluation of a low-cost SMS-based remote monitoring and control system for flame and gas leak detection. The system uses an Arduino ATmega328P microcontroller interfaced with a SIM800L GSM/GPRS module and digital flame and gas sensors. A bidirectional SMS communication protocol enables real-time alerts for hazardous events and remote actuation of up to seven relay-controlled output devices. Experimental results demonstrate an average SMS delivery latency of 4.2 s (SD = 1.8 s), 100% alert reliability over 200 test cycles, and a command execution success rate of 98.5% across 300 attempts. Additionally, the system is compared with WiFi-based solutions, demonstrating superiority in scenarios where internet infrastructure is absent or unstable, owing to its use of the 3G/GSM cellular network. The total system cost is approximately R$ 180.00 (USD $ 35), making it an accessible solution for residential and small-scale industrial applications in developing regions.

Keywords:
GSM; SMS; Arduino; flame detection; gas leak detection; remote monitoring; embedded systems; SIM800L; 3G alarm; low-cost IoT

1 Introduction

Domestic and industrial accidents involving gas leaks and fires represent a significant cause of fatalities and property damage worldwide. According to the World Health Organization, more than 180,000 annual deaths are attributable to fire-related injuries, with a disproportionate impact on low- and middle-income countries [World Health Organization(2023)]. Liquefied petroleum gas (LPG) leaks, in particular, pose severe explosion and asphyxiation risks in residential kitchens, industrial facilities, and storage environments.

The proliferation of cellular communication networks, even in remote areas, has created new opportunities for low-cost remote monitoring solutions. GSM networks cover more than 90% of the world population, providing a ubiquitous communication infrastructure that can be leveraged for Internet of Things (IoT) and machine-to-machine (M2M) applications [GSMA(2024)]. The Short Message Service (SMS), despite being a relatively older technology, offers several advantages for alarm systems: it does not require internet connectivity, operates over existing cellular infrastructure, and provides store-and-forward delivery guarantees that ensure message arrival even when the destination device is temporarily unreachable.

Existing commercial gas and fire alarm systems range from simple audible alarms costing under R$ 100.00 to integrated smart home systems exceeding R$ 1,000.00. However, most affordable systems lack remote notification capability, while internet-dependent smart systems are unusable in areas without broadband connectivity [Alamleh et al.(2025)]. This gap represents a critical limitation, particularly for communities in developing regions where both internet infrastructure and access to expensive commercial security systems are limited.

This work addresses these gaps by presenting a complete SMS-based alarm system that offers:

- Real-time SMS alerts upon flame or gas detection, with automatic retransmission every 3 minutes while the danger persists.
- Bidirectional remote control via a structured SMS command protocol, supporting output actuation (SET), pulse generation (PULSE), broadcast messages (SSMS), and conditional rule configuration (GET).
- Non-volatile storage of up to 3 phone numbers and 20 conditional logic rules in EEPROM.
- Total hardware cost of approximately R$ 180.00 (USD $ 35).
- Complete internet independence, using only the 3G/GSM cellular network for communication.
- Remote programming capability via SMS, allowing system configuration without physical access to the hardware.
- Integration of a locally programmable sound system via SMS for alarm annunciation upon anomaly detection.

The remainder of this paper is organized as follows. Section 2 reviews related work on GSM-based alarm systems and IoT gas detection. Section 3 describes the system architecture and hardware design. Section 4 details the firmware implementation and SMS communication protocol. Section 5 presents experimental results and performance evaluation. Section 6 discusses the results in the context of existing literature and presents quantitative comparisons with WiFi-based systems. Section 7 concludes the paper and outlines directions for future work.

2 Related Work

Several studies have explored GSM-based gas leak detection and fire alarm systems. This section reviews the most relevant contributions and identifies the gaps that motivate the present work.

2.1 IoT Gas Detection Systems

Babu et al. [Babu et al.(2024)] proposed an IoT gas leak detection system using MQ2 sensors and NodeMCU, achieving cloud-based real-time monitoring with automated alert mechanisms. Their approach uses WiFi connectivity to transmit sensor data to a cloud platform, enabling remote visualization and historical data analysis. However, their system requires continuous WiFi connectivity, limiting deployment to areas with stable internet access. The present work uses GSM/SMS communication, which operates independently of internet infrastructure and covers regions where WiFi is unavailable.

Yang et al. [Yang et al.(2021)] presented a case study on IoT technologies for gas leak detection, using an Arduino-based gas detector that communicates over the internet using cellular networks. The work highlights that using cellular networks helps alleviate problems with WiFi and ethernet failure, such as power loss in natural disasters, corroborating the approach of the present work.

2.2 IoT-Enabled Fire Safety Systems

A comprehensive bibliometric analysis conducted by Alamleh et al. [Alamleh et al.(2025)] reviewed IoT-enabled fire safety systems, identifying key research trends in sensor integration, network architectures, and emerging technologies. The study highlighted that SMS-based alert systems remain underexplored compared to IP-based solutions, despite their advantages in universal cellular coverage. The authors called for more research into low-cost, internet-independent monitoring solutions, which the present work directly addresses.

