Grenze International Journal of Engineering and Technology, June Issue

An IoT-Enabled Multi-Sensor LPG Monitoring System with Predictive Analytics and Automated Refill Integration

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***Abstract*— Liquefied Petroleum Gas (LPG) is one of the primary fuels used for household cooking. However, in most homes, the remaining gas level in a cylinder is still monitored manually, making it difficult to estimate the exact time for refill booking. Since depletion becomes noticeable only when the cylinder is almost empty, users often face sudden interruptions and potential safety concerns. To address this limitation, this work presents an IoT-enabled multi-sensor LPG monitoring system that continuously tracks cylinder status using pressure, temperature, and gas leakage sensors. The collected data is processed to estimate the available LPG more accurately, reducing dependence on manual checking. In addition to monitoring, the system supports automated refill requests either through an SMS gateway or via direct API integration with LPG suppliers. Experimental evaluation of the prototype showed stable gas level estimation, leak detection within a few seconds, and minimal communication delay. The overall design uses cost-effective components, making the solution scalable and suitable for household adoption in India while enhancing both safety and user convenience.**

***Index Terms*— IoT, LPG monitoring, multi-sensor system, predictive analytics, smart regulator, automated refill, gas consumption forecasting, smart home integration.**

I. Introduction

Liquefied Petroleum Gas (LPG) is considered an important low-carbon energy source for households today due to its clean combustion and operational efficiency. It is widely available and commonly used across many regions, particularly in Asia and Africa, where LPG cylinders serve as the primary fuel for cooking and small-scale heating. Government initiatives aimed at improving accessibility and affordability have further strengthened its role as a household necessity. Despite its widespread adoption, users continue to face challenges in managing cylinder refills. The current refill process is often uncertain and inconvenient, leading to unexpected depletion during essential household activities. Manual booking methods, especially in high-demand areas, may introduce delays through call centers or distributor-based systems. Accurately estimating the remaining gas level and predicting usage duration remains difficult, which has encouraged both researchers and industry professionals to explore technology-driven alternatives. The emergence of the Internet of Things (IoT) has enabled continuous monitoring, remote access, and faster data collection in domestic applications.

Grenze ID: 01.GIJET.12.2.9_22

Several commercial and experimental systems have combined sensors and microcontrollers to monitor LPG parameters such as pressure, weight, and ultrasonic reflections. However, many of these approaches trigger alerts only at critical levels and face limitations related to measurement accuracy, scalability, and integration with supplier logistics.

Since measurements based on a single parameter are more prone to inaccuracies, relying on only one sensing method does not provide sufficient reliability. Moreover, many existing systems function mainly as reactive alert mechanisms and do not incorporate predictive capabilities. Without consumption forecasting, users are unable to plan refills in advance for better household management. Another important limitation is the lack of integration with LPG supplier networks. In most cases, refill booking is still carried out manually through mobile applications, distributors, or customer service centers. Because monitoring and supply chain operations remain separate, the overall advantages of IoT-based automation are not fully realized. A truly intelligent system should not only monitor gas levels but also establish direct communication with supplier platforms to enable automatic refill processing. Such integration would enhance user convenience while also improving operational efficiency for providers. To address these gaps, this work proposes an IoT-based multi-sensor LPG monitoring system that incorporates predictive analytics along with automated refill functionality. By combining temperature, pressure, and weight sensing, the system improves measurement precision and reduces errors associated with individual sensors. The predictive model estimates the number of days remaining before depletion; however, these estimates may vary depending on changes in usage patterns over time. Users are given the flexibility to confirm or modify booking requests through connected mobile devices, ensuring transparency and control. In addition, continuous leak monitoring and emergency alert mechanisms enhance overall safety. The proposed framework offers a practical and scalable alternative to traditional approaches. Its emphasis on cost-effective components and adaptable design makes it suitable for deployment in developing regions, supporting broader smart home and smart city objectives focused on automation, safety, and efficient energy management.

II. Related Work

Over the last decade, both academic researchers and industry practitioners have explored solutions to improve Liquefied Petroleum Gas (LPG) monitoring and refill management. Prior work in this area can generally be grouped into sensor-based monitoring approaches, IoT-enabled systems, predictive modelling techniques, supply-chain integration frameworks, and safety-focused designs. While notable progress has been made, several practical and technical limitations still remain.

