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Proceeding Paper

LPG Smart Guard: An IoT-Based Solution for Real-Time Gas Cylinder Monitoring and Safety in Smart Homes †

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Abstract: An advanced IoT-based Liquefied Petroleum Gas (LPG) cylinder monitoring and safety system is presented in this work. The proposed technique provides continuous monitoring of residential gas usage and detects any potential leakage. It utilizes an MQ135 gas sensor for gas leakage detection, a load cell to monitor the weight of the cylinder, and a DHT22 sensor for temperature sensing. The sensors are mounted on a customized trolley for domestic LPG cylinders. All the sensors are connected to NodeMCU microcontroller, which exchanges sensor data with a cloud platform using HTTP GET and POST method to transmit the data to a cloud-based MySQL database. Unlike other existing methods, the proposed approach does not necessitate any modifications to the existing setup, which includes the gas cylinder, regulating valve, and distribution pipe. Furthermore, a mobile application that emphasizes the needs of the user is developed to enable a wider range of functionalities using cloud data collected from the sensors. The software facilitates the real-time monitoring of gas levels, provides comprehensive usage records for daily, weekly, and monthly intervals, issues immediate alarms in the event of gas leakage, low gas levels, and detects any unauthorized movement of the LPG cylinder such as theft. The proposed technique not only improves user safety but also streamlines gas cylinder management with predictive analytics based on gas consumption trends and projected days of usage. Moreover, the application includes a functionality that automatically orders a new cylinder with the vendor when the gas level drops below the predetermined threshold, therefore ensuring continuous availability of gas supply.

Keywords: IoT; gas leakage detection; gas level monitoring; smart home safety

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1. Introduction

Liquefied Petroleum Gas (LPG) is a source of energy that people cannot easily live without in today's world. The reason is, it is widely used in houses, industries, and commercial sectors for cooking and space heating purposes. Its use has been associated with the biggest risks in the form of leaks and explosions. Such incidences have resulted in devastating consequences continent-wide.

The risks associated with LPG can increase due to the difficulties in handling gas cylinders. Users exhaust the gas without their knowledge, which can be highly inconvenient, especially during important operations. This disturbs not only daily activities but also poses severe safety hazards. A related issue is that management of cost is inefficient due to the lack of gas consumption data, which limits the possibility for users to engage in budgeting exercises for their energy needs.

The consequences of an empty LPG cylinder go beyond being just an inconvenience. In industrial applications, for instance, an empty cylinder could actually stop the whole production process, causing tremendous downtime and money loss. This can leave the families with no means of cookery.

There is a risk of accident especially when gas has leaked into a poorly ventilated area. Most of the fearful accidents associated with LPG usage are gas explosions. Waste gas is liable to burn while collecting in some corner, and with a spark or flame, a gas explosion takes place. This leads to an immense blast, literally destroying anything, plus the fact that a number of people are hurt and others killed in the process. Reports indicate that many of these explosions could have been prevented if early warning systems were in place to detect leaks before they became dangerous [1].

Statistics say it all. In India, some 5122 LPG-related accidents have been reported in the seven-year period from 2017 to 2023, causing many of the recorded injuries and fatalities when set aside result in the substantial property damages. The insurers have paid more than 67.62 crore (circa $8.3 million) as claims in the same period according to [2].

