AI-Driven Intelligent Monitoring and Predictive Alert System for LPG Cylinder Lifecycle

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Abstract – In this project, we present the design and development of a smart, IoT-enabled system for real-time monitoring of LPG cylinder weight and we target house logistic. The system is engineered to enhance safety, efficiency, and inventory management in LPG distribution networks. A load cell sensor is integrated to develop vehicle platform to continuously measure the weight of cylinder. The data is processed using a microcontroller, which calculates the remaining gas content based on calibrated thresholds. When the gas level in any cylinder drops below predefined limits (e.g., 50%, 25%), the system automatically transmits alerts to a connected mobile application via wireless communication. This ensures timely refilling, prevents unexpected depletion, and enables remote monitoring by suppliers or users. The mobile interface provides a user-friendly dashboard for real-time status updates, historical data logs, and predictive analytics. This innovation is particularly useful for commercial LPG delivery services, where efficient tracking of cylinder usage and proactive refilling are critical. The system is scalable, cost-effective, and adaptable to various types of gas cylinders and transport platforms.

Keywords - Artificial Intelligence, Internet of Things, Predictive Analytics, Load Cell Sensor, Smart Monitoring, Embedded Systems.

1. INTRODUCTION

Liquefied Petroleum Gas (LPG) is one of the most widely used energy sources in domestic, commercial, and industrial sectors due to its high calorific value, clean combustion characteristics, and ease of storage and transportation. In both developing and developed regions, LPG plays a crucial role in meeting household cooking requirements, supporting heating systems, and enabling small-scale industrial operations. Despite these advantages, traditional LPG management practices remain inefficient and lack intelligent automation, resulting in several operational and safety-related challenges.

Conventional LPG usage monitoring methods primarily rely on manual inspection or basic mechanical indicators to estimate the remaining gas quantity. These methods are often inaccurate and inconvenient, as users are usually unaware of the exact gas level until the cylinder is nearly empty. Such unexpected depletion can interrupt daily activities and operational workflows. Additionally, undetected gas leakage poses serious safety risks, including fire and explosion hazards, which can threaten human life and property. Therefore, there is a critical need for an intelligent and automated solution capable of monitoring, analyzing, and predicting the LPG cylinder lifecycle with minimal human intervention.

The rapid advancement of the Internet of Things (IoT) has enabled real-time data acquisition, communication, and remote monitoring in applications such as smart homes and industrial automation. IoT-based systems facilitate continuous sensing and transmission of physical parameters such as weight, temperature, and pressure to cloud platforms for analysis.

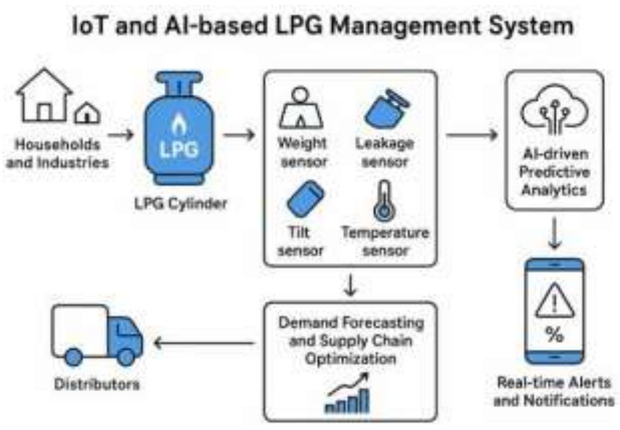

Fig. 1. 1: Block Diagram of AI-Driven IoT-based LPG Management System

The proposed AI-Driven Intelligent Monitoring and Predictive Alert System for LPG Cylinder Lifecycle aims to overcome the limitations of traditional LPG management by integrating sensor-based data acquisition, wireless IoT connectivity, and AI-driven predictive analytics. The system is designed to monitor critical parameters such as gas weight (for consumption analysis), temperature and pressure (for safety assurance), and environmental gas concentration (for leak detection). The collected data is transmitted to a cloud-based platform via Wi-Fi-enabled microcontrollers such as the ESP8266, ensuring real-time access and remote monitoring through mobile or web interfaces.