A. Sensor-Based LPG Monitoring Systems

Initial LPG monitoring solutions primarily relied on direct sensing mechanisms. Weight-based approaches employed load cells to measure the gradual reduction in cylinder mass during usage. Although these systems provided reasonably accurate measurements under stable conditions, their performance was affected by uneven placement and external vibrations. Ultrasonic sensing later emerged as a non-invasive alternative that analysed sound wave reflections from the cylinder surface. These observations suggest that single-sensor approaches alone may not provide consistent reliability in real-world environments.

B. IoT-Enabled Smart LPG Systems

With the advancement of the Internet of Things (IoT), monitoring systems began integrating sensors with wireless communication modules and microcontrollers. Such systems enabled remote observation of LPG cylinders through mobile or web-based platforms. Many implementations generated alerts when gas levels dropped below predefined thresholds. Although these solutions demonstrated the potential of IoT in domestic LPG management, most operated as reactive systems without forecasting future consumption. Furthermore, integration with supplier networks was rarely included, limiting functionality primarily to household-level monitoring.

C. Predictive Models and Machine Learning Approaches

More recent studies have examined predictive analytics for estimating residential energy consumption. Techniques such as regression analysis and time-series models, including ARIMA, have been applied to forecast LPG usage and estimate depletion timelines. However, a significant portion of this research remains simulation-based, with limited validation in practical household settings. Additionally, predictive models that depend on a single sensor input are more susceptible to noise and measurement errors. Incorporating multi-sensor data can enhance prediction robustness and improve overall system dependability.

D. Integration with LPG Supply Chain Systems

Despite advancements in monitoring technologies, integration between consumer-level systems and supplier logistics remains minimal. In many regions, refill booking continues to be performed manually through mobile applications, SMS services, or customer support channels. Although certain commercial platforms offer automated booking features, these solutions are often expensive and less accessible in developing areas. Academic prototypes also tend to avoid the complexities involved in direct API integration with distributors. As a result, real-time monitoring systems frequently remain limited to notification-based functionality rather than achieving full automation.

E. Safety-Oriented LPG Monitoring Research

Safety considerations have been addressed in several studies focusing on gas leakage detection. Sensors such as MQ-2 and MQ-6 are commonly used to detect abnormal LPG concentrations and trigger alarms. Some systems further incorporate automatic shut-off mechanisms to prevent hazardous situations. However, in many cases, safety monitoring is developed independently from consumption tracking systems. This separation leads to fragmented implementations rather than unified solutions that combine monitoring, automation, and safety within a single architecture.

F. Research Gaps and Motivation for Proposed Work

A review of existing literature indicates that comprehensive integration of multi-sensor fusion, predictive analytics, automated refill booking, and safety monitoring within a single framework is still uncommon. Many available systems rely on proprietary hardware or single-sensor configurations, which may reduce affordability and scalability for low- and middle-income households.

Common limitations observed in prior work include:

- reliance on single-sensor measurements that affect accuracy,
- reactive alert mechanisms without predictive capability,
- lack of supplier-side integration, and
- safety solutions implemented separately from consumption monitoring.

To overcome these challenges, the proposed system integrates temperature, pressure, and weight sensors with predictive modeling and direct supplier connectivity through APIs or SMS gateways. By combining affordability, multi-sensor accuracy, forecasting capability, and logistical coordination, the framework aims to provide a practical and scalable solution suitable for real-world deployment.

II. PROPOSED METHODOLOGY

The proposed system offers a multi-sensor IoT-enabled LPG monitoring solution that aims to address the limitations of traditional methods. By combining different sensing technologies, predictive analytics, and automated refill processes, the system improves accuracy, safety, and user convenience. The overall workflow of the system is illustrated in Fig. 1. The hardware and software integration is shown in Fig. 2.

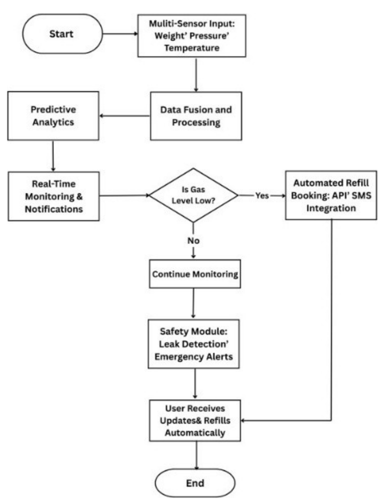

Fig. 1. Flowchart

A. System Architecture

The system architecture is organized into three functional layers.

- The sensing layer consists of temperature, pressure, and weight sensors interfaced with an ESP32 microcontroller. The ESP32 was selected due to its built-in Wi-Fi support, low power consumption, and cost efficiency.
- The processing layer is responsible for sensor data fusion, calibration adjustments, and consumption forecasting using predictive algorithms.
- The communication layer connects the system to LPG provider platforms through APIs or SMS gateways, transmitting processed information to cloud servers or mobile applications.