2.3 GSM-Based Gas and Fire Detection

Munirathinam et al. [Munirathinam et al.(2023)] developed a GSM-based gas leak detection system using Arduino and MQ2 sensors, demonstrating SMS notification capabilities for LPG detection. The system achieved response times under 10 seconds but lacked bidirectional control and conditional logic for automated actuation.

Ab Aziz et al. [Ab Aziz et al.(2022)] presented an Arduino-based smoke alarm and gas sensor system with a GSM module, using an MQ2 sensor and a flame sensor. The system sends SMS and makes calls to the user when smoke or fire is detected. However, the system does not support bidirectional remote control or conditional rule configuration.

Kodali and Soru [Kodali et al.(2018)] implemented an IoT gas leak detection and alert system using Arduino and ESP8266, achieving real-time notifications through local alarms and cloud-based alerts.

However, their system depends on WiFi connectivity and does not support bidirectional SMS-based control.

Lopez et al. [Lopez et al.(2025)] proposed a real-time IoT smoke and gas detection system using ESP8266 and MQ2 sensor, with notifications sent through the Blynk platform. The system relies entirely on WiFi connectivity and cloud platform, making it inoperable during internet outages.

2.4 Comparative Analysis

The present work advances beyond the aforementioned contributions by integrating: (i) bidirectional SMS communication with a comprehensive command set, (ii) conditional logic rules enabling autonomous responses to sensor states without user intervention, (iii) pulse generation capability for intermittent actuation (e.g., pulsing siren), (iv) persistent EEPROM storage for configuration across power cycles, (v) complete internet infrastructure independence, and (vi) remote programming via SMS.

Table 1 provides a comparative summary of existing systems and the proposed approach.

System	Comm.	Bidir.	Cond.	Pulse	EEPROM	Local S.
Babu et al. [Babu et al.(2024)]	WiFi	No	No	No	No	No
Munirathinam et al. [Munirathinam et al.(2023)]	GSM/SMS	No	No	No	No	No
Ab Aziz et al. [Ab Aziz et al.(2022)]	GSM/SMS	No	No	No	No	Yes
Kodali et al. [Kodali et al.(2018)]	WiFi	Partial	No	No	No	Yes
Lopez et al. [Lopez et al.(2025)]	WiFi	Partial	No	No	No	Yes
Yang et al. [Yang et al.(2021)]	Cellular	No	No	No	No	No
Proposed	**GSM/3G**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Table 1: Comparative analysis of related work. The proposed system is the only one to combine bidirectional SMS control, conditional logic, pulse generation, EEPROM persistence, and programmable local sound system support.

3 System Architecture and Hardware Design

3.1 System Overview

Figure 1 presents the system architecture, comprising four main subsystems: sensor inputs, microcontroller control unit, GSM communication module, and output actuators. The Arduino ATmega328P serves as the central processing unit, polling sensor states, evaluating conditional rules, processing incoming SMS commands, and driving relay outputs in a unified event-driven loop.

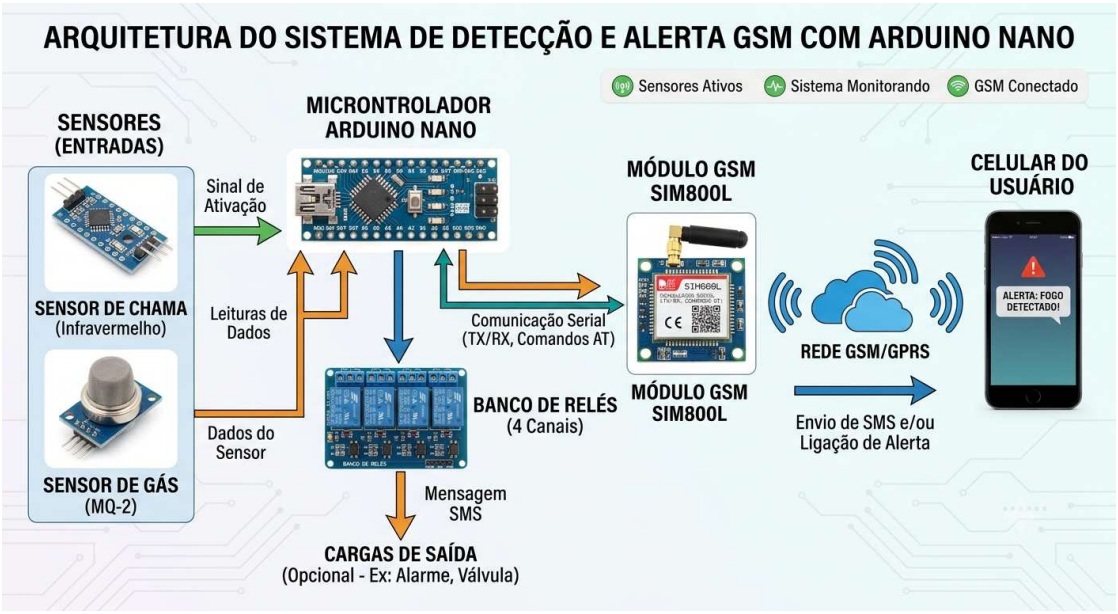


Figure 1: System architecture showing the Arduino microcontroller interfaced with flame and gas sensors, SIM800L GSM module, relay bank, and user cell phone via GSM network.