2. Literature Review

A.K. Srivastava et al. [3] developed an IoT-based system for LPG level monitoring and leakage detection using a cylindrical container with water, to simulate the consumption of gas, and lighters for leak detection. An LCD and a mobile application were added to make the device functional. M.S. Kumaran et al. [4] developed a system that monitors LPG levels with a load cell sensor, detects leaks with an MQ-6 sensor, and uses an ESP-32 microcontroller to display data on an LCD and transmit it to mobile applications, offering both local and remote monitoring. A. Macker et al. [5] proposed a framework that monitors LPG cylinder weight and gas concentration, automatically sending SMS alerts to users and operators when thresholds are reached. The system uses GSM Modem and sensors, allows automatic cylinder booking and alerts users of potential gas leaks. N. Mahfuz et al. [6] developed a portable LPG detection system using integrated NodeMCU, MQ5, and MQ6 sensors, and DHT11 for temperature and humidity monitoring with data access from a web server and SMS alerts for leak access. M. Dai et al. [7] suggested a cost-effective, battery-powered device with mass flow sensing capabilities for effective and practical management of gas cylinders for applications with critical needs like medical oxygen supply, along with cloud-enabled functionalities. S.N. Zinnuraain et al. [8] presented a cost-effective system to connect with LPG leakage and usage monitoring, using IoT to notify users via a mobile app. E.N. Odonkor et al. [9] presented a system designed with Proteus and Arduino software, incorporating a solenoid valve, temperature, and gas sensors to monitor and control LPG flow, detecting leaks and preventing fire outbreaks. The gas supply automatically shuts off when leaks or high temperature are detected. S. Chawla et al. [10] adopted an advanced safety system for LPG gas cylinders, which integrates gas leakage and fire detection, weight monitoring with voice control for enhanced user safety and convenience. K. S. Chakradhar et al. [11] introduced an IoT-based LPG leak detection system for residential and commercial premises, using an Arduino-based MQ06 sensor. Using the ESP8266 Wi-Fi module for real-time monitoring and data transmission, users are alerted via a web interface.

While current methods of LPG leak detection and monitoring offer various functionalities, they often lack comprehensive integration and real-time data tracking across different time frames. Most of the existing systems focus mainly on gas leakage detection or simple weight monitoring, without detailed usage records for daily, weekly, and monthly trend tracking. Moreover, some systems require modifications to the gas valve that could be harmful and lead to damage to the device. Additionally, low battery warning is ignored by some methodologies, which can result in failure during a very critical period of the system. In contrast, this paper integrates all these features into one single, non-invasive solution. The proposed work provides integral monitoring of gas consumption over time, along with prompt leakage detection and alert. The system also includes low battery warnings to ensure continuous operation without modifications of the existing gas infrastructure. This multi-component, integrated approach addresses the shortcomings in the current solutions and provides a safer and more reliable way of managing LPG cylinders.

3. Methodology

The proposed system uses an integrated structure of sensors and micro-controllers that gives instantaneous information on the concentration of gases, possible leakages, and safety notifications. The components used in the system are:

1. NodeMCU (ESP8266): It is the microcontroller of the system. All the sensor data are processed through this unit, which transmits the information via Wi-Fi to a cloud. The NodeMCU with an embedded Wi-Fi module can continuously send updates and notifications in real time to the user by communicating with the mobile application.
2. Gas Sensor (MQ135): The gas sensor is used to detect hazardous gases including LPG. It operates based on the principle that a change in the resistance level varies with the presence of the gas which is converted to a signal readable by NodeMCU. If the gas concentration crosses the preset limit, then the system would activate an alarm and send notifications to the users.
3. Temperature and Humidity Sensor (DHT22): The surrounding temperature and humidity around the LPG cylinder are measured by the DHT22 sensor. This plays a significant role in monitoring environmental factors that may lead to gas leaks and other safety hazards. The DHT22 produces accurate readings handled by NodeMCU and displayed on the user interface, thereby ensuring the system works with safe limits of temperature and humidity.
4. Load Cell (50 kg) with HX711: This sensor makes use of a linear bar load cell of up to 50 kg, which is adequate for most LPG cylinders used at home. The load cell has an interface of the HX711 24-bit analog-to-digital converter for accurate weight measurement. This provides the information on the amount of gas left inside a cylinder according to its weight.

4. Proposed Solution

4.1. Block Diagram

Figure 1 illustrates the general configuration of the IoT-based monitoring system that uses the Node MCU microcontroller. Different sensors such as temperature, load, and gas sensors feed input to the system, and the system responds to the same by local alarm through LEDs and a buzzer. It has on-board wireless connectivity that transfers the real-time data to a mobile app and cloud, thereby allowing remote accessibility for monitoring and control.

