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Development of a Load Cell-Based System for LPG Consumption and Cost Estimation

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ABSTRACT

Liquefied Petroleum Gas (LPG) is widely used in households and small-scale commercial activities due to its practicality and combustion efficiency. However, users often experience difficulties in accurately determining the remaining gas quantity and estimating the associated operational costs. This study proposes a load cell-based LPG monitoring system capable of measuring the remaining LPG mass and estimating gas consumption costs in real time. The proposed system integrates a load cell sensor, HX711 signal conditioning module, Arduino Uno microcontroller, DS1307 Real-Time Clock (RTC), LCD display, and user input interface. The monitoring algorithm calculates the remaining gas mass, gas percentage, and operational cost based on the observed rate of mass reduction over time. To improve measurement stability, a one-dimensional Kalman Filter is implemented to suppress sensor noise and short-term fluctuations. System validation was conducted through simulation using the Wokwi environment, where LPG consumption behavior was represented by predefined mass datasets with Gaussian noise characteristics of $\mu = 0$ *kg and* $\sigma = 0.001$ *kg. The simulation considered three consumption scenarios with rates of 0.15 kg/h, 0.25 kg/h, and 0.10 kg/h, corresponding to theoretical operational costs of 62.5 Rp/h, 104.2 Rp/h, and 41.7 Rp/h, respectively. The results demonstrate that the proposed system successfully tracks LPG mass variations and accurately identifies changes in consumption patterns. Furthermore, the Kalman Filter effectively reduces measurement fluctuations while maintaining responsiveness to actual load variations, resulting in smoother and more reliable cost estimation. The proposed monitoring approach provides a practical solution for real-time LPG consumption monitoring and operational cost awareness, particularly for household and small-business applications.*

***Keywords**: LPG monitoring, load cell, Kalman filter, operational cost estimation, real-time monitoring.*

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) remains one of the most widely utilized energy sources in daily household and small-scale commercial activities. The increasing use of LPG is mainly influenced by its practical implementation, easy availability, and relatively efficient combustion performance for cooking applications [1], [2], [3]. In addition, LPG is widely regarded as a cleaner alternative to traditional fuels such as firewood and charcoal because it produces lower emissions and contributes to reducing environmental degradation, particularly in developing countries [4]. Despite these advantages, LPG is categorized as a non-renewable energy resource; therefore, its utilization should be managed more efficiently and responsibly [5].

One of the common issues encountered by LPG users is the difficulty in determining the remaining gas content inside the cylinder accurately [6], [7], [8]. In most cases, users estimate the remaining gas only through intuition or by observing the intensity of the stove flame. Such conditions often result in the gas supply unexpectedly running out during operation, particularly in restaurants, coffee shops, and culinary businesses with relatively high gas consumption rates. This situation may interrupt operational activities and lead to both time and economic losses.

Several LPG cylinders are currently equipped with simple indicators or measurement scales; however, the provided information is generally limited and lacks sufficient accuracy [9], [10]. Conventional analog weighing systems also suffer from several drawbacks, including limited precision, pointer oscillation that complicates reading, and the inability to provide detailed information regarding gas consumption behavior and operational expenditure. Consequently, the available information is still considered insufficient for practical monitoring purposes.

Recent technological developments have encouraged the adoption of smart monitoring systems based on sensors, microcontrollers, and Internet of Things (IoT) technologies. These systems not only provide information regarding the remaining LPG quantity but can also improve user awareness regarding energy consumption and operational efficiency. Furthermore, intelligent monitoring systems can be extended with additional safety functions, such as gas leakage detection and fire prevention mechanisms, to enhance household safety.

At present, LPG monitoring systems are no longer limited to identifying the remaining gas quantity alone. The monitoring concept can be further extended toward real-time operational cost estimation based on gas consumption patterns. Cost-related information expressed in currency per unit time is considered more intuitive for users, especially small business owners, because it can be directly associated with ongoing operational expenses [11], [12], [13]. Therefore, a monitoring system capable of measuring LPG cylinder weight while simultaneously estimating gas consumption costs automatically is highly desirable.

