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Next Generation IoT Framework for Smart LPG Cylinder Monitoring, Safety Detection and Autonomous Refill Booking

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Abstract

The proposed Next-Generation IoT Framework for Smart LPG Cylinder Monitoring, Safety Detection, and Autonomous Refill Booking is an intelligent solution aimed at ensuring increased safety, energy savings, and convenience in LPG use. This system is comprised of sensors such as load sensor, gas leak detector, pressure and temperature sensor coupled with a low power microcontroller and wireless communication module like NB-IoT or LoRaWAN. Load sensor helps in determining the quantity of LPG left in the cylinder based on its current weight. The sensors can detect any leakage in the gas, changes in pressure and temperature, or any movement and raise instant alarm along with alerting remotely in real time. Cloud backend will carry out further analysis and trigger refill booking automatically with the help of gas services provider through secure API integration.

Keywords: Internet of Things (IoT), Smart LPG Monitoring, Gas Leakage Detection, Real-Time Monitoring, Safety Alert System.

1. Introduction

Internet of Things (IoT) is a major technological step forward as it allows for the connection of physical devices with digital systems. By using sensors, actuators, embedded

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software, and internet connectivity, common objects are being made "smart" by allowing them to collect, process, and share data. In addition to traditional machine-to-machine communication, IoT includes cloud computing, real-time analytics, and intelligent decision-making, thus giving it more functionality than machine-to-machine communication. All of these advancements have led to the creation of smart environments in various areas such as healthcare, transportation, agriculture, and home automation. Since its conceptual start in the late 20th Century, the IoT has evolved continuously due to advances in wireless communication, data processing and low-cost embedded systems. One area where IoT is widely applied is in enhancing the safety and efficiency of both domestic and industrial environments. For instance, Liquefied Petroleum Gas (LPG) cylinders are commonly used for cooking in residential and commercial kitchens because they are relatively inexpensive and provide very high energy efficiencies. However, LPG usage carries various risks, particularly spillage, over-consumption of LPG, and lack of timely monitoring. In the past monitoring has been performed with manual and reactive methods that create safety hazards, cause economic losses and delay any actions that may be needed during an emergency situation. This shows the increasing need to develop a smart and automated LPG monitoring system to provide real-time data and alerts.

The Internet of Things (IoT) can help address issues related to continuous monitoring and intelligent control as well as automated controls via remote communication capabilities. Sensor Data is transmitted wirelessly using a variety of communication systems (i.e.: Wi-Fi, GSM, IoT protocols) to cloud-based platforms, enabling users to remotely view their LPG levels, identify anomalies, and receive information through a mobile or online application. Cloud computing enhances the capabilities of the system by providing an environment for storing, analysing, and predicting information regarding users' LPG use to ensure efficient use of gas and timely refilling.

IoT-based systems also improve the safety of consumers and businesses by providing automated processes and real-time alerting mechanisms. The proposed smart LPG monitoring system will utilize sensors to detect gas leaks or otherwise identify abnormal conditions. Where such a condition is identified, an immediate notification will be provided alerting mobile users, sounding alarms, and contacting emergency services. The reduction in human intervention when such an event occurs and the increased speed at which a resolution occurs, directly results in safer environments for consumers and businesses. Overall, the IoT-enabled LPG monitoring system will create safer operational environments for both consumers and businesses, while contributing to the creation of smarter and more secure living environments.

2. Literature Review

The integration of the Internet of Things (IoT) into gas leak detection systems is receiving increasing attention for its security enhancements, real-time capability, and minimization of accidents in residential and industrial applications. A number of researchers have studied various types of gas leak detection systems that feature IoT-enabled LPG monitoring systems with different types of architecture, sensor technologies, and communication protocols. For example, Mahfuz et al. [1] described a smart monitoring and detection system that uses gas sensors and microcontrollers to detect LPG leaks and notify customers through IoT platforms. While their system is capable of real-time monitoring, it lacks the prediction capabilities required to anticipate LPG leaks.

Similarly, Kodali et al. [2] developed a gas monitoring and detection system for industrial safety by combining gas sensors with the IoT and detecting dangerous gases leaks. Although this system is intended for use in industrial environments, there is limited scalability due to the system's current design and level of performance. Research efforts after these contributions focused on enhancing both the design and application of the systems developed by Mahfuz et al. [1] and Kodali et al. [2].