2. OVERVIEW OF PROJECT

The proposed AI-Driven Intelligent Monitoring and Predictive Alert System for LPG Cylinder Lifecycle is designed as an integrated hardware and software framework that enables real-time tracking, analysis, and prediction of LPG cylinder parameters. The system merges the physical sensing capabilities of IoT devices with the analytical power of artificial intelligence to create an autonomous and adaptive platform for managing the entire LPG lifecycle efficiently and safely. The fundamental objective of the system is to continuously monitor gas levels, detect potential leakage, forecast future consumption patterns, and alert users before critical conditions arise.

The core of the system architecture consists of various sensors, signal conditioning units, and a microcontroller that serve as the primary data acquisition and processing components. A load cell sensor, interfaced with an HX711 amplifier module, is used to measure the total weight of the cylinder and calculate the exact quantity of LPG remaining after deducting the tare weight. The load cell operates based on strain gauge deformation, converting mechanical force into measurable electrical signals that correspond to the amount of gas present in the cylinder. This data is collected and processed by a microcontroller such as an ESP32, NodeMCU (ESP8266), or Arduino Nano which is responsible for filtering the sensor output, performing initial computation, and classifying the gas level into defined categories such as full, half, low, or empty.

In parallel, a gas leakage detection module—typically using an MQ-135 sensor is deployed to ensure user safety by sensing the concentration of LPG vapours in the surrounding environment. When the detected concentration exceeds a predefined safety threshold, the microcontroller activates an audible buzzer, visual indicators, and simultaneously sends a digital alert through the connected IoT platform. This immediate response mechanism ensures that any potential hazards due to gas leakage are addressed promptly. The entire sensing and control unit is powered through a regulated DC source or rechargeable battery setup, providing uninterrupted operation even in cases of power failure. For extended communication range and deployment flexibility, optional GSM or LoRa modules can be incorporated, especially in regions lacking stable Wi-Fi connectivity.

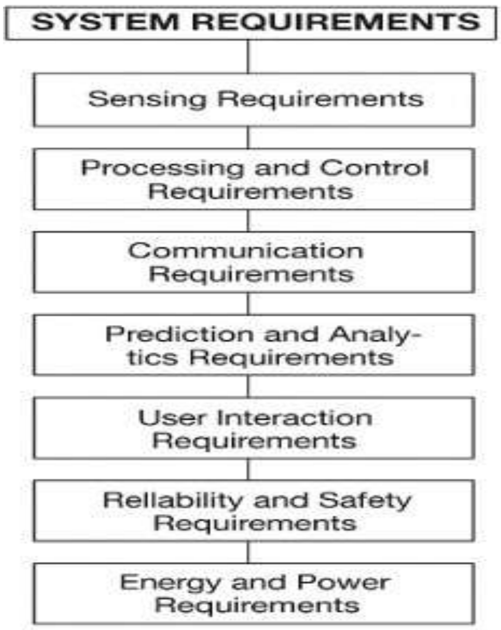

Fig. 2. 1: Block diagram of system requirements

The software and communication architecture of the system enable seamless data transfer and visualization. The firmware embedded in the microcontroller manages sensor calibration, data collection, and wireless communication through protocols such as MQTT, HTTP, or Blynk IoT. The processed data comprising gas level, leakage status, temperature, and timestamp is transmitted wirelessly via Wi-Fi or GSM networks to a cloud-based platform. On the user side, a dedicated mobile or web application provides an interactive dashboard that displays the real-time gas level, historical usage trends, safety alerts, and estimated refilling timelines. The application also supports notifications and warning messages through push alerts or SMS, ensuring that users are instantly informed of critical conditions. The cloud server, such as Firebase, AWS IoT Core, or Thing Speak, functions as a secure data repository and computation hub, managing storage, retrieval, and analytics tasks while enabling multi-user access and scalability across different operational environments.

The intelligence of the system lies in its AI-driven predictive module, which utilizes supervised learning algorithms trained on historical consumption data to anticipate future gas usage patterns. By analyzing parameters such as average daily consumption, time intervals between refills, ambient temperature variations, and user behaviour trends, the AI model predicts the expected depletion date of the LPG cylinder. This predictive capability transforms the system from a reactive monitoring tool into a proactive management solution that automatically generates refill reminders, optimizes resource utilization, and minimizes unexpected gas shortages. Moreover, the adaptive learning feature allows the model to continuously refine its accuracy as new data is collected, ensuring reliable forecasting even under changing usage conditions.