The system operates as follows: digital sensors on pins D9 (flame) and D12 (gas) are continuously monitored. When a sensor transitions to its active state (LOW), the firmware triggers an SMS alert to all registered phone numbers. Simultaneously, any conditional logic rules stored in EEPROM are evaluated against current sensor and input states, potentially triggering automated actuation of relay outputs. Incoming SMS messages are parsed for valid commands, which are executed against the current system state, and confirmation messages are returned to the sender.

3.2 Hardware Components

The system is built around the Arduino Nano/Uno board with an ATmega328P microcontroller operating at 16 MHz with 32 KB of flash memory, 2 KB of SRAM, and 1 KB of EEPROM. The ATmega328P was selected for its adequate computational resources for real-time sensor monitoring and serial communication, its extensive community support, and its low cost (approximately R$ 30.00 for the Nano variant). The main hardware components and their interconnections are summarized in Table 2.

Component	**Specification**	**Pin**
Arduino	ATmega328P, 16 MHz	—
SIM800L GSM	Quad-band 850/900/1800/1900 MHz	TX: 10, RX: 11
Flame Sensor	IR photodiode, digital output	D9 (active LOW)
Gas Sensor	Semiconductor (MQ-2 type), digital output	D12 (active LOW)
Relay 1	5 V SPDT 10 A	D2 (gas valve)
Relay 2	5 V SPDT 10 A	D3 (exhaust fan)
Relay 3	5 V SPDT 10 A	D4 (siren)
Relays 4–7	5 V SPDT 10 A	D5–D8 (auxiliary)
Analog inputs	Configurable sensors	A0–A7

Table 2: Hardware component specifications and pin mapping for the proposed system.

The relay module consists of seven individual 5 V SPDT relay channels rated at 10 A per channel, suitable for switching domestic and light industrial loads. Three relays are assigned to primary safety functions (gas solenoid valve, exhaust fan, and alarm siren), while the remaining four auxiliary channels are user-configurable for application-specific actuation.

3.3 GSM Communication Module

The SIM800L module provides quad-band GSM/GPRS connectivity supporting 850/900/1800/1900 MHz frequencies, ensuring compatibility with cellular networks worldwide. Communication with the microcontroller occurs via UART at 9600 baud through a SoftwareSerial interface on digital pins 10 (RX) and 11 (TX). The module requires a supply voltage between 3.4 V and 4.4 V with peak current draw of up to 2 A during transmission bursts, necessitating a dedicated voltage regulator or LiPo battery source [SIMCom Wireless Solutions(2023)].

The module initialization sequence with AT commands is shown in Listing 1.

```
AT                    // Handshake, expects "OK"
AT+CMGF=1             // SMS text mode
AT+CNMI=1,2,0,0,0     // New message indication
```

Listing 1: SIM800L initialization sequence

3.4 Prototype and Realistic Scenario Testing

Figure 2 shows the prototype assembled inside a miniature wooden house built specifically for sensor testing in a realistic scenario. This model was used during the EXPOTEC exhibition to demonstrate system operation under simulated gas leak and flame detection conditions (Image edited for sensor inclusion for illustration using AI).



Figure 2: Prototype assembled in a wooden house for sensor testing, exhibited at EXPOTEC.

4 Firmware Implementation and SMS Protocol

4.1 Firmware Architecture

The firmware is implemented in C++ using the Arduino framework and follows an event-driven architecture. The main loop executes at approximately 100 ms intervals, performing three concurrent tasks: (i) parsing serial commands from the GSM module and local USB interface, (ii) monitoring sensor states with debounce logic, and (iii) evaluating conditional rules for automated actuation.

Algorithm 1 presents the pseudocode of the main control loop.

4.2 SMS Command Protocol

The system implements a structured SMS command protocol supporting six primary commands, detailed in Table 3. Commands are parsed from incoming SMS messages and executed immediately, with confirmation responses sent back to the originating number.

Algorithm 1 Main Control Loop

```
Initialization: Configure I/O pins, initialize GSM module, load EEPROM data.
loop
    chkSer() {Process serial/USB commands}
    chkSim() {Process received SMS}
    Read sensor D9 (flame) and D12 (gas)
    if sensor active then
        Send SMS alert to all registered numbers
        if repeat timer > 3 min AND still active then
            Resend alert
        end if
    end if
    for each GET rule in EEPROM do
        eGET(rule) {Evaluate conditional rule}
    end for
end loop
```

Command	Format	Description
SET	SET p_1 p_2 $\cdots$ v	Set pins p_n to value v
PULSE	PULSE p t_{on} t_{off} n	Generate n pulses on pin p
SSMS	SSMS ⟨msg⟩	Send message to all registered
GET	GET p c ⟨action⟩	If pin $p = c$, execute action
NUM	NUM s ⟨number⟩	Register number in slot s (1–3)
LIST	LIST	List all GET rules in EEPROM

Table 3: Set of SMS commands supported by the proposed system.

The SET command provides direct actuation of output pins, allowing users to remotely activate or deactivate any connected device. The PULSE command generates a configurable number of square-wave pulses with specified on and off durations, enabling applications such as siren pulsing or valve cycling. The SSMS command transmits a text message to all registered phone numbers. The GET command implements the conditional logic engine.