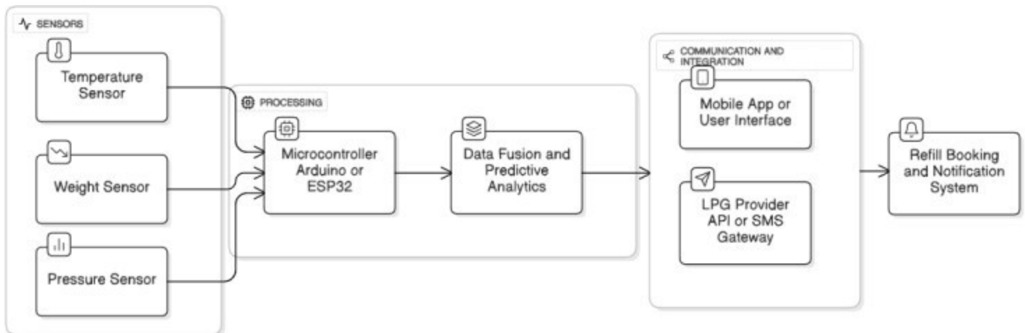

Fig. 2. Block Diagram

B. Multi-Sensor Integration

To enhance system reliability, multiple sensing methods are employed. The weight sensor measures the remaining LPG quantity within the cylinder. The pressure sensor monitors internal cylinder conditions, while the temperature sensor compensates for environmental variations. An MQ-6 gas sensor is included for continuous leak detection. The hardware setup incorporates a load cell with an HX711 amplifier, a BMP180 pressure sensor, and a DS18B20 temperature sensor.

C. Predictive Analytics

Predictive modeling is applied to estimate the remaining usable duration of the LPG cylinder. The model analyzes historical consumption behavior along with real-time sensor inputs to forecast depletion timelines. The algorithm operates locally on the ESP32, while cloud storage supports data logging and long-term analysis. This arrangement ensures efficient performance with minimal computational cost.

D. Automated Refill Integration

When the system detects that gas levels fall below a defined threshold, it initiates automatic refill requests through supplier APIs or SMS gateways, particularly in regions with limited connectivity. Users retain control by confirming, modifying, or canceling bookings through a mobile application that provides real-time status information.

E. Safety and Emergency Features

Leak detection is continuously carried out using the MQ-6 gas sensor. If abnormal gas concentrations are identified, alerts are immediately transmitted via SMS and mobile notifications. Future enhancements may incorporate solenoid valves operated through the ESP32 GPIO pins to enable automatic gas shut-off during emergency situations.

III. EXPERIMENTAL SETUP AND IMPLEMENTATION

A. Hardware Components

The proposed system is built using low-cost, commercially available components to ensure affordability and reliability for Indian households. A load cell combined with an HX711 amplifier measures cylinder weight, which serves as the primary indicator of LPG consumption. A BMP180 pressure sensor monitors variations in regulator pressure, providing additional measurement support under different environmental conditions. The ESP32 microcontroller (NodeMCU-32S) functions as the main processing unit due to its low power consumption, built-in Wi-Fi capability, and suitability for IoT applications. Its integrated communication features eliminate the need for separate modules, reducing both system complexity and cost. For safety purposes, an MQ-6 gas sensor is used to detect LPG leakage, enabling both consumption monitoring and hazard detection. The complete system operates using a regulated 5V DC power adapter to ensure stable performance in household environments.

Table I presents the components, specifications, and estimated costs in Indian Rupees (INR). The overall prototype cost ranges between INR 1,800 and 2,500, making it suitable for middle-class households.

TABLE I: HARDWARE COMPONENTS USED IN THE PROTOTYPE

Components	Model	Spec.	Use	Cost (INR)
Load Cell + HX711	20–50 kg	±0.01 kg	Weight measurement	450–600
Pressure Sensor	BMP180/ MPX5010	0–10 kPa	Gas pressure	300–500
Temp. Sensor	DS18B20	–55 to 125°C	Temp. adjustment	120–200
Microcontroller	ESP32	Wi-Fi + BT, 240		
MHz	Control + IoT	500–700		
Gas Sensor	MQ-6	200–10,000 ppm	Leak detection	200–300
Comm. Module	ESP32 Wi-Fi	802.11 b/g/n	Data transfer	Included
Power Supply	5V Adapter	220V AC–5V DC,		
2A	Power unit	150–250		

B. Software Components

The software design consists of device-level control, cloud-based data handling, and user interaction.