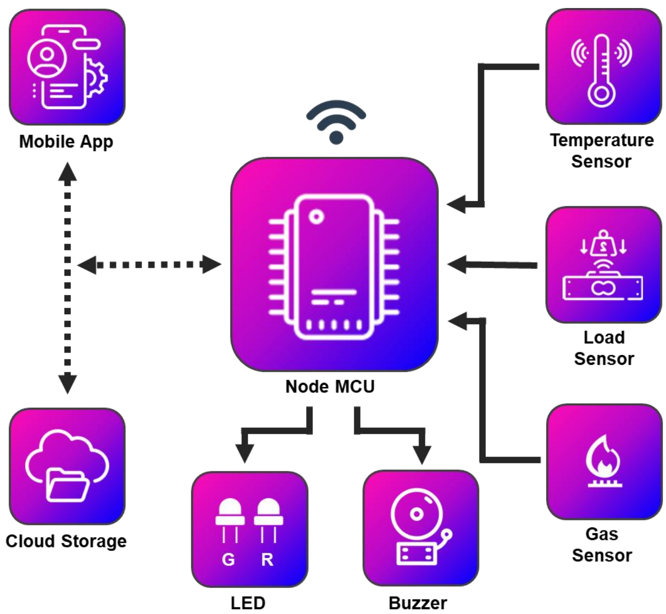

Figure 1. Block diagram of the proposed system.

Figure 2. Real-time implementation of the proposed system.

4.2. System Description:

The system includes several interconnected hardware devices that perform various functions aimed at enabling effective monitoring and increasing user convenience. The most central item within this system is an innovatively designed smart tray that allows for smooth movement of the gas cylinder in all the directions within the kitchen or any other room. The tray provides not only a stable platform for the cylinder but also a place to mount critical components that include a battery, a NodeMCU microcontroller, sensors, and alert mechanisms that enable advanced functionality for the system.

The system's functionality is simplified in Figure 3, starting right from initialization to real-time decision-making based on sensor data and server connectivity. Figure 3 shows how the system constantly checks on gas usage and environmental conditions for timely alerts and notifications to the user via a buzzer.

The NodeMCU microcontroller is the central processing unit of the system. In general, it is responsible for the control and data acquisition from all sensors of the system, data processing, and subsequent passing to the cloud server via Wi-Fi. NodeMCU, respected for its space-saving structure, integrated with Wi-Fi, allows immediate tracking and uploading of data online, thus providing the ability to have the users' cylinder information monitored remotely by using a mobile application. The system is powered by a battery, ensuring continuous operation. A low battery alert is also included to notify the users about recharging the battery to avoid system failures.

The MQ135 Gas Sensor continuously monitors the atmosphere around the gas cylinder in case of a leakage. In case of a leak, the sensor sends a signal to NodeMCU, which will turn on an audible alarm using an onboard buzzer and send a similar notification to the user's mobile device. Thus, ensuring immediate response which is very critical regarding an accident and safety of users. Besides gas leak detection, the system adopts the DHT22 sensor to measure temperature and humidity in the surrounding. This particular sensor continuously monitors the environmental conditions around the cylinder and give information on its safety status. The two sensors shall be put in operation day and night in providing the real-time current safety conditions of a place. The system also has a load cell interfaced to it, measuring the quantity of gas left within the cylinder. After the sensor measures the weight of the cylinder, this would be transmitted into the NodeMCU to calculate the amount of gas by removing the tare weight of the cylinder, which was fed previously. The load cell has to be activated at hourly intervals so that gas consumption can be rightly measured and the consumer has to be informed about their trends, which enables them to manage their gas. All of these makes the system user-friendly and lets the user know its status at a glance with visual and audible notification. Two LEDs are mounted on the tray: one red, indicating the on/off system status, and another green, indicating internet connectivity status. That way, users can easily check that the system is up and it's connected to the cloud. In addition, a buzzer is used to alert users on major events such as gas leaks and high-temperature readings in an attempt to lead to better safety practices.