Several previous studies have investigated LPG monitoring systems using weight sensors, pressure sensors, and microcontroller-based technologies. Tsai [14] proposed an Internet of Things (IoT)-based LPG monitoring system utilizing a smart weighing plate to observe LPG cylinder weight in real time. The collected usage data were transmitted through an IoT platform, enabling distributors to predict cylinder refill demands and optimize distribution strategies more efficiently. Another study conducted by Dody Samudera and Ari Sugiharto [15] presented an IoT-based gas leakage and fire warning system. In their work, a load cell sensor was employed to measure LPG cylinder weight so that users could monitor the remaining gas quantity. The load cell was integrated with an ESP8266 microcontroller, and the measurement results were transmitted to an online database for website-based monitoring. In addition to gas weight monitoring, the system also incorporated an MQ-2 gas sensor and a flame sensor for detecting gas leakage and fire hazards.

Research related to weight-based price estimation systems has also been reported in other application domains. Ogunbiyi et al. developed an electronic price-estimation weighing system capable of automatically calculating product prices based on measured weight and user-defined unit costs. Their system utilized an ATmega328P microcontroller, HX711 module, load cell sensor, and keypad interface to support commercial weighing applications. Although the proposed system demonstrated accurate weight-based price calculations, its primary focus was on static product pricing rather than continuous monitoring of resource consumption over time [16].

Unlike previous studies, the present research focuses specifically on LPG consumption monitoring and real-time operational cost estimation. The proposed system integrates a load cell sensor, HX711 module, Arduino Uno, and a DS1307 Real-Time Clock (RTC) module to calculate gas consumption rates based on actual elapsed time. Furthermore, a one-dimensional Kalman Filter is implemented to reduce measurement noise and improve the stability of mass and cost estimation results. While previous electronic weighing systems mainly calculate prices from instantaneous weight measurements, the proposed approach estimates LPG operational costs dynamically in Indonesian Rupiah per unit time by considering the rate of gas consumption.

Based on these considerations, this study aims to design an LPG monitoring system capable of measuring the remaining LPG mass and estimating operational gas costs in real time through a user-friendly LCD interface. The novelty of this research lies in the integration of time-based LPG consumption analysis, real-time operational cost estimation, RTC-assisted consumption monitoring, and Kalman Filter-based signal processing within a single embedded monitoring platform. The proposed system is expected to assist household users and small-scale business operators in managing LPG consumption more efficiently and economically. Since this work is currently focused on the system design and simulation stage, the primary emphasis is placed on hardware architecture development, monitoring algorithms, and system validation through virtual simulation prior to physical implementation.

II. METHOD

This study employed a system design method to develop the conceptual framework of a load cell-based LPG monitoring system. The research primarily focuses on the system architecture, operational workflow, and embedded monitoring concept without conducting direct physical implementation or hardware performance testing. The proposed system was designed to measure LPG cylinder weight and display the estimated gas consumption cost through an LCD interface in real time.

The system architecture was developed using several main components, including a load cell sensor for cylinder weight measurement, an Arduino Uno microcontroller as the primary processing unit, and an LCD module as the information display interface. In the proposed configuration, the load cell was positioned beneath the LPG cylinder base to continuously detect weight variations during operation. The acquired sensor data were subsequently processed by the Arduino Uno to estimate the remaining LPG mass and calculate the operational gas cost.

The monitoring algorithm was designed to convert the measured cylinder weight into remaining gas information by subtracting the tare weight of the empty cylinder from the total measured weight. The processed data were then utilized to estimate the LPG consumption behavior and operational cost in Indonesian Rupiah per minute. The calculated information was intended to be displayed on the LCD module, enabling users to monitor both the remaining LPG quantity and the estimated real-time operational cost more conveniently.

In addition to the hardware architecture, the system design also incorporates signal processing and filtering mechanisms to improve measurement stability. A Kalman Filter algorithm was integrated into the proposed monitoring workflow to reduce noise and small fluctuations commonly associated with load cell measurements. The filtering stage was intended to generate more stable estimation results before the information is displayed to the user interface.

Overall, the proposed design method provides a conceptual framework for developing a real-time LPG monitoring system capable of estimating both remaining gas mass and operational consumption cost using a load cell-based sensing approach.

A. System Design

The hardware configuration of the proposed monitoring system was designed as illustrated in Figure 1. The design diagram describes the interconnection between the load cell sensor, microcontroller unit, real-time clock module, and LCD module as an integrated LPG monitoring system. Section A represents a 3 kg LPG cylinder positioned on top of a supporting platform (cylinder stand). The stand functions as a medium for transferring the mechanical load from the cylinder to the load cell sensor. When the LPG mass decreases during usage, the resulting change in force is transmitted directly to the load cell as a mechanical input signal. The load cell is placed beneath the stand to ensure that the entire cylinder load can be measured consistently and stably.