- Device Layer: The ESP32 was programmed using the Arduino IDE with C/C++ libraries for sensor interfacing, wireless communication, and data filtering. Pre-processing steps such as temperature compensation and noise reduction were handled locally.
- Cloud Layer: Data was transmitted using the MQTT protocol to open-source IoT platforms. Storage, visualization of usage trends, and user authentication were managed through services such as ThingSpeak and Firebase.
- User Layer: A mobile application provides real-time cylinder monitoring, displaying remaining gas levels, estimated depletion time, and refill notifications. Refill requests are initiated through SMS gateways or LPG supplier APIs.

All software tools utilized were open-source, avoiding additional financial cost.

C. Experimental Setup

The prototype was evaluated in a controlled laboratory environment simulating typical household conditions. The LPG cylinder was positioned on the load cell base, while the temperature and pressure sensors were installed near the regulator assembly. The MQ-6 gas sensor was placed close to the cylinder to monitor potential leakage. The ESP32 and sensors were mounted on a breadboard powered by a stable 5V supply.

Sensor readings were recorded at 10-second intervals and transmitted to the cloud via Wi-Fi. Testing conditions were varied by adjusting room temperature, simulating different cooking patterns, and altering cylinder levels (full, half, and near-empty). These variations allowed assessment of system performance under realistic usage conditions.

D. Implementation Workflow

The operational workflow has six stages:

- Data collection from temperature, pressure, weight, and gas sensors.
- Local processing, which includes calibration, filtering, and data fusion.
- Predictive analytics to estimate how much longer the device can be used.
- Cloud transmission using Wi-Fi to IoT platforms.
- Automatic refill initiation through API or SMS.
- User notification through the mobile application.

E. Safety Considerations

Considering the hazardous nature of LPG, safety was treated as a priority. The MQ-6 sensor continuously monitors gas concentration and triggers alerts through the mobile application when abnormal levels are detected. The system design allows future integration of automatic shut-off valves. Fail-safe mechanisms were implemented to prevent incorrect refill requests during abnormal sensor readings.

IV. Results and Discussion

A. Experimental Results

The hardware prototype was evaluated in a laboratory environment designed to simulate typical household cooking conditions. Three cylinder levels were tested: full (14.2 kg), half (7 kg), and near-empty (2–3 kg). The load cell delivered stable readings with an error margin below 100 g, indicating its suitability for LPG monitoring. The pressure sensor responded to ambient temperature variations and successfully differentiated between full and near-empty states. When combined with temperature measurements, the influence of environmental factors on overall accuracy was reduced.

During leakage experiments, the MQ-6 sensor detected LPG presence effectively and generated alerts within 5–7 seconds under elevated gas exposure. Data transmission from the ESP32 to the cloud remained consistent, enabling near real-time monitoring. The mobile application provided timely refill notifications, displayed consumption patterns, and estimated the remaining usage duration. Table II presents a summary of the system performance observed during testing.

Table II summarizes the observed system performance.

TABLE II: EXPERIMENTAL RESULTS OF THE PROPOSED LPG MONITORING SYSTEM

Performance Metric	Experimental Result
Cylinder weight levels tested	Full (14.2 kg), Half (7 kg), Near-empty (2–3 kg)
Weight measurement error	< 100 g
Gas leakage detection time	5–7 seconds
Cloud data transmission latency	< 2 seconds
Prediction accuracy	85–90%
System operational stability	99% during testing
Estimated prototype cost	INR 1,800–2,500

B. Predictive Analytics Performance

The predictive model estimated cylinder depletion based on historical usage data. Experimental results indicated an accuracy range of 85–90%, depending on variations in cooking habits.

More consistent usage patterns produced higher prediction accuracy, while irregular consumption resulted in minor deviations. This forecasting capability reduced the likelihood of sudden gas depletion by issuing advance notifications.

C. Cost Efficiency Analysis

Cost effectiveness was a key consideration in the system design. Commercial smart LPG monitoring solutions typically range between INR 5,000 and INR 10,000. In comparison, the developed prototype utilizes standard components costing approximately INR 1,800 to INR 2,500. This affordability makes the system practical for middle-class households and adaptable for broader community use. The integrated Wi-Fi functionality of the ESP32 eliminated the need for additional communication hardware, further reducing overall cost and system complexity.

D. Comparison with Existing Works

Most existing LPG monitoring systems use single-sensor methods like weight or ultrasonic sensing, which often leads to limited accuracy.