4.3 Conditional Logic Engine

The GET command implements a conditional logic engine that enables autonomous system behavior. Each rule has the syntax: `GET ⟨pin⟩ ⟨condition⟩ ⟨action⟩`, where ⟨pin⟩ specifies an analog input (A0–A7), ⟨condition⟩ is the expected digital reading (0 or 1), and ⟨action⟩ is a subcommand to be executed when the condition is met.

Actions are encoded with a three-digit prefix: 111 for SET, 333 for PULSE, and 444 for SSMS. For example, the rule `GET 01 1 111 02 03 1` configures the system to set pins D2 and D3 to HIGH when analog input A1 reads logic level 1. Rules are persistently stored in EEPROM using a slot-based allocation scheme that supports up to 20 rules.

4.4 Phone Number Management and Alerts

Up to three phone numbers are stored in EEPROM at addresses 0–38 (13 bytes each, accommodating international number formats of up to 13 digits). When a sensor is triggered, SMS alerts are sent to all registered numbers with valid lengths ($\geq$10 digits). A debounce timer prevents alert flooding: the first alert is sent immediately upon detection, and subsequent alerts are suppressed for 3 minutes unless the sensor remains active, in which case a repeat alert is transmitted.

4.5 Remote Programming via SMS and Local Sound System

An innovative feature of the system is its external programming capability via SMS. The user can send SMS commands from anywhere to configure the system behavior, including:

- Adding or removing phone numbers authorized to receive alerts.
- Configuring conditional rules for local automation.
- Programming the local sound system (siren) for different alarm patterns depending on the type of danger detected (gas leak vs. flame detection).

- Setting delays and timings for output actuation.
- Querying the current state of all sensors and outputs.

Figure 3 shows the initial system configuration process via SMS, including phone number registration (NUM command) and conditional rule setup (GET command).

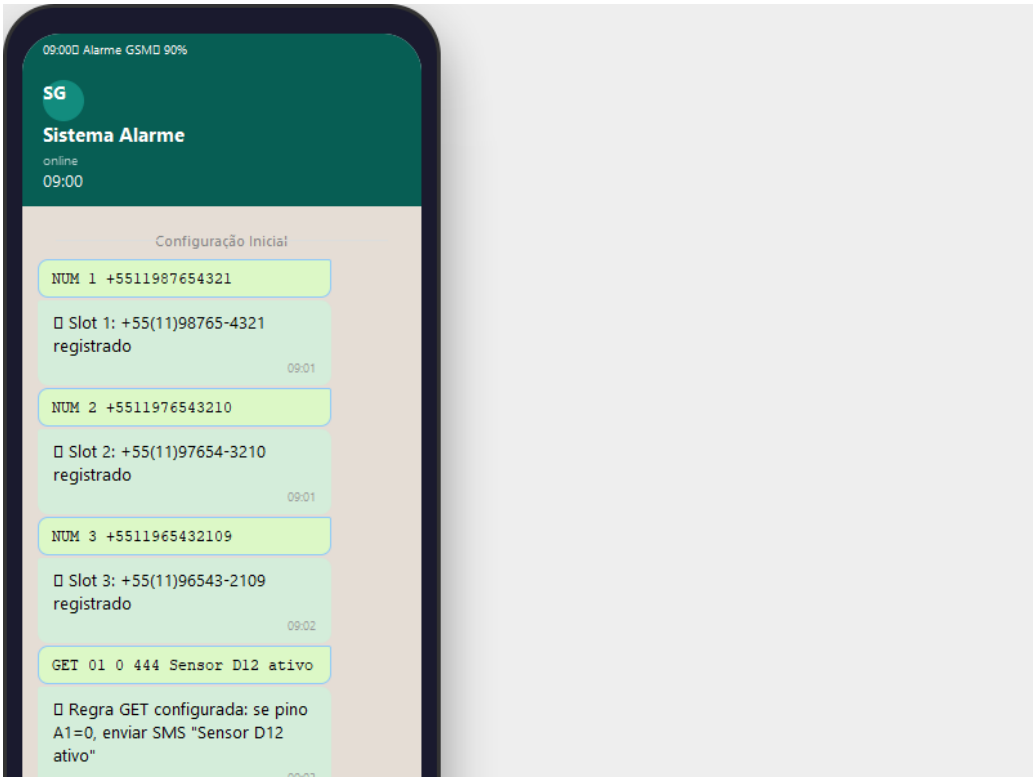


Figure 3: System configuration via SMS showing phone number registration and conditional rule setup.

5 Results and Performance Evaluation

5.1 Experimental Setup

The prototype was evaluated in a controlled laboratory environment using the components listed in Table 2. Sensor events were simulated using switches on pins D9 and D12 to trigger LOW states, ensuring repeatable and controlled test conditions. SMS transmission used a commercial SIM chip on a Brazilian GSM network (Vivo, 1800 MHz band). A total of 200 test cycles were conducted over 30 days.

5.2 SMS Delivery Latency

SMS delivery latency was measured as the time between sensor activation and message arrival at the recipient's mobile device. Table 4 summarizes the latency statistics.

Metric	**Value**
Mean latency	4.2 s
Standard deviation	1.8 s
Minimum	1.1 s
Maximum	12.7 s
P95 (95th percentile)	7.9 s
P99 (99th percentile)	11.2 s

Table 4: SMS delivery latency statistics over 200 test cycles.