In operation, the system follows a continuous data cycle that begins with sensor-based data acquisition, followed by real-time processing and wireless transmission to the cloud, where data is analyzed and visualized. The AI engine interprets this information to forecast the next refill date and identify any anomalies that might suggest leakage or abnormal consumption. Alerts are then automatically dispatched to users, ensuring that they remain informed and can take timely action. This closed-loop process of sensing, analyzing, predicting, and alerting creates a self-sustaining intelligent ecosystem capable of managing LPG consumption autonomously.

The integration of IoT and AI technologies in this architecture offers several significant benefits, including enhanced user safety through instant leak detection, reduced operational downtime through predictive refilling alerts, and improved transparency through real-time monitoring and historical data visualization. Furthermore, the system supports scalability and remote accessibility, making it suitable not only for domestic households but also for commercial kitchens, small-scale industries, and community-level LPG distribution networks. By leveraging real-time data analytics and machine learning, the system contributes to building a smarter and safer energy management infrastructure aligned with the principles of Industry 4.0 and sustainable smart living.

3. LITERATURE REVIEW

The evolution of Internet of Things (IoT) architectures has significantly transformed the design of monitoring and safety systems across domestic and industrial applications. Early research in IoT-based monitoring primarily focused on real-time data acquisition and remote visualization using wireless-enabled embedded platforms such as Arduino and ESP32. These systems employed Wi-Fi or GSM modules to transmit sensor data to cloud servers, enabling remote supervision through web dashboards or mobile applications. Although these implementations improved accessibility and operational transparency, their logic frameworks were predominantly threshold-based and reactive in nature.

Sensor-centric monitoring systems have demonstrated substantial improvements in measurement precision and operational reliability. Load cell-based weight measurement systems integrated with high-resolution analog-to-digital converters (e.g., HX711) provide accurate force-to-voltage conversion for quantitative analysis. Such systems are widely adopted for resource estimation due to their high sensitivity and low measurement error. Similarly, gas detection systems utilizing MQ-series semiconductor sensors operate based on variable resistance principles in the presence of combustible gases. These systems typically employ comparator-based or microcontroller-driven threshold detection to trigger alarms when gas concentration exceeds safety limits. While effective in hazard detection, these implementations lack predictive modeling and adaptive learning capabilities.

Recent advancements in Artificial Intelligence (AI) and Machine Learning (ML) have introduced predictive analytics into embedded IoT ecosystems. Supervised learning algorithms such as linear regression, autoregressive integrated moving average (ARIMA), and time-series forecasting models have been employed to estimate consumption trends and forecast depletion timelines. Furthermore, lightweight neural network architectures suitable for resource-constrained embedded environments have been explored to enhance prediction accuracy without excessive computational overhead. These predictive frameworks enable anomaly detection, trend extrapolation, and probabilistic forecasting, thereby shifting system operation from reactive threshold-based alerting to proactive decision support.

Cloud-integrated IoT systems further extend functionality through scalable data storage, distributed analytics, and real-time synchronization. MQTT- and HTTP-based communication protocols facilitate efficient low-latency data transmission between edge devices and cloud servers. However, despite these technological advancements, existing research largely addresses sensing, communication, or predictive analytics as isolated modules. Comprehensive architectures that tightly integrate multi-sensor data acquisition, reliable wireless communication, edge-level preprocessing, and AI-driven lifecycle forecasting within a unified framework remain limited.

Moreover, most previously reported systems lack adaptive retraining mechanisms that continuously refine predictive accuracy based on newly acquired data. Scalability across multiple nodes, secure data transmission, energy-efficient operation, and industrial-grade robustness are additional aspects that are insufficiently addressed in current literature.

4. CONCLUSION

The development of the AI-Driven Intelligent Monitoring and Predictive Alert System for LPG Cylinder Lifecycle represents a significant advancement in smart energy management. By integrating IoT and AI technologies, the proposed system delivers accurate, real-time, and predictive monitoring of LPG usage. The coordinated interaction between hardware and software ensures continuous data acquisition, reliable communication, and timely alerts, effectively preventing gas depletion and leakage-related accidents.

The experimental results confirm that the system provides measurable benefits, including enhanced safety, improved user convenience, and optimized resource utilization. The scalable architecture allows deployment in both domestic and industrial environments. As automation and energy efficiency continue to shape modern infrastructure, this project establishes a strong foundation for intelligent, sustainable, and data-driven LPG management systems.

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