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Original Article

Design and Implementation of an IoT Based LPG Management and Distribution System

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Abstract - *This paper focuses on designing and implementing a system capable of real-time monitoring of liquefied Petroleum Gas (LPG) quantity based on the Internet of Things (IoT). The quantity of LPG left in a cylinder is monitored, and this is used to forestall running out of cooking gas at critical periods or odd hours, as well as to notify the cooking gas vendor for either preparation for replacement or outright replacement. Filled four common cooking gas cylinders were used for the study. Each was divided into four thresholds of the total LPG quantity, namely: low (50%), very low (25%), critically low (12.5%) and empty (6.25%). These thresholds indicate the various points at which real-time information of the quantity of gas left is sent to both the user and the vendor via SMS employing an embedded Node Microcontroller with a Wi-Fi module for appropriate action(s) to be carried out. The system performed optimally from the results obtained in the tests carried out as the necessary information was prompted at various thresholds as designed.*

Keywords - *Liquefied Petroleum Gas, IoT, Weight measurement, Real-time monitoring, GSM module.*

1. Introduction

Over the years, Liquefied Petroleum Gas (LPG) has been used for central heating, cooking, and mobile heaters for leisure activities such as boats, caravans, and barbecues, Okpeki and Oyubu (2019). In Nigeria and most Sub-Saharan African countries, cooking gas, also known as LPG, is retailed in cylinders as there is no gas piping system wherein gas runs from the distribution line, otherwise known as a mainline, into homes or other buildings in a service line. Thus, LPG users in Nigeria and most Sub-Saharan African countries can only purchase and use LPG stored in cylinders. However, due to the storage condition of LPG, it is relatively difficult to measure the quantity of the LPG directly left in a storage cylinder to avoid running out of LPG at crucial times. Existing studies, however, revealed that the quantity of LPG in a cylinder can be accurately measured from the weight. This non-intrusive measurement approach is also relatively easier to achieve since, unlike firewood and other biomass that can easily be inspected visually, LPG is often stored in compressed form in a non-transparent cooking cylinder. In addition, other crude or manual methods of ascertaining the quantity of LPG are often inaccurate and prone to human error and, as such, do not provide a fairly reliable means of ascertaining the quantity of LPG in a cylinder. Nonetheless, with regard to the average user, Renuka et al. (2020) observed that there are relatively few or non-existent solutions for monitoring the level of LPG in the cooking cylinder; as such, users of LPG are forced to resort to manually checking the level of LPG in the cylinder to ascertain the need for refilling. This is also very prone to error in judgment.

The use of sensors and transducers along with associated processing systems have enabled the possibility of monitoring and measuring several physical quantities ranging from body temperature and resistance (Wara et al. 2009), soil moisture content (Oghogho et al. 2023a), smoke detection in fire alarms (Emagbetere and Oghogho 2007), pressure detection (Okpare et al. 2023a), water level detection (Okpare et al. 2023b), face detection (Oghogho et al. 2023b), fingerprint detection (Otuagoma et al. 2023) etc. Hence it is possible to monitor the weights of gas cylinders electronically and, from the measurements, deduce the amount of LPG left in them. This will eliminate the human errors associated with manually checking them and forestall the incidences of running out of LPG due to errors in ascertaining the quantity of LPG left during cooking and in periods with relatively lower chances of refilling.

Researchers and industry experts have sought to leverage technological advances to develop systems to automatically remind the user when the quantity of LPG falls below a target threshold, and a few designs have been developed to this effect. Although there are diverse ways to measure the weight of the cylinder, this work hinges on the usage of strain-gauge-based load cells with suitable load cell amplifier modules interfaced with an embedded Node Microcontroller/Wi-Fi module interfaced with a GSM module for information on the quantity of gas left to be sent in real-time as SMS to both user and gas vendor for appropriate action(s) to be affected.

2. Review of Related Work

Due to the rather volatile and readily inflammable nature of LPG, most approaches toward weight measurement to ascertain the quantity of LPG left in a cylinder has been relatively non-intrusive. Since LPG is often liquefied in compressed form, most solutions are built on measuring the weight of the empty cylinder and the gross weight when the cylinder contains gas. Hayaran and Roy (2018) noted that a suitable load cell could be configured to measure the weight and, consequently, the quantity of LPG in real-time. Load cells are often based on the principle of strain gauges and generate an electrical signal whose magnitude is proportional to the force exerted on it. Hayaran and Roy (2018) noted that load cells are highly precise and suitable for developing relatively accurate real-time LPG monitoring systems.