Ahmed et al. [3] developed an IoT-based LPG leak detection system for residential and commercial use that includes wireless communications capabilities. Jena et al. [4] built on the work of Ahmed et al. by combining IoT and successful sensing technologies to create a more accurate and responsive leakage detection mechanism. Oo et. al [5] proposed a new hybrid system that monitors, both LPG amounts and leaks, thus improving how usable oil is, as well as preventing accidents. Many research articles have explored LPG monitoring with regards to gas leaks too.

Srivastava et al. [6] suggested using Internet of Things (IoT) devices to automatically track the amount of gas remaining in the cylinder, giving users better visibility for timely refilling and more efficient resource management. Yahaya et al. [7] had developed a leaking and monitoring device that could do both. They gave some automation capabilities, such as being able to control valves or shut off valves using remote access. Both Meshram et al. [8]

and Manhas et al. [9] demonstrated low-cost, frequently deployable IoT-based leak detectors, making them economically feasible and easy to implement within residential settings. Microcontroller-based monitoring and control systems have been developed and tested around the world.

Anuradha et al. [10] demonstrated a monitoring and control system, using IoT-enabled, microcontroller technology, which has the ability to respond automatically to gas leaks. More recent contributions from prior researchers have included the development of improved-real-time, reliable, smart monitoring devices. For example, Olayiwola et al. [11] presented an improved, more reliable, smart device with new alert notification capabilities. Additionally, Rakesh et al. [12] contributed an automatic alert notification system, using SMS, to immediately alert users even at low-internet connections. The recent developments of more advanced IoT systems have shown improvements made in collecting and utilizing data, with actionable advanced analytics. Furthermore,

Altaie et al. [13] proposed an IoT-enabled system that provides data analysis capabilities to predict whose gas use patterns and determine potential gas leaks. Further, Ojo et al. [14] discussed about real-time monitoring as well as system efficiency while Jadhav et al. [15] utilized the ESP32 microcontroller for better connectivity and faster processing capabilities. There have been efforts to introduce user-friendly notification mechanisms and smart communication tools as well. For instance, Afiyat et al. [16] used Telegram Bot Notification in an IoT-based LP gas leak detection system to provide instantaneous notifications.

The above analysis reflects the growing trend of intelligent and connected safety solutions. However, there are some challenges associated with the existing LPG leak detection systems. For example, there is room for improvement in terms of predicting future leakage and the system being dependent on network connectivity. There is also no standard framework for implementing such systems at scale.

3. Problem Statement

Cylinders filled with liquefied petroleum gas (LPG) are commonly used by individuals and industries for cooking and heating purposes. The current systems employed to measure LPG usage and consumption lack sufficient monitoring and protection systems. Users cannot gauge the quantity of gas remaining in the cylinder, resulting in unforeseen exhaustion of the gas and causing inconveniences. Moreover, leaking gas from the cylinder can be dangerous because it may cause hazards, including fires or explosions. The existing monitoring systems concentrate on either detecting the leakage of the gas or monitoring the quantity of gas left in the cylinder.

However, most of these systems require users to manually arrange for gas refill booking despite receiving low gas alert notifications. Besides, current systems have several limitations, including limited sensors, absence of real-time monitoring, non-scalable designs, and complex usage interfaces. Hence, the necessity arises to design an intelligent IoT-enabled LPG monitoring system to effectively monitor the quantity of gas left in the cylinder, detect any leaking gas, notify users about possible hazards, and arrange for automatic gas refill booking once the gas level falls below the specified threshold.

4. Proposed System

This proposed system monitors the LPG cylinder level, detects any leakages, and autonomously arranges for the cylinder refills. This system makes use of sensors, microcontrollers, and internet connections to perform the monitoring activities for the user. In the proposed system, a load cell sensor is used to detect the weight of the LPG cylinder that is needed to estimate the level of the gas left in the cylinder. Gas leak detector (MQ-6 and MQ-2) is utilized to sense any leaking of LPG gas. These sensors are linked to a microcontroller like Arduino or ESP8266/ESP32, that process all these signals and collect data from these sensors. Data collected by the system is transferred to a server or mobile application using IoT through Wi-Fi or GSM modules. In addition, users can check the status of their cylinders via an app or web interface on their phones. When the gas level goes down below a certain threshold value, the system sends alerts, and autonomously starts refill booking services. If any leakage occurs, then the system triggers alarm or notifies the user through SMS or mobile applications.

The proposed monitoring system uses the four major components of an IoT-enabled system (shown in Figure 1), including common forms of sensing, processing, communication, and control, to achieve automated monitoring of LPG cylinders in conjunction with continuous monitoring of gas levels for safety.