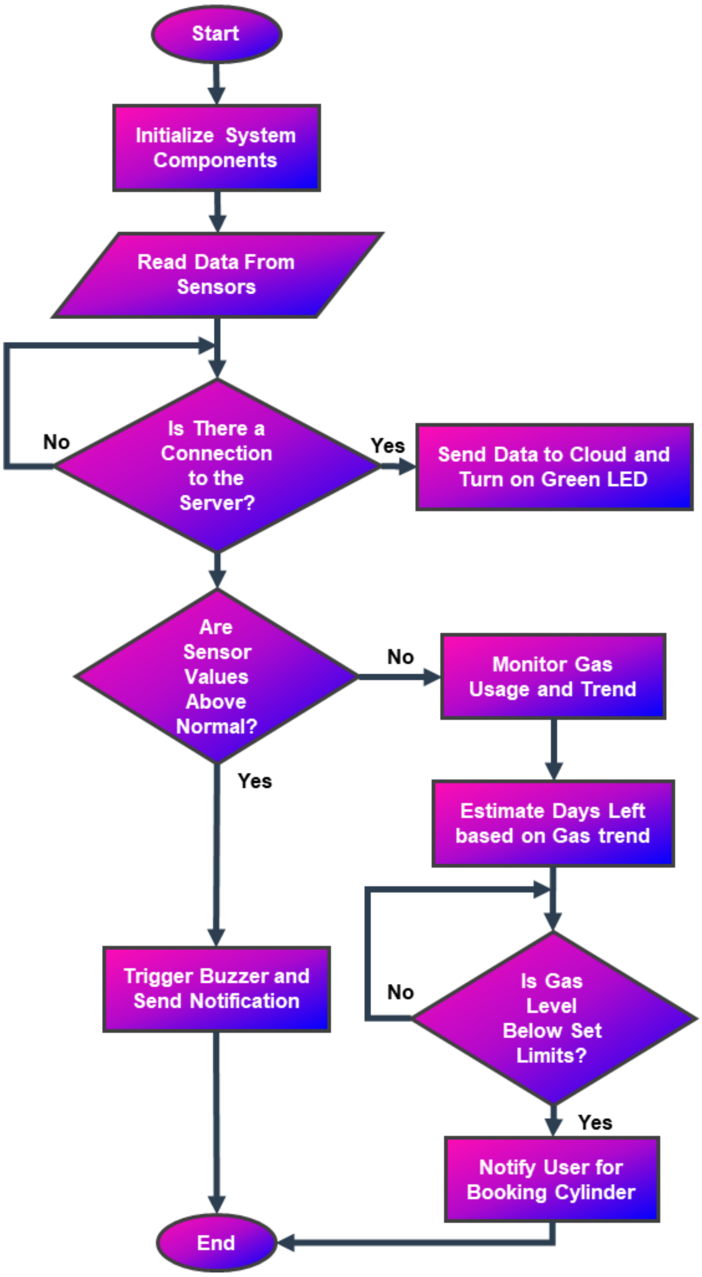

Figure 3. Flowchart of functionality of the proposed system.

The MQ135 Gas Sensor continuously monitors the atmosphere around the gas cylinder in case of a leakage. In case of a leak, the sensor sends a signal to NodeMCU, which will turn on an audible alarm using an onboard buzzer and send a similar notification to the user's mobile device. Thus, ensuring immediate response which is very critical regarding an accident and safety of users. Besides gas leak detection, the system adopts the DHT22 sensor to measure temperature and humidity in the surrounding. This particular sensor continuously monitors the environmental conditions around the cylinder and give information on its safety status. The two sensors shall be put in operation day and night in providing the real-time current safety conditions of a place. The system also has a load cell interfaced to it, measuring the quantity of gas left within the cylinder. After the sensor measures the weight of the cylinder, this would be transmitted into the NodeMCU to calculate the amount of gas by removing the tare weight of the cylinder, which was fed previously. The load cell has to be activated at hourly intervals so that gas consumption can be rightly measured and the consumer has to be informed about their trends, which enables them to manage their gas. All of these makes the system user-friendly and lets the operator know its status at a glance with visual and sound signals. Two LEDs are mounted on the tray: one red, indicating the on/off system status, and another green, indicating internet connectivity status. That way, users can easily check that the system is up and it's connected to the cloud. In addition, a buzzer is used to alert users on major events such as gas leaks and high-temperature readings in an attempt to lead to better safety practices.

The data from NodeMCU is shared on the cloud and accessed via an application interface through a mobile device. This application provides the account of the user, registration and verification of login credentials for proper protection of data from unauthorized persons. The application's interface provides functionality to add a new cylinder or connect to an already existing one, while monitoring the current weight of the gas and analyzing usage trends supported by visualizations like bar charts. Graphs display gas consumption on daily, weekly, and monthly levels, giving users a great way to monitor their gas usage. This, in turn, provides access to historical data to study past trends and perform forecasts for the remaining days of gas based on average daily usage. It has also been integrated with other forms of alarms and notifications that would keep users updated on various conditions like gas leakage, high temperature, low levels of gas, status of the battery, Wi-Fi connectivity, and unauthorized movements. Each of these alarms, if triggered, causes a pop-up notification in the smartphone for effective communication. It also provides a facility for an automatic trigger of SMS to the gas supplier for cylinder refills and can be customized at the firmware level.