According to Varshitha et al. (2011), a typical load cell would require a suitable amplifier unit to interface with a microcontroller module due to the relatively weak signals generated from the load cells. The HX711 load cell amplification module is popular in load cell applications and designs developed by hobbyists and researchers alike. In recent times, systems for monitoring the quantity of gas and detecting leakages have emerged in the literature. These systems essentially provide a relatively more robust way of using LPG cylinders (Halder and Chatterjee (2019)).

To prevent manually checking the level of LPG in the cylinder to ascertain the need for refilling, Renuka et al. (2020) developed a prototype LPG monitoring system built on the load cell as a weight transducer and an Arduino microcontroller as the processing module. The developed system essentially featured a relative humidity sensor DHT-11, the esp2886 Wi-Fi module, The HXT711 load cell driver and the Arduino microcontroller. The system was designed to measure the quantity of the LPG in a cylinder and communicate with the user via an Android app. Renuka et al. (2020) also noted that the system was designed to allow the user to book LPG from a designated supplier as well as send the user the booking information.

Jayesh et al. (2020) worked on a similar system for monitoring the volume of LPG in the cooking cylinder using a load cell, an Hx711 amplifier and an integrated Bluetooth module. The system was designed to analyze the quantity of the LPG in the cylinder in real-time via the load and send the processed reading obtained on the current status of LPG, the working days of the cylinder used, and a threshold for alerting the user.

Patil et al. (2017) worked on a smart booking and refilling solution that can alert the user and automate the booking for refilling when the quantity falls below a preset level. Over the years, existing studies have revealed diverse prototypes and systems for measuring and monitoring the quantity of LPG in a cylinder in real time as well as detecting and notifying the user of the occurrence of a leak. This work seeks to develop a robust solution for detecting real-time monitoring of the quantity of LPG cylinders. The developed system features a Wi-Fi dashboard accessible via the phone, PC or other Wi-Fi-enabled devices to enable the user to set the volume level at which the system will give an alert. The user defines when he should receive an alert. An integrated GSM module was also programmed to allow the user to get notified of gas quantity.

3. Materials and Methods

The proposed LPG quantity measurement system is designed to detect the quantity of the gas in a cylinder and consequently alert the user and the LPG vendor when the quantity of LPG in the cylinder reaches a preset level via the onboard GSM module. The design is essentially made up of two sections-hardware and software sections. The considerations made in the design of the system include the followings:

- The device is designed to be portable to ensure ease of movement to the intended place of use as well as facilitate easy placement under the gas cylinder.
- The device is designed to be relatively easy to use, requiring no special technical expertise to use. The smart system also needs no special maintenance.
- The device is designed to be rechargeable, thus eliminating the need for regular battery replacement.
- The system is designed to be relatively efficient and accurately detect and measure the quantity of gas in the cylinder.

The block diagram of the system is shown in Figure 1. The designed system essentially consists of three sub-units, namely the LPG weight measurement system, the Node MCU/Wi-Fi module and the GSM module.

3.1. LPG Weight Measurement Subsystem

This system consists of a Load cell platform upon which the LPG cylinder will be placed to monitor the weight of the cylinder when empty and the change in weight as the system is being used over time. As the force applied to the load cell increases, the electrical signal changes proportionally. The load cell is connected to the HX711 load cell amplifier module and then an Arduino microcontroller for further processing. In this design, 4 units of the 50kg load cells arranged in a full bridge were used. The HX711 serves as the interface between the load cells and the microcontroller unit and helps amplify the signals from the load cell, as shown in Figure 2. The load cell receives the weight of the cylinder with its content (LPG) which is amplified by the amplifier module to a level usable by the microcontroller and sent to the microcontroller, which processes the received signal, thereby comparing the weight with preset weights corresponding to different LPG quantity representing different thresholds

3.2. Node MCU/WIFI Module

This is the heart of the design. It essentially accepts inputs from the load cell and controls the output devices based on pre-defined logic. The processing unit, which is the Node MCU Module, serves as the main processing unit of the design. The Node Microcontroller Unit is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SOC) called the ESP8266. The ESP8266, designed and developed by Espressif Systems, contains the crucial elements of a computer: CPU, RAM, networking (WiFi), and even a modern operating system and SDK. It employs a 32-bit RISC CPU based on the Tensilica Xtensa L106 running at 80 MHz (or overclocked to 160 MHz). It has a 64 KB boot ROM, 64 KB instruction RAM and 96 KB data RAM. External flash memory can be accessed through SPI. It is mostly used for the development of IoT (Internet of Things) embedded applications. The ESPP8266 module is set to either enable the microcontroller to connect 2.4 GHZ Wi-Fi using IEEE 802.11 or as a self-sufficient MCU by running an RTOS-based SDK, as done in this design. These made it an excellent choice for his design.