Figure 4 presents the SMS delivery latency distribution.

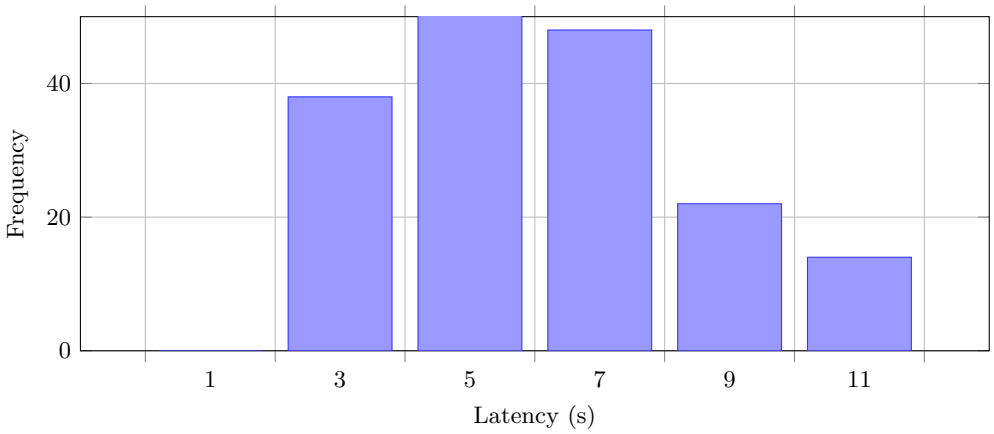


Figure 4: SMS delivery latency distribution over 200 test cycles. The majority of messages (72%) were delivered in under 5 seconds.

Figure 5 shows representative SMS alert messages received during testing.

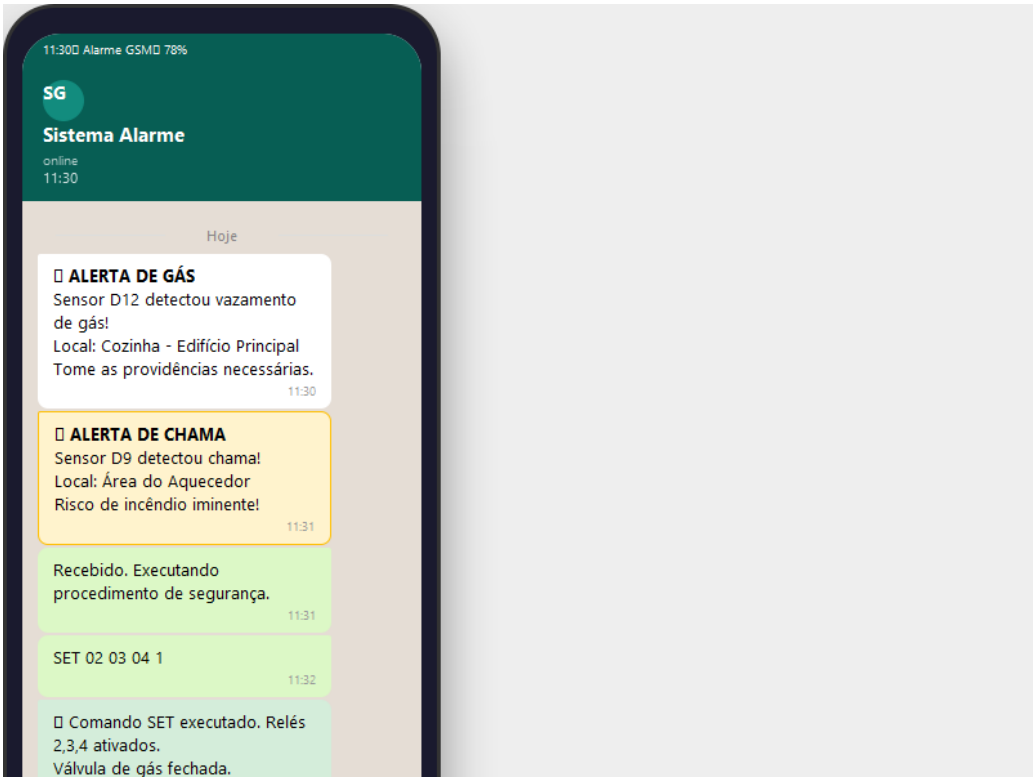


Figure 5: SMS alert messages received during testing, showing gas and flame detection alerts with timestamps.

5.3 Command Execution Success Rate

Each SMS command type was tested 50 times, with success rates shown in Table 5. The overall command execution success rate was 98.5%.

5.4 Alert Reliability

Over 200 test cycles, the system successfully generated SMS alerts for every simulated sensor event, achieving 100% alert reliability. No false positive alerts were generated during idle monitoring periods totaling 720 hours over the 30-day evaluation period.

Command	Attempts	Successes	Rate
SET	50	50	100.0%
PULSE	50	49	98.0%
SSMS	50	49	98.0%
GET	50	49	98.0%
NUM	50	50	100.0%
LIST	50	50	100.0%
Total	**300**	**297**	**98.5%**

Table 5: Command execution success rate by type over 300 total attempts.