Many prototypes also send only reactive notifications without any predictive insights or supplier integration. In contrast, the proposed system provides:

- Multi-sensor fusion for better accuracy
- Predictive analytics for proactive planning
- Automated refill integration for supplier connectivity
- Real-time gas leak detection for safety assurance

These combined features offer more functionality than many previously reported systems.

E. Limitations

Although the results were encouraging, certain limitations were observed. Measurement accuracy depends on proper alignment of the load cell, and uneven placement may introduce errors. The predictive model requires initial data collection to achieve optimal performance. In addition, API-based supplier integration may depend on local infrastructure availability and distributor collaboration.

F. Discussion

The findings indicate both technical viability and economic feasibility. Multi-sensor integration improved overall measurement consistency, while predictive analytics enhanced user preparedness. The cost-effective design supports wider adoption without imposing significant financial burden. By integrating safety monitoring, automated refill processing, forecasting, and consumption tracking within a single framework, the system demonstrates potential to improve household energy management.

V. Conclusion

This study presented an IoT-enabled multi-sensor LPG monitoring system integrating predictive analytics with automated refill functionality. By combining weight, pressure, temperature, and gas sensors, the system provided reliable level estimation and prompt leak detection. Experimental validation confirmed accurate measurement, low communication latency, and stable operation. The predictive component enabled advance refill planning, reducing the risk of unexpected depletion. A key advantage of the proposed approach is its affordability, making it suitable for middle-class households and scalable for wider deployment. Automated refill support through APIs or SMS gateways further enhances user convenience and supply-chain coordination. Overall, the system offers a practical solution for improving household safety, energy monitoring, and user comfort. Future work may focus on advanced learning-based prediction models, integration of automatic shut-off mechanisms, and large-scale field implementation with distributor networks.

References

[1] D. Balogun, S. Shamim, U. Sipai, N. Kothari, T. Trivedi, and V. Patel, “LPG Smart Guard: An IoT- Based Solution for Real-Time Gas Cylinder Monitoring and Safety in Smart Homes,” Engineering Proceedings, vol. 82, no. 1, p. 9, 2024.

[2] “Estimation and Prediction of LPG Gas Using Data Analytics,” International Journal of Engineering Research & Technology, vol. 10, no. 08, 2019.

[3] B. Jena et al., “LPG gas leakage detection system using IoT,” ScienceDirect, 2023.

[4] T. Babu et al., “Enhancing Gas Leak Detection with IoT Technology,” ScienceDirect, 2024.

[5] F. M. Foysal, S. Mondal, T. Riyad, S. Sikder, M. A. Rimon, and J. Hasan, “Integrated IoT-Based Smart Billing and LPG Gas Leakage Detection System for Energy Efficiency and Safety in Smart Living,” Journal of Engineering Research and Reports, vol. 27, no. 1, pp. 1–15, 2025.

[6] “Real-Time Detection and Alerting System for LPG Gas Leakage with Integrated Weight-Based Consumption Tracking,” IJFMR, vol. 7, no. 2, 2025.

[7] T. Sutikno, M. H. Ar-Rasyid, T. Wahono, and W. Arsadiando, “Smart LPG Monitoring and Automatic Booking System using IoT,” in Proc. Int. Conf., 2023.

[8] A. Okubanjo et al., “Real-time LPG leakage monitoring system using IoT and cloud technology,” Sigma Journal of Engineering and Natural Sciences, 2025.

[9] O. Flores-Cortez, R. Cortez, and B. Gonzalez, “Design and Implementation of an IoT-Based LPG and CO Gas Monitoring System,” arXiv preprint arXiv:2107.07406, 2021.

[10] B. Lalithadevi and S. Krishnaveni, “ExAIRFC-GSDC: An Advanced Machine Learning-Based Interpretable Framework for Accurate Gas Leakage Detection and Classification,” International Journal of Computational Intelligence Systems, 2025.

[11] P. P. Bairagi, “IoT-Based LPG Monitoring and Controlling System,” Annals of Multidisciplinary Research, Innovation and Technology (AMRIT), vol. 2, no. 1, 2023.

[12] M. G. T. Espinoza et al., “IoT and Business Intelligence-Based Model Design for LPG Control, Monitoring, and Distribution,” Preprints, 2024.

[13] A. B. Edward et al., “Development of a Smart Monitoring System for Advancing Gas Cylinder Safety and Efficiency,” ScienceDirect, 2024.

[14] A. Wasfi et al., “Detection of Butane and Propane Gases via C2N Sensors: First-Principles Modeling,” Scientific Reports, vol. 13, Art. no. 19314, 2023.