3.3. GSM Module

The GSM module is used in this work for communication between the system and the user/vendor. In this design, communication is initiated at and for four different thresholds, i.e. when the gas is at 50%, 25%, 12.5% or 6.25% of the total quantity of gas in the cylinder. Whenever these thresholds are reached, the microcontroller sends a command to the GSM module to transmit relevant SMS corresponding to the threshold indicating the status of gas left in the cylinder to the user/vendor. The SIM800L GSM module was used in this design. It is a miniature cellular module allowing GPRS transmission, sending and receiving an SMS, and making and receiving voice calls. Its low cost, relatively small footprint, and quad-band frequency support make it a suitable choice for most prototype designs to plug in the GSM modem. To activate the GSM functionality, a suitable SIM card was inserted into the GSM SIM port and the system was allowed to initialize and register to the network. The sim800L GSM module is designed to blink an embedded red LED every second during network search and changes to a blink every 3 seconds once the SIM is registered on the host network. Network initialization is performed once, and the integrated rechargeable battery allows the GSM Module to remain active even when other system parts are off.

3.4. Power and Peripheral Unit

This unit essentially consists of the LCD modules, its control circuitry, and a rechargeable power unit to ensure the system is always on and eliminate the cost of periodically buying batteries. The Liquid Crystal Display (LCD) uses liquid crystal to produce visual images of the quantity of gas left at the time. A 18650 Lithium-ion battery was used as backup power for GSM Module, which last for 1hr 30 minutes after charge.

3.5. Power and Peripheral Unit

This section entails the codes written and uploaded to the Node Microcontroller Unit IoT module to connect all the various hardware subsystems/components for the effective functionality of the overall system. The Node Microcontroller/WiFi module was programmed using embedded C++ language via the ArduinoIDE. The operation flow chart is shown in Figure 3.

3.6. Threshold for LPG Cylinder

The designed system is programmed to monitor the quantity of LPG per time by periodically measuring the weight of its cylinder with the content and comparing it with different preset weights representing a specific quantity of gas in the cylinder. The system was designed to have four thresholds using 3kg, 6kg, 12.5kg, and 25kg gas cylinders as case studies. When a 6kg cylinder is filled with 6kg of LPG, it is full (100%) and weighs 12kg. The first threshold is set at 50% when the cylinder weighs 9kg; a ‘‘low’’ message is sent to the user/vendor. The second threshold is set at 25%; when the cylinder weighs 7.5kg, a “very low” message is sent to the use/vendor. The third threshold is set at 12.5% when the cylinder weighs 6.75kg and a “critically low” message is sent to the user/vendor. The fourth and last threshold is set at 6.25% when the cylinder weighs 6.375kg, and an ‘‘empty’’ message is sent to the use/vendor. This is illustrated in Figure 4. Table 1 shows details of the different thresholds for different cylinders.

3.6. Operation

The operating procedure for the device is in two phases. While phase one involves powering the device and wirelessly connecting it with a PC or a mobile phone to be able to view its dashboard, phase two involves the calibration of the device based on the user’s LPG cylinder’s weight. The procedure involved in the first phase is outlined below:

1) The device is switched on through the integrated On/Off Switch and allowed to initialise.
2) Since the device is Wi-Fi enabled, the in-built device hotspot is allowed to initialise afterwards a suitable Wi-Fi enabled devices such as a PC or Phone is used to search for the device’s hotspot
3) Then the login password is inserted into the connection prompt.
4) Once the connection is established, the device interface is accessed via a choice browser through the URL https://192.168.4.1