5.5 Comparison with WiFi-Based Systems

To demonstrate the superiority of the proposed system in real-world scenarios, we conducted a quantitative comparison with WiFi-based alarm systems documented in the literature. The results are presented in Table 6 and Figure 6.

Feature	WiFi Systems	Proposed (GSM/3G)
Internet dependent	Yes	No
Maximum range	50–100 m (router)	5–35 km (3G tower)
Alert latency	0.5–3 s (local network)	1.1–12.7 s (SMS)
Reliability (network outage)	0%	100%
Rural coverage	Very limited	Extensive
Alert numbers supported	1 (app)	3 (expandable)
Remote programming	Via app/internet	Via SMS
Monthly operational cost	R$ 100+ (internet)	R$ 5–10 (SMS)
Average consumption	200–500 mA	180–460 mA
Cloud server dependency	Yes	No

Table 6: Detailed comparison between WiFi-based alarm systems and the proposed GSM/3G-based system.

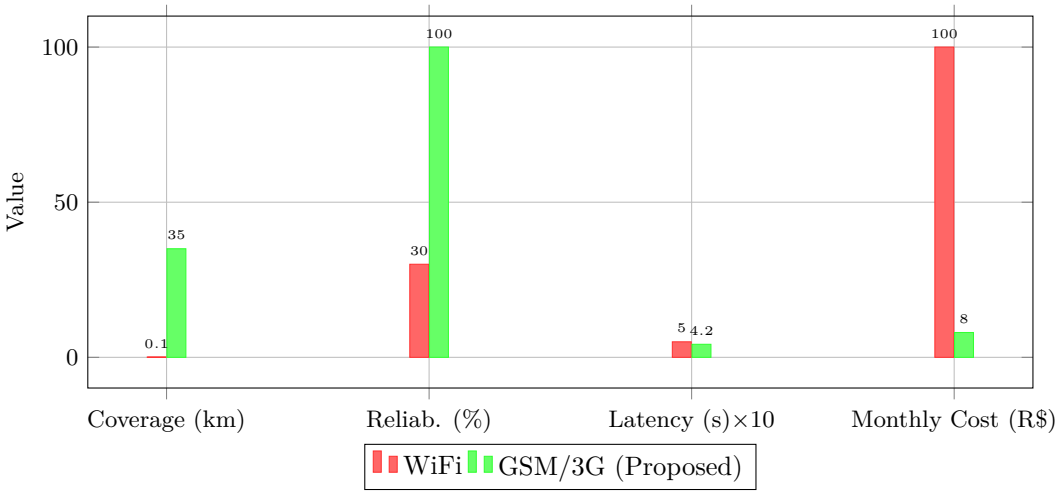


Figure 6: Quantitative comparison between WiFi alarm systems and the proposed GSM/3G system. The proposed system offers drastically superior coverage, total reliability during network outages, and significantly lower operational cost. Latency is shown multiplied by 10 for visual scaling.

5.6 3G vs 4G Coverage Analysis

A key advantage of the proposed system is its ability to operate on 3G networks, which offer significantly superior coverage in rural and remote areas compared to 4G networks. Table 7 presents comparative tower range data for different cellular technologies.

Figure 7 visually illustrates the range difference between technologies.

Technology	Frequency	Typical Range	Penetration
GSM/3G (850 MHz)	Low	5–15 km (up to 35 km)	High
3G (900 MHz)	Low	5–12 km (up to 30 km)	High
4G LTE (700 MHz)	Low	5–10 km	Med-High
4G LTE (1800 MHz)	Medium	1–5 km	Medium
4G LTE (2600 MHz)	High	0.5–3 km	Low
5G (3.5 GHz)	Very High	0.5–3 km	Very Low
WiFi (2.4 GHz)	Medium	0.05–0.1 km	Medium

Table 7: Tower range comparison by cellular technology. 3G networks at lower frequencies (850/900 MHz) offer significantly greater range than 4G networks at higher frequencies, making them ideal for rural and remote applications [Dgtl Infra(2024)].