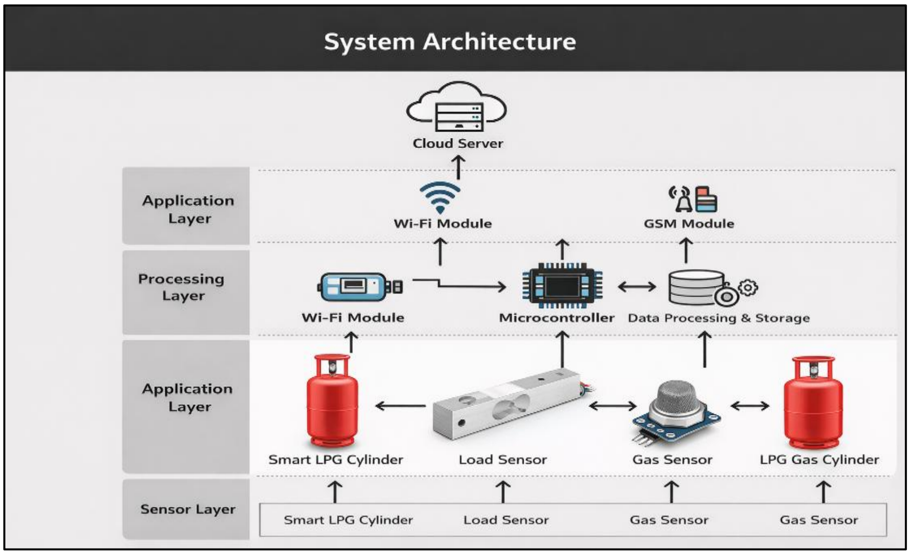

Figure 1. Overall Architecture of The Proposed

- **Sensing Layer:** The sensing layer collects real-time data from the LPG system. It includes sensors such as a load cell sensor to measure the weight of the LPG cylinder and a gas sensor (MQ-2/MQ-6) to detect gas leakage. These sensors continuously monitor the cylinder condition and send raw signals to the processing unit.

- **Processing Layer:** The processing layer consists of the microcontroller (Arduino or ESP32), which acts as the main control unit of the system. It receives data from the sensors, converts analog signals into digital values, processes the data, and determines whether the gas level is low or if leakage is detected.

- **Communication Layer:** The communication layer transfers the processed data from the microcontroller to the cloud or mobile device. It uses Wi-Fi or GSM modules to send real-time data, alerts, and system status information to the cloud platform for remote monitoring.

- **Application Layer:** The application layer provides the user interface through a mobile app or web dashboard. Users can monitor LPG levels, receive leakage alerts, view notifications, and initiate or confirm automatic LPG refill booking through this layer.

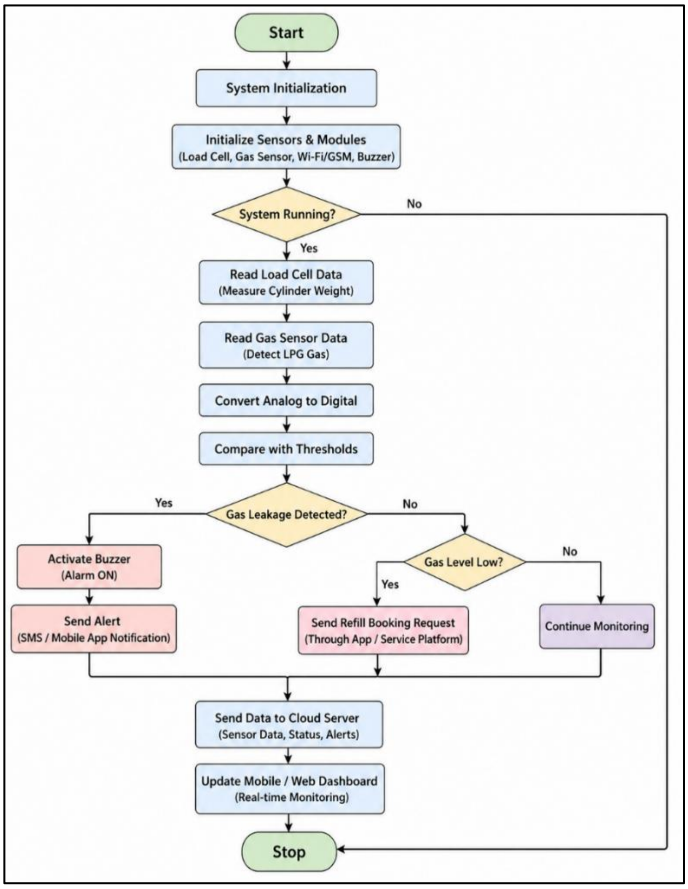

Figure 2. Operational Workflow of The System

Figure 2 illustrates the operational workflow of the proposed IoT-based smart LPG cylinder monitoring system. This process forms part of the system's continuous cycle, where there is constant gathering of data, analysis of that data, and decision-making based on such analysis.