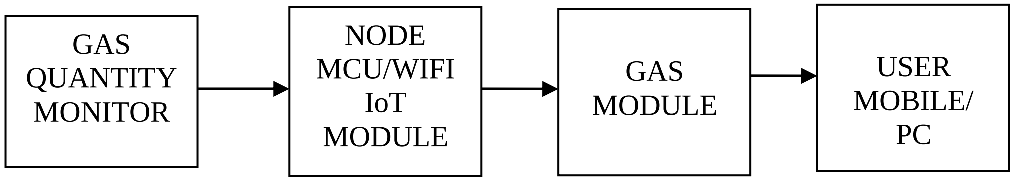

Fig. 1 Block diagram of the system

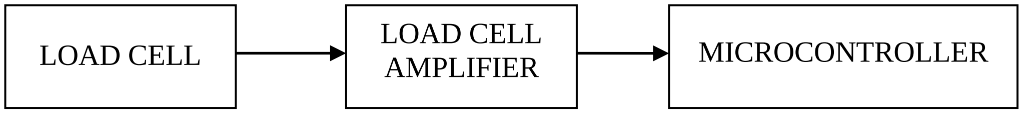

Fig. 2 Block diagram of the Weight Measurement System

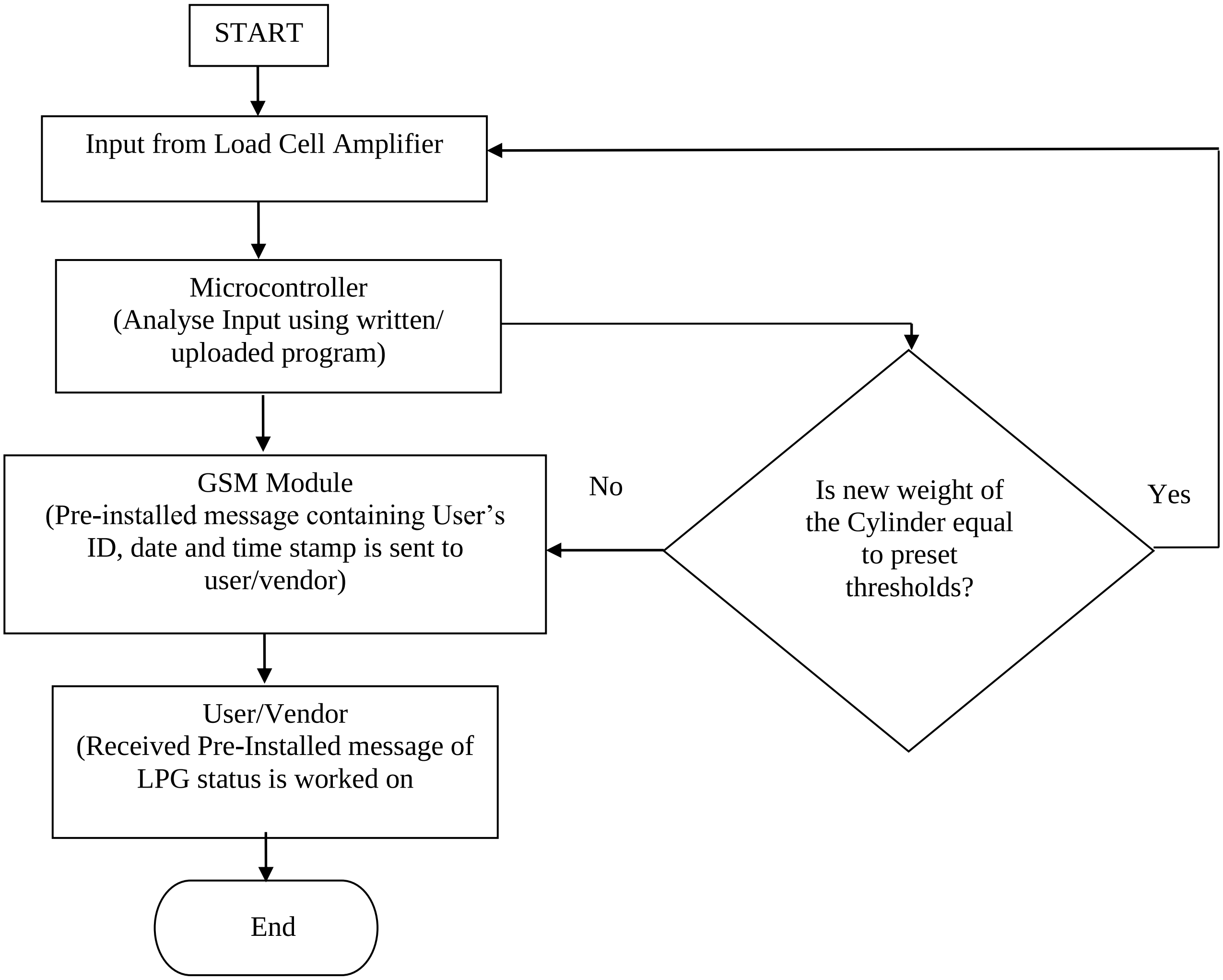

Fig. 