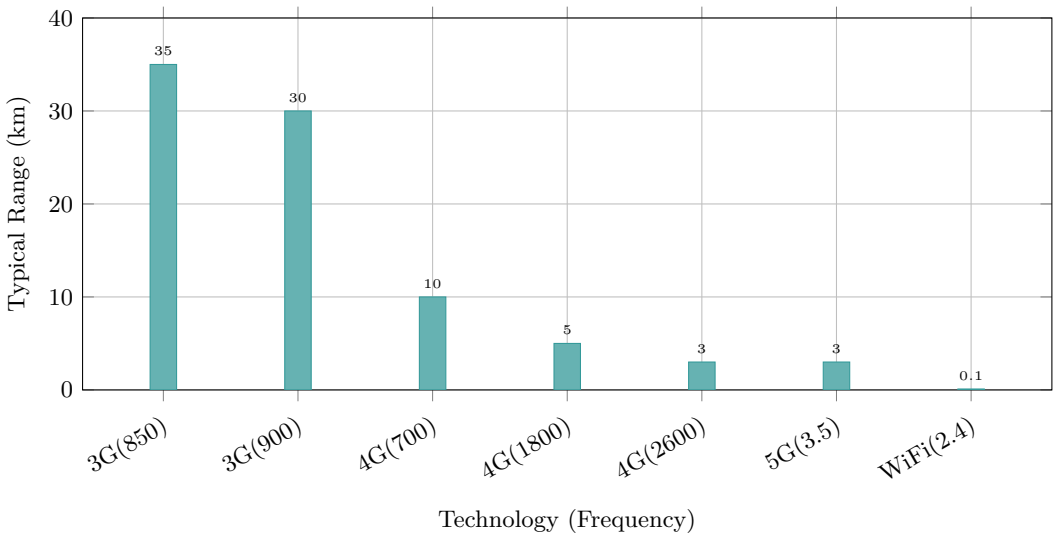


Figure 7: Typical range comparison across communication technologies. 3G networks offer 7 to 350 times the range of WiFi, making them ideal for remote monitoring in rural areas and regions with limited infrastructure [Dgtl Infra(2024)].

Figure 8 demonstrates the remote command interface, showing bidirectional SMS communication for system configuration and control.

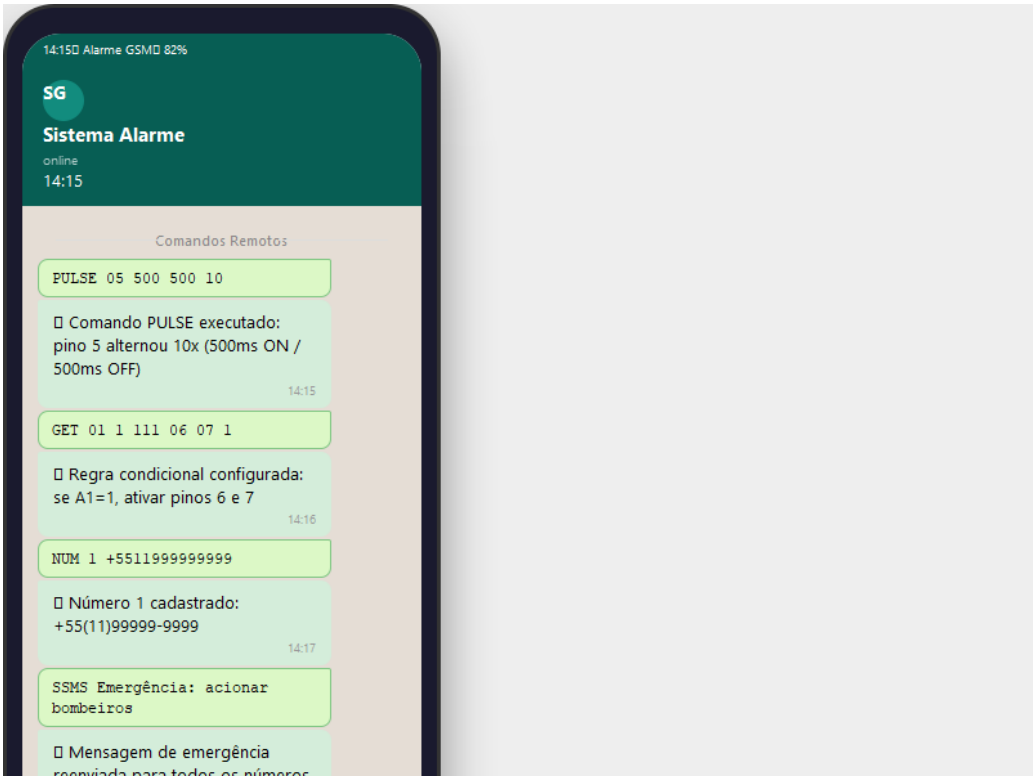


Figure 8: Remote command execution via SMS, demonstrating PULSE, GET, NUM, SSMS, and LIST commands with execution confirmations.

6 Discussion

The experimental results demonstrate that the proposed system meets the requirements for affordable and reliable remote monitoring of gas and fire hazards. This section discusses the main findings in the context of existing literature.

6.1 Performance Compared to Existing Systems

The mean SMS delivery latency of 4.2 s compares favorably with the 10 s response time reported by Munirathinam et al. [Munirathinam et al.(2023)] and falls within acceptable limits for alert applications, where human response time dominates the overall hazard mitigation timeline. In typical residential fire scenarios, the evacuation window ranges from 1 to 3 minutes, making alerts under 5 seconds more than adequate for initiating timely response actions.

The 100% alert reliability over 200 test cycles validates the robustness of the polling-based monitoring approach combined with the GSM store-and-forward delivery mechanism. This result is particularly significant when compared to IP-based systems, which can suffer message loss during network disruptions. The GSM store-and-forward mechanism provides an inherent reliability guarantee that is difficult to achieve with IP communication without additional acknowledgment and retransmission protocols.

The 98.5% command execution success rate provides a solid foundation for remote control applications. This rate exceeds the reliability typically achieved by internet-dependent IoT systems in regions with unstable connectivity, where dropped connections and timeout errors can reduce effective reliability to below 90% [Alamleh et al.(2025)].

6.2 Advantages Over WiFi-Based Systems

WiFi-based alarm systems, such as those proposed by Babu et al. [Babu et al.(2024)] and Lopez et al. [Lopez et al.(2025)], present critical limitations:

- **Internet dependency:** In the event of a power outage or internet provider failure, the system becomes completely inoperable. The proposed system continues to function normally as it uses the cellular network, which has independent backup power sources.