Section B illustrates the load cell sensor used to detect variations in LPG cylinder weight. The sensor operates based on the strain gauge principle, where mechanical deformation causes changes in electrical resistance. As the gas mass decreases, the resistance value inside the load cell also changes, producing a very small analog voltage signal. Since the generated signal has a low amplitude and is highly sensitive to noise, additional signal conditioning and amplification are required before further processing can be performed by the microcontroller.

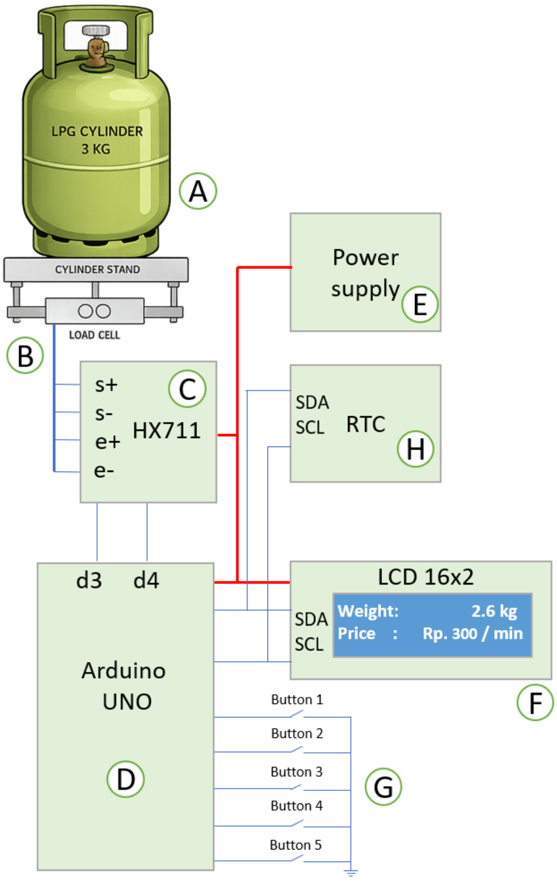


Figure 1. Proposed system design

In Section C, an HX711 module is employed as both a signal amplifier and an Analog-to-Digital Converter (ADC). The HX711 receives input signals from the load cell through the S+, S−, E+, and E− terminals. The module subsequently amplifies the analog signal and converts it into high-resolution digital data that can be processed by the Arduino Uno. Communication between the HX711 and Arduino is established through the data and clock pins connected to pins D3 and D4, respectively. The HX711 module was selected due to its high sensitivity and suitability for low-scale mass measurement applications.

Section D presents the Arduino Uno, which functions as the primary control and processing unit of the system. The Arduino receives digital data from the HX711 module and performs sensor calibration, mass calculation, gas consumption analysis, and operational cost estimation. The measured weight data are utilized to estimate the remaining LPG mass and calculate gas consumption costs based on the predefined LPG price parameter and the observed consumption rate. In addition, the Arduino manages communication with the LCD and RTC modules and reads user input from the push-button interface used for system configuration.

Section E represents the power supply unit responsible for providing operating voltage to the entire circuit. The power supply distributes electrical power to the Arduino Uno, HX711 module, RTC module, and LCD display. Stable voltage regulation is essential to maintain accurate load cell readings and ensure continuous system operation without measurement disturbances.

In Section F, a 16×2 LCD module with an I^2C communication interface is utilized to display measurement results in real time. The LCD presents key monitoring parameters, including the remaining LPG mass, the percentage of gas remaining, and the estimated operational gas cost. The I^2C interface was selected because it reduces the number of required Arduino pins, resulting in a simpler and more efficient wiring configuration. The displayed information enables users to monitor LPG consumption conditions directly without manual inspection.

Section G shows five push buttons that function as the system input interface. These buttons are intended for menu navigation, LPG price configuration, cylinder-capacity selection, sensor calibration, data reset operations, and other parameter adjustment functions depending on system requirements. Each button is connected to the Arduino input pins and operates using a digital switching mechanism with internal pull-up resistors.

Section H represents the DS1307 Real-Time Clock (RTC) module, which provides accurate time and date information for the monitoring system. The RTC communicates with the Arduino Uno through the shared I^2C bus using the SDA and SCL lines and operates at the standard I^2C address of 0x68. The RTC is used to provide time references for calculating LPG consumption rates and estimating operational costs over specific observation intervals. By utilizing real-time timestamps, the system can determine the rate of mass change ((dm/dt)) more accurately and generate time-based consumption statistics. The integration of the RTC module also ensures that monitoring data remain synchronized with actual operating time, making the system more suitable for long-term monitoring applications.