All hardware components are powered on when the system starts up, including the load cell sensor, combustible gas sensors (MQ-2 or MQ-6), networking microcontroller (such as an Arduino or ESP32), communications module (Wi-Fi or GSM) and buzzer, and will continually operate as intended. During the sensing stage of system operation (continuous real-time data retrieval via sensors), the load cell will generate information regarding the total weight of an LPG cylinder in order to estimate how much energy (gas) remains in the cylinder, and the gas sensor will generate an alert to indicate the presence of a combustible gas in the area surrounding the gas cylinder.

The analog signals from each of these two sensors will be routed to the microcontroller, which will convert the analog values into digital signals, compare these digital values against their pre-defined threshold values, and use the result of this comparison to decide regarding whether or not the cylinder is "safe" or not. If the gases detected in the area surrounding the LPG cylinder exceed the threshold values determined to be acceptable, then an alert will be generated immediately via the buzzer and through the use of notifications and/or SMS messages to notify a user of the imminent danger. If the leakage is absent, the system continues with its next task of monitoring the levels of gas. Whenever the weight of the cylinder falls below a certain threshold, it will detect that the gas level is too low, triggering automatic booking for refilling through the application/service portal. All data collected by the sensors, status messages of the system, and other alerts are uploaded to the cloud server through IoT-based communications.

5. Results and Discussion

The functionality of the suggested IoT-based smart LPG cylinder monitoring system was analyzed based on its real-time operation. As mentioned in table 1, The system is composed of several components such as sensing, processing, and communication blocks that are responsible for continuous monitoring and intelligent decisions. The use of the Arduino microcontroller in combination with gas and load cell sensors allowed us to effectively obtain both environmental and cylinder information. It is important to note that gas threshold and weight limitations were essential criteria for initiating different alert and automation processes. The obtained results prove that the IoT-based system works efficiently when it performs the task of monitoring LPG cylinders. In particular, it can correctly determine the weight of a cylinder and report its remaining level in real time. If the measured value becomes lower than the pre-set threshold, the automatic booking process starts. Finally, the communication block allows transmitting sensor data to the cloud service and UI without any delays.

Table 1. Technical Specifications and Configuration Parameters of the Proposed System

Parameter	Specification
Microcontroller	Arduino
Gas Sensor	MQ-2
Weight Sensor	Load Cell

Communication	Wi-Fi
Programming Language	Embedded C, Python
System Configuration	Intel i5, 8 GB RAM
Sampling Type	Real-time monitoring
Gas Threshold	Predefined ppm limit
Alert Mechanism	Buzzer, SMS, Blynk app
Data Processing	Threshold-based logic

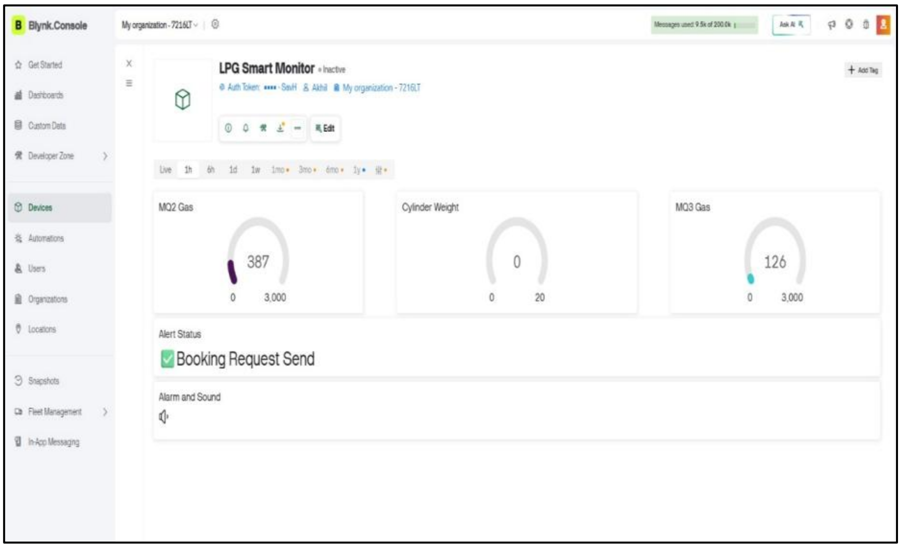

Figure 3. Real-Time Monitoring Interface Displaying LPG Cylinder Weight, Gas Level Percentage, and System Status