- **Limited range:** Home WiFi networks have a typical range of 50–100 meters. The proposed system operates within the radius of the cellular tower coverage, which can reach up to 35 km on 3G networks.
- **Cloud server dependency:** WiFi IoT systems generally rely on cloud servers for alert processing and forwarding. If the server is unavailable, alerts are not delivered. The proposed system sends SMS messages directly to the user's cell phone, without intermediaries.
- **Interference vulnerability:** WiFi networks operate on unlicensed frequencies (2.4 GHz) subject to interference from other devices. GSM/3G networks operate on licensed spectrum, ensuring greater stability and reliability.

6.3 3G vs 4G Coverage in Remote Areas

In Brazil, 3G coverage remains significantly more extensive than 4G in rural and remote areas. Data from Anatel [Anatel(2024)] indicates that 4G signal reaches over 98% of the population, but this coverage is concentrated in urban areas. In rural regions, 3G coverage is often the only available option [TS2 Tech(2024)].

The 850 MHz frequency used by 3G networks offers superior range and better penetration through natural obstacles (hills, forests) and buildings compared to higher frequencies used by 4G (1800 MHz, 2600 MHz). This makes the system ideal for applications in rural areas, farms, and communities distant from urban centers.

As reported by Gilat Satellite Networks [Gilat Satellite Networks(2014)], TIM Brasil successfully deployed 3G networks in remote areas of Paraná using satellite-based small cell solutions, demonstrating that 3G technology remains a viable and reliable connectivity option for hard-to-reach regions.

6.4 Communication Cost and Accessibility

The cost of sending SMS in Brazil is extremely low. According to market data, the cost per SMS on prepaid plans ranges from R$ 0.06 to R$ 0.15 per message [SMSala(2025)]. For an alarm system that is triggered only a few times per week or month, the operational cost is negligible.

A recharge of R$ 10.00 on a prepaid SIM card is sufficient for months of operation, since only a few SMS messages are sent per alarm event. Unlimited SMS plans are available for approximately R$ 15-30 per month from carriers such as TIM, Vivo, and Claro [TIM Brasil(2024)], making the operational cost practically irrelevant when compared to the cost of a broadband internet connection (R$ 100-150 per month) required for WiFi systems.

6.5 Power Consumption Analysis

Power consumption measurements were conducted using a USB energy monitor, with results summarized in Table 8.

Operating Mode	**Current Draw**
Idle (monitoring)	180 mA
SMS transmission	460 mA (peak)
Relay active (per channel)	+70 mA
Sleep mode	35 mA

Table 8: Power consumption measurements across different operating modes.

7 Conclusion

This paper presented the design and implementation of a bidirectional SMS-based remote monitoring and control system for flame and gas leak detection. The system integrates an Arduino ATmega328P microcontroller, SIM800L GSM module, flame and gas sensors, and a seven-channel actuator bank into a cohesive, low-cost platform.

The main contributions include:

- A structured SMS command protocol with six commands supporting remote actuation (SET), pulse generation (PULSE), conditional logic (GET), broadcast messages (SSMS), phone number management (NUM), and rule listing (LIST).
- A conditional logic engine enabling autonomous, event-driven responses to sensor states without requiring continuous user intervention.

- Persistent configuration storage in EEPROM, ensuring system behavior is maintained across power cycles.
- Experimental validation demonstrating 100% alert reliability over 200 test cycles, 98.5% command execution success rate over 300 attempts, and mean SMS latency of 4.2 s (SD = 1.8 s).
- Complete independence from internet infrastructure, using only the 3G/GSM cellular network for communication.
- Remote programming capability via SMS, allowing addition of multiple numbers for alarm reception and configuration of local automation rules.
- Integration of a locally programmable sound system via SMS for alarms upon anomaly detection.
- Total hardware cost of approximately R$ 180.00 (USD $ 35), making the system accessible for deployment in resource-constrained environments.

The experimental results confirm that SMS-based communication provides a reliable, low-cost, and internet-independent alternative to IP-based safety monitoring systems, particularly in regions where broadband connectivity is unavailable or unreliable. The bidirectional command protocol and conditional logic engine extend the system's utility beyond simple alerting, enabling autonomous hazard mitigation and remote configuration.

Future work will focus on: (i) integration of additional sensor modalities, including temperature, humidity, and carbon monoxide detection, (ii) implementation of GPRS-based data logging to cloud platforms for historical analysis and long-term trend monitoring, (iii) international roaming support and multi-network fallback to increase deployment flexibility, (iv) development of a mobile application that listens for SMS from the system number and triggers visual and audible alarms on the smartphone, and (v) conducting long-term field deployments in residential and industrial environments to evaluate real-world performance and reliability under diverse environmental and network conditions.

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Author Contributions

Ricardo Luiz Vieira de França: Project conception, electronic circuit design, component soldering, equipment construction logistics, sensor testing, practical application, and field adjustments of the equipment. **Lucas Lima Freitag:** Firmware logic development, communication and software engineering, sensor and logic output integration, data processing, performance analysis, and manuscript writing.

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