5. Results and Discussions

The data collected from the peripheral sensors connected to the NodeMCU is displayed on the Serial Monitor and simultaneously sent to the server using the HTTP Get-Post method. Figure 4 represents a screenshot of the Serial Monitor, showing key information such as the connection status to the NodeMCU and server, current gas levels, temperature, humidity, and various status indicators. To optimize memory usage, only the gas level data is stored, while other information (such as temperature, humidity, and status indicators) is displayed live within the application but not stored.

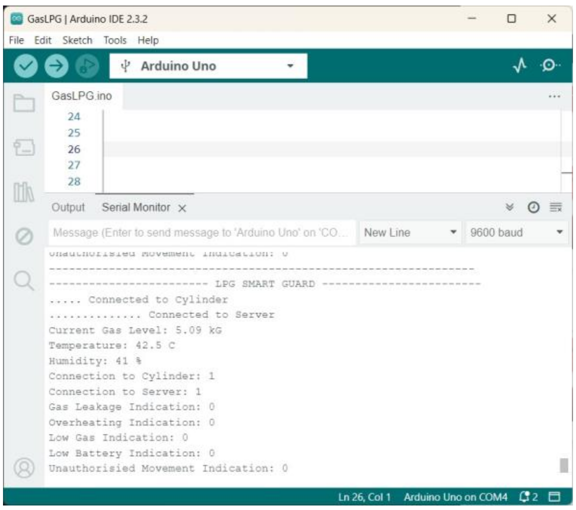

Figure 4. Serial Monitor with results.

Figure 5 shows a chart of gas consumption over the last seven days, including today's consumption. This chart allows users to track gas usage trends over the past week, helping them monitor daily consumption patterns. Figure 6 presents a broader view of the gas consumption trend from the time a new cylinder is registered in the app. By analyzing this data, users can estimate the remaining gas in the cylinder and predict the number of days left until the cylinder is likely to run empty, enabling more effective management of their gas usage.

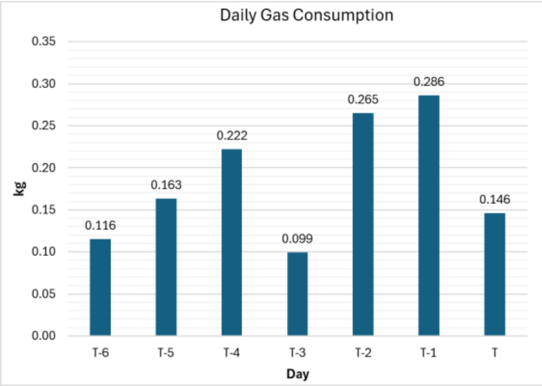

Figure 5. Daily gas consumption.

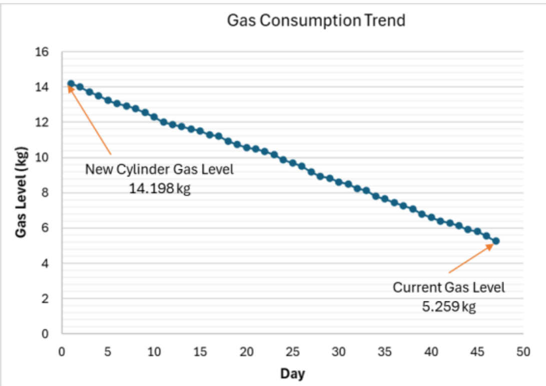

Figure 6. Gas consumption trend.

Mobile Application Description

Figure 7 shows the all-in-one functionality of the LPG Smart Guard mobile application. Logging being seamlessly performed, real-time gas level monitoring, temperature, and humidity tracking are available, as well as trend analysis of gas consumption via interactive graphs.