Overall, the proposed system operates by continuously measuring the LPG cylinder weight using the load cell sensor. The acquired analog signal is amplified and converted into digital data by the HX711 module before being processed by the Arduino Uno. The RTC module provides timing information that enables the calculation of gas consumption rates and cost estimation over predefined periods. The processed information is subsequently used to estimate the remaining LPG mass, gas percentage, and operational gas cost. Finally, the calculated results are displayed on the LCD module in real time, enabling users to monitor LPG consumption behavior during system operation.

B. Sowftware Design

Figure 2 illustrates the operational flowchart of the proposed LPG monitoring system developed using an

Arduino-based embedded platform. The flowchart represents the logical implementation of the system algorithm and describes the continuous real-time monitoring process performed by the device.

The process begins with the "system initialization stage", where all hardware peripherals are configured, including the HX711 module, load cell sensor, LCD 16×2 display, push-button interface, and initial operating parameters such as LPG price, tare cylinder weight, and full gas capacity. In addition, the Kalman Filter parameters are initialized before the system enters the main monitoring loop.

After initialization, the system continuously acquires measurement data from the load cell sensor through the "Read Load Cell" process. The analog signal generated by the strain gauge is amplified and converted into digital data by the HX711 module before being processed by the Arduino Uno. The measured value corresponds to the total weight of the LPG cylinder.

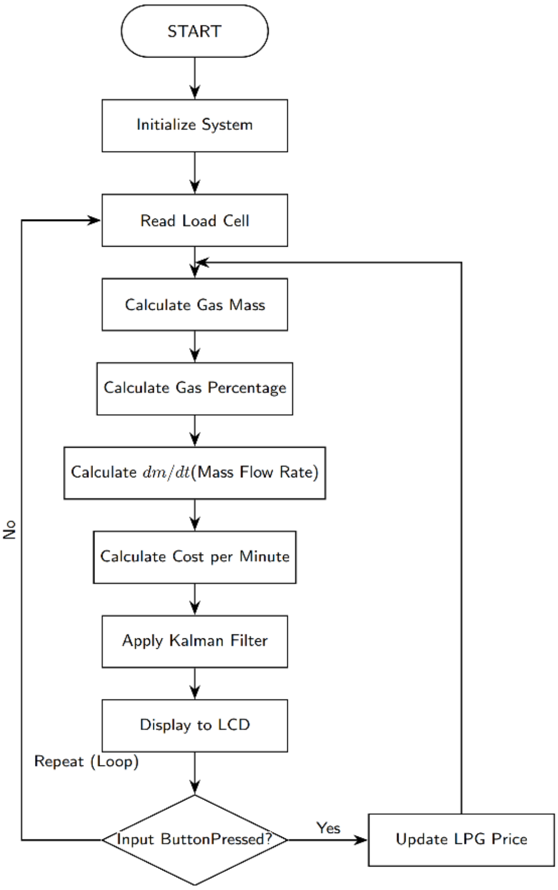


Figure 2. System algorithm

The remaining gas mass is then calculated by subtracting the tare weight of the empty cylinder from the measured total weight, as expressed by (1).

$$m_{gas} = m_{total} - m_{tare} \qquad (1)$$

Where m_{gas}represents the remaining LPG mass, $m_{total}$is the measured total weight, and $m_{tare}$is the empty cylinder weight. To avoid invalid readings, negative values are automatically set to zero.

Next, the system estimates the remaining gas percentage relative to the maximum LPG capacity using (2).

$$gas\ percentage = \left(\frac{m_{gas}}{m_{full}}\right) \times 100\% \qquad (2)$$

where m_{full}denotes the maximum LPG capacity of the cylinder.

To estimate real-time LPG consumption, the algorithm calculates the rate of mass change over time (dm/dt). This value represents the current gas usage rate based on the ongoing operating condition of the stove or gas appliance.

The operational cost per minute is subsequently estimated by multiplying the gas consumption rate by the LPG unit price coefficient, as expressed by (3).

$$Cost_{min} = \left|\frac{dm}{dt}\right| \times P \qquad (3)$$

where Prepresents the LPG price per kilogram. Using this approach, the displayed cost dynamically follows the actual gas consumption pattern. A higher flame intensity produces a larger mass reduction rate, resulting in a higher estimated operational cost per minute.