Figure 3 illustrates monitoring in real-time via user interface/dashboard for LPG cylinder parameters. Therefore, it indicates such key parameters as the weight of the cylinder and percentage of gas level (and status of the system). This monitoring shows that the sensor readings are continuously updated to provide accurate and timely information to the user. The consistency and regularity of the readings have shown that the sensing layer and data acquisition process are operating correctly without any noise or fluctuation. This demonstrates the reliability of the load cell sensor as well as the effectiveness of the data processing unit for converting raw signals into useful information.

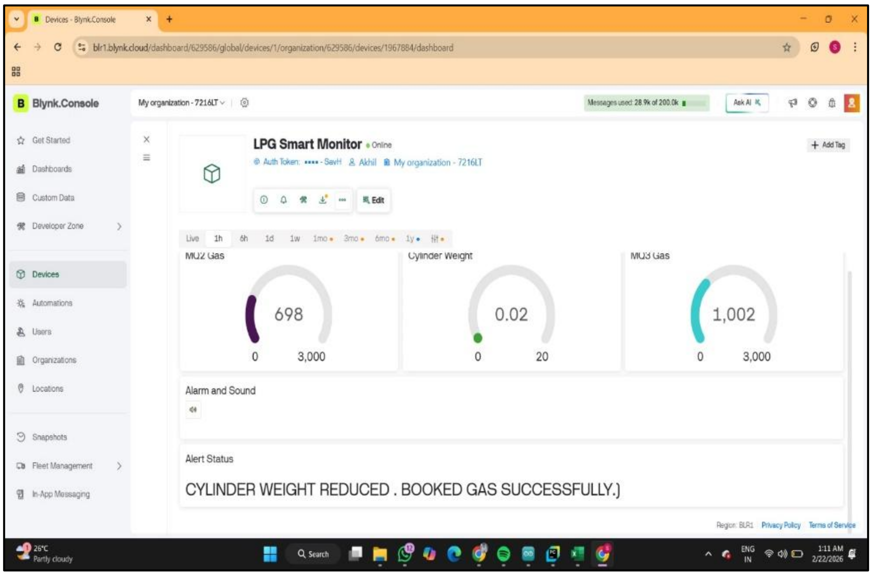

Figure 4. Automated Alert Generation and LPG Refill Booking Process Triggered by Low Gas Level Detection

The scenario shown in figure 4 has been captured while testing the system. In this scenario, the gas sensor detects LPG concentration above its threshold (predefined). Therefore, once this occurs, the system immediately goes into alert mode. Using safety mechanisms such as buzzer alarms and notification triggers, the indications has been activated because of high sensitivity and fast response time from an MQ-2/MQ-6 sensor. Additionally, the fast response indicates that the system is capable of adequately handling/monitoring emergency situations to reduce possible risks from gas leakage.

Whenever the LPG reaches a level lower than the threshold value, an alert is raised along with a booking request being initiated by the system. The result will be a display of notification alerts or messages showing the successful booking or the message transmitted regarding the alert. This verifies that there was proper integration between the sensor, decision making, and the application layers as required.

In summary, the outcomes clearly show that the system performs at high levels of accuracy concerning the estimation of LPG level and leak detection as well as in executing the alerts and booking procedures. From a careful review of the analysis carried out based on the results, the system appears to be reliable and applicable in practical settings. In comparison with other conventional systems used for LPG detection and monitoring, the present system scores much better in terms of safety and efficiency.

6. Conclusion

The proposed IoT-based smart LPG cylinder monitoring system is an appropriate approach to enhancing safety, efficiency, and ease of use in gas-consuming environment. Due to incorporation of load cells as well as MQ series of gas sensors in the IoT-based smart system, there will be effective monitoring of the levels of LPG, as well as timely identification of any leakages of the gas. According to the results of the experiment, the proposed design has been shown to enhance effective sensing, processing, and communicating of data gathered by the sensors while ensuring the user gets notified instantly of emergency conditions. In addition, automatic booking of gas refill by the system is important in preventing the unexpected exhaustion of the gas. Efficient interaction among sensing, processing, communicating, and application layers is an indication of effectiveness of the proposed design. Based on the findings of the experiment, it can be concluded that the proposed IoT-based system works effectively.

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