The Smart Gas Cylinder Monitoring System provides a reliable app for mobile devices, allowing users to access their information and key services from anywhere. The provision of intuitive interfaces has been made possible for smooth operation of the app, besides many other contributions towards the enhancement of home gas cylinder security management. Some of the key features and functionalities of the mobile application include:

1. User authentication and configuration

This application requires the user to register and login into their platform for security purposes. The user, once signed in, can either add a new cylinder into the system or create a link with one that has already been set up. The first setup involves giving some general information regarding the gas cylinder, for instance, the tare weight, so that there could be an efficient manner of monitoring the gas level.

Figure 7. Data dashboard of mobile application.

2. Dashboard Overview

The whole application is depending upon the dashboard, which gives a summarized overview about the status of a gas cylinder that includes:

- Current Gas Level: Provides the real content of gas within the cylinder in percentage and weight.
- Temperature and Humidity: The temperature and humidity readings from the DHT22 are instantaneous and show prevailing environment conditions around the gas cylinder.
- System Status Indicators: Graphical indications of power and connectivity states of the system.

3. Gas Usage Tracking

Fundamental functional elements of the application include monitoring over time the amount of gas used. The app provides daily, weekly and monthly consumption charts. It offers bar graphs for users to get clear indications of their gas consumption trends. User shall be allowed to toggle between the daily, weekly or monthly view to understand their consumption habits over different periods. Stats for daily, weekly and monthly usage with average daily consumption of gas are displayed.

4. Past Data and Forecasts

Historical data trends have a dedicated section within the app where users can perceive how much gas is consumed in the past. This includes:

- A line graph showing day-to-day gas consumption for a set period which will enable the users to develop trends that will lead to very informed decisions based on past trends
- The projected number of days left. This is based on the current gas on hand and average daily usage, the application projects and displays an estimation of reserve days of gas availability. It would help the user know exactly when it is necessary to refill.

5. Cylinder Booking

This eases the procedure of acquiring a new gas cylinder by the user. The users are able to simultaneously order a new cylinder by just sending an automated message to the gas vendor through the app. The message can be customized at the firmware level to include specific details as needed. This feature ensures that users will not be caught out by surprise shortages of gas and have enough gas to manage.

6. Alarm and Notification System

The application also provides a very comprehensive alarm and notification system dealing fully with security. The following alarms are integrated into the system:

- When gas leakage is detected, the gas leakage alarm sends an immediate alert upon detection of leakage by the MQ135 sensor.
- When the temperature sensor detects a temperature beyond the set limit of safety, an alarm is triggered to warn the user of any impending hazard.
- The application notifies the user when the gas level falls below a specified threshold, thereby encouraging them to arrange for a refill.
- Alerts the user if the battery of the system is too low and will keep functioning.
- If the system detects poor Wi-Fi connectivity, the application alerts and notify the user to check their network connection.
- Moving the cylinder off the tray without authorization triggers an alarm, raising suspicions of theft or mishandling.

Each of these alerts triggers a pop-up notification on the user's mobile device, ensuring that information is conveyed timely and relevantly, even if the app itself is not in active use.

6. Future Scope

The proposed system, while innovative, has a few limitations that could be further refined. The design uses a load cell to approximate the gas contained in a cylinder. A load cell would only determine the entire weight of the gas plus the cylinder. Since cylinders may have different tare weights, such methods could lead to inaccuracy in determining the actual LPG level. To overcome this, future iterations of the system could utilize ultrasonic sensors at the base of the cylinder, which would provide very accurate measurements of the gas content, irrespective of the weight of the cylinder.

7. Conclusions

The proposed IoT-based LPG cylinder monitoring and safety system provides a comprehensive solution for enhancing the safety, convenience, and efficiency of domestic gas usage. By integrating various sensors, the system ensures continuous and reliable data collection. The use of NodeMCU microcontroller and cloud-based MySQL database allows seamless communication between the sensors and a mobile application, facilitating real-time monitoring and proactive alerts.

The ability of the proposed system to predict gas consumption trends, offer detailed usage analytics, and automatically reorder a new cylinder before existing cylinder run out of gas, sets it apart from conventional methods. Furthermore, its non-intrusive design ensures that it can be easily integrated into existing setups without requiring any alterations to the LPG system components. This innovative approach enhances user safety, reduces the risk of gas-related incidents, and provides a streamlined solution for managing gas supply. Overall, this system demonstrates significant potential in transforming the way households manage and monitor their LPG usage, improving both user convenience and safety.

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