Since load cell measurements are susceptible to noise and small fluctuations caused by vibration and environmental disturbances, a one-dimensional Kalman Filter is implemented to improve the stability of the estimated values. The Kalman Filter operates recursively by combining the current measurement with the previous estimation to minimize measurement uncertainty and reduce noise effects.

The prediction stage of the Kalman Filter updates the estimation error covariance according to (4)[17].

$$P_k = P_{k-1} + Q \qquad (4)$$

where $P_k$is the current estimation error covariance, $P_{k-1}$is the previous estimation error covariance, and Qrepresents the process noise covariance.

The Kalman Gain is then calculated using (5).

$$K_k = \frac{P_k}{P_k + R} \qquad (5)$$

where R denotes the measurement noise covariance. The Kalman Gain determines the contribution of the new measurement relative to the previous estimation.

The filtered estimation value is updated according to (6).

$$\hat{x}_k = \hat{x}_{k-1} + K_k(z_k - \hat{x}_{k-1}) \qquad (6)$$

where $\hat{x}_k$is the updated estimation, $\hat{x}_{k-1}$is the previous estimation, and $z_k$is the current measurement input. In this system, the input variable corresponds to the estimated LPG cost per minute derived from the gas consumption rate.

Finally, the estimation error covariance is corrected using (7).

$$P_k = (1 - K_k)P_k \qquad (7)$$

The implementation of the Kalman Filter significantly reduces rapid fluctuations in the estimated cost value, resulting in a smoother and more stable display on the LCD interface.

The filtered outputs, including remaining gas mass, gas percentage, and estimated operational cost per minute, are displayed on the LCD 16×2 module in real-time. This allows users to directly monitor LPG usage conditions without manual inspection.

In addition to the monitoring functionality, the system incorporates a user input interface consisting of five push buttons: UP, DOWN, LEFT, RIGHT, and ENTER. During the “Check Input Button” stage, the system continuously evaluates button states. When the ENTER button is pressed, the algorithm enters the LPG price configuration mode, allowing users to modify the LPG price directly through the interface. The updated value is then used in subsequent cost estimation calculations.

Finally, the algorithm returns to the sensing stage, forming a continuous monitoring loop that enables real-time measurement, filtering, and operational cost estimation throughout system operation.

C. Experimental Scenario

To evaluate the performance of the proposed LPG monitoring system, an experimental simulation was conducted using the Wokwi virtual circuit environment. The simulation approach was selected to validate the system algorithm, signal processing method, and real-time operational cost estimation prior to physical hardware implementation.

In the simulation environment, LPG consumption behavior was represented using predefined gas mass data stored in the Arduino memory. The dataset was organized in the form of an array containing sequential weight values that represent the gradual reduction of LPG mass over time. Each array element corresponds to a simulated gas mass reading at a discrete time interval t_i. The mass variation was modeled using a piecewise linear function to represent different gas consumption conditions during operation, expressed as (8).

$$W(t) = \begin{cases} W_0 - 0.15t, & 0 \leq t < 1 \\ W_0 - 0.15 - 0.25(t-1), & 1 \leq t < 1.5 \\ W_0 - 0.275 - 0.10(t-1.5), & 1.5 \leq t < 2.5 \end{cases} \quad (8)$$

where $W(t)$ denotes the LPG mass at time t, while W_0represents the initial gas mass. The three operating intervals correspond to low, medium, and high LPG consumption conditions, allowing the monitoring algorithm to be evaluated under varying operational patterns.

The use of a predefined dataset was necessary because the Wokwi platform does not provide a native load cell sensor model or HX711 module simulation. Consequently, direct sensor acquisition could not be implemented within the virtual environment. Nevertheless, the dataset-based approach does not significantly affect the validity of the experiment because the generated data were designed to emulate practical load cell behavior, including gradual mass reduction and measurement fluctuations typically observed in real sensing systems.

To reproduce realistic sensor disturbances, Gaussian-distributed noise was intentionally added to the simulated LPG mass dataset using the Gaussian library developed by Ivan Seidel for Arduino-based systems. The injected noise represents common load cell disturbances such as vibration, electrical interference, mechanical instability, and ADC quantization effects. The measurement model is expressed as (9).

$$W_{measured}(t) = W_{true}(t) + \mathcal{N}(0, \sigma^2) \quad (9)$$

where $W_{true}(t)$represents the ideal LPG mass value, while $\mathcal{N}(0, \sigma^2)$denotes zero-mean Gaussian noise with variance σ^2. The introduction of Gaussian noise enabled the simulated dataset to closely resemble actual load cell measurements and allowed the Kalman Filter performance to be evaluated under realistic sensing conditions. Table 1 summarizes the Gaussian noise parameters used to emulate load cell measurement uncertainty. A zero-mean Gaussian distribution with a standard deviation of 0.001 kg was selected to represent realistic sensor fluctuations. The generated noise was added to the theoretical LPG mass data before applying the Kalman Filter, allowing the filtering algorithm to be evaluated under conditions that closely resemble practical load cell measurements.

TABEL 1. GAUSSIAN NOISE PARAMETERS

Parameter	**Value**	**Unit**
Mean (μ)	0	kg
Standard Deviation (σ)	0.001	kg
Variance (σ^2)	10^6	kg²

During the simulation process, the Arduino program sequentially reads the stored mass data and processes them as if they originated from an actual load cell sensor. The algorithm subsequently performs several computational stages, including remaining gas mass estimation, gas percentage calculation, gas consumption rate calculation (dm/dt), operational cost estimation per minute, and Kalman Filter processing.

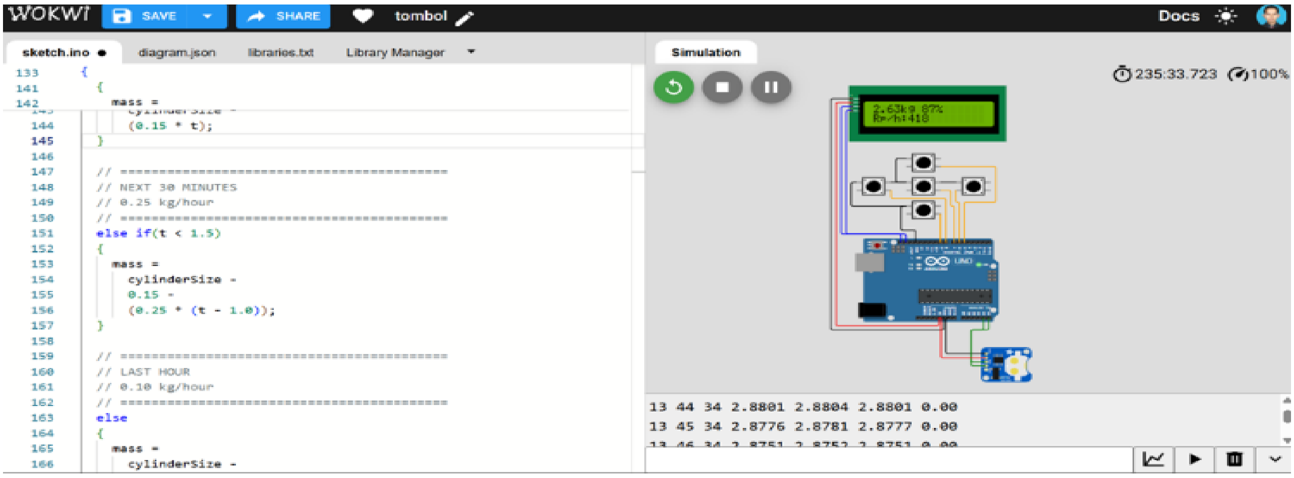
The processed outputs were displayed through two different interfaces. First, the calculated parameters were presented on the LCD 16×2 module to simulate the real-time embedded user interface. Second, all numerical outputs were transmitted through serial communication and displayed on the Serial Monitor within the Wokwi environment. The serial monitor output included the simulated gas mass, remaining gas percentage, raw operational cost estimation, and filtered operational cost estimation after Kalman filtering.

The serial data were subsequently collected and used for further analysis and visualization. The obtained results were utilized to evaluate the stability of the estimation process, analyze the Kalman Filter response, and compare the raw and filtered outputs under dynamic LPG consumption. To evaluate the performance of the proposed LPG monitoring system, an experimental simulation was conducted using the Wokwi virtual circuit environment. The simulation approach was selected to validate the system algorithm, signal processing method, and real-time operational cost estimation prior to physical hardware implementation.

III. RESULTS AND DISCUSSION

A. Hardware Design and Simulation Environment

Figure 3 illustrates the hardware configuration of the proposed LPG monitoring system implemented in the Wokwi simulation environment. The system consists of an Arduino Uno microcontroller, a 16×2 LCD with I²C communication, a DS1307 Real-Time Clock (RTC) module, and five push buttons used for menu navigation and parameter adjustment. The simulation platform was selected to verify the operational logic of the proposed system before physical implementation.



```
{
  {
    mass =
      cylinderSize -
      (0.15 * t);
  }

  // ==========================================
  // NEXT 30 MINUTES
  // 0.25 kg/hour
  // ==========================================
  else if(t < 1.5)
  {
    mass =
      cylinderSize -
      0.15 -
      (0.25 * (t - 1.0));
  }

  // ==========================================
  // LAST HOUR
  // 0.10 kg/hour
  // ==========================================
  else
  {
    mass =
      cylinderSize -
```

```
13 44 34 2.8801 2.8804 2.8801 0.00
13 45 34 2.8776 2.8781 2.8777 0.00
```

Figure 3. Hardware design and simulation environment

The Arduino Uno serves as the main processing unit responsible for executing the LPG monitoring algorithm. In the actual implementation, LPG mass would be measured using a load cell sensor combined with an HX711 signal conditioning module. However, because Wokwi does not provide native support for load cell and HX711 simulation, the sensor readings are represented by a predefined dataset stored in the Arduino memory. The dataset emulates realistic LPG consumption behavior under different operating conditions and is used as the input source for the monitoring algorithm.

The DS1307 RTC module is connected through the I2C bus and provides real-time information, including hours, minutes, and seconds. The RTC data are used to synchronize the monitoring process and calculate the gas consumption rate over a specified observation period. This approach allows the system to estimate gas usage and operational cost based on actual elapsed time rather than program execution cycles.

A 16×2 LCD module with an I²C interface is employed to display monitoring information in real time. The first line of the LCD presents the remaining LPG mass and the corresponding percentage of gas remaining in the cylinder. The second line displays the estimated gas consumption cost calculated from the measured consumption rate and the user-defined LPG price. The use of the I²C interface reduces wiring complexity and minimizes the number of Arduino pins required for display communication.

Five push buttons are incorporated to provide user interaction with the system. The buttons are configured using the internal pull-up resistor mode and are assigned to menu navigation functions, including left, right, up, down, and enter. Through this interface, users can modify system parameters such as LPG price and cylinder capacity (e.g., 3 kg, 5 kg, or 12 kg cylinders). This feature enables the monitoring system to adapt to different LPG cylinder specifications without requiring software modifications.

During operation, the Arduino continuously reads the simulated LPG mass data from memory, applies a Kalman Filter to reduce measurement noise, calculates the remaining gas percentage, and estimates the operational gas cost based on the consumption rate. The processed information is displayed on the LCD and simultaneously transmitted to the serial monitor for data logging and performance evaluation. The serial output includes the timestamp provided by the RTC, the original mass value, the noisy measurement, the Kalman-filtered value, and the estimated gas cost.

B. LPG Mass Monitoring Performance

Figure 4 presents the variation of LPG mass during the observation period. The blue solid line represents the measured sensor data, while the orange dashed line represents the output after Kalman Filter processing.

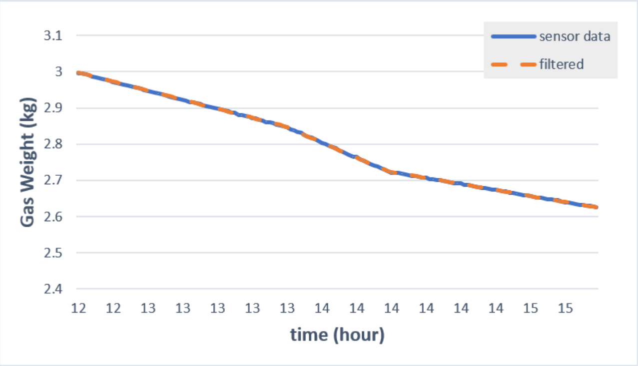


Figure 4. LPG mass monitoring

The decrease in mass is not uniform across the entire observation period. During the initial stage, the reduction trend is relatively gradual, corresponding to the low-consumption condition of 0.15 kg/h. A steeper decline is observed around the middle of the monitoring period, which corresponds to the increased consumption rate of 0.25 kg/h. After this phase, the slope becomes less steep, indicating the lower consumption rate of 0.10 kg/h. These changes demonstrate that the proposed system can capture variations in gas usage patterns under different operating conditions.

The comparison between the raw sensor data and the filtered output shows that both curves follow nearly identical trends. The Kalman Filter successfully suppresses small measurement fluctuations while preserving the actual dynamics of LPG consumption. No significant delay or distortion is observed in the filtered signal, indicating that the selected filter parameters provide an appropriate balance between noise reduction and responsiveness.

The close agreement between the two curves also suggests that the measurement noise introduced into the simulated load cell data was relatively small. Consequently, the Kalman Filter acts primarily as a smoothing mechanism, producing a more stable estimation of the remaining gas mass. This stability is particularly important because the filtered mass value is subsequently used to calculate the gas consumption rate and estimate the operational cost.

Overall, the results indicate that the proposed monitoring system is capable of tracking LPG mass changes accurately while providing stable measurements through Kalman Filter processing. The filtered output can therefore serve as a reliable basis for real-time gas consumption monitoring and cost estimation.

C. Real-Time Cost Estimation

Figure 5 illustrates the real-time gas price estimation per hour over a 2.5 hour simulation period, comparing the theoretical baseline, the noise-corrupted signal, and the Kalman-filtered output. The profile clearly depicts three distinct operational regions corresponding to the predefined LPG consumption scenarios as can be seen in Table 2.

TABEL 2. LPG CONSUMPTION SCENARIOS

Region	Time Interval (h)	LPG Consumption Rate (kg/h)	Theoretical Mean Cost (Rp/h)
Region 1	0.0 – 1.0	0.15	62.5
Region 2	1.0 – 1.5	0.25	104.2
Region 3	1.5 – 2.5	0.10	41.7

The raw signal from the load cell (Noised, represented by the solid grey line) suffers from severe high-frequency fluctuations. These electrical and mechanical disturbances cause the computed cost to swing erratically, occasionally dropping below zero or spiking up to Rp160/hour. Feeding this raw data directly to the hardware display would result in flickering text that is unreadable to the end-user.

Implementing the Kalman Filter (Filtered, represented by the solid red line) effectively resolves this issue. The algorithm dampens the extreme fluctuations without sacrificing the system's responsiveness to genuine load changes. As a result, the filtered curve closely tracks the Theoretical baseline (the dashed black line). This provides a smooth, reliable data stream that is ideal for real-time monitoring on low-cost microcontrollers.

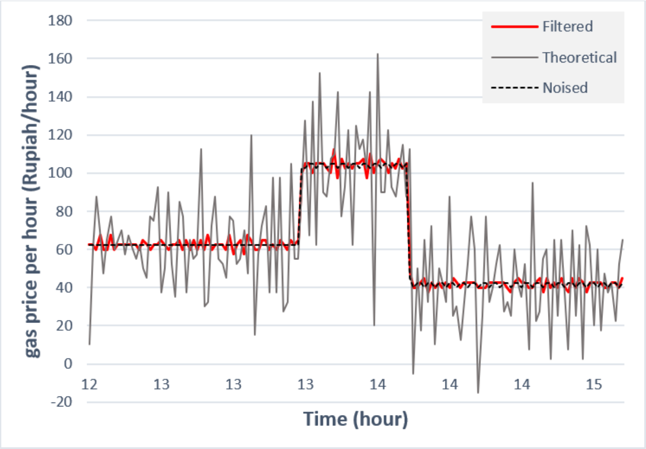


Figure 5. Real-time gas price estimation

IV. CONCLUSIONS

This study proposed the design and simulation of a load cell-based LPG monitoring system capable of estimating both the remaining LPG mass and the operational gas cost in real time. The system integrates a load cell sensor, HX711 signal conditioning module, Arduino Uno microcontroller, DS1307 real-time clock, LCD display, and user input interface to provide continuous monitoring of LPG consumption behavior. A Kalman Filter was incorporated to improve measurement stability by reducing noise and short-term fluctuations commonly associated with load cell measurements.

Simulation results conducted in the Wokwi environment demonstrated that the proposed system successfully tracked LPG mass variations under different consumption scenarios. The filtered mass measurements closely followed the theoretical consumption profile while effectively suppressing measurement noise. Furthermore, the operational cost estimation algorithm was able to identify different consumption levels corresponding to low, medium, and high LPG usage conditions. The Kalman Filter significantly improved the readability and stability of the displayed cost information by minimizing rapid fluctuations in the raw estimation signal.

The main contribution of this work is the introduction of a real-time LPG operational cost estimation feature that directly converts gas consumption behavior into monetary information, making the monitoring process more intuitive for end users. This capability can assist households and small-scale businesses in managing LPG consumption more efficiently and economically. Future work will focus on implementing the proposed system using actual hardware, performing sensor calibration and accuracy evaluation, validating the cost estimation model under real operating conditions, and integrating data logging and IoT communication features for remote monitoring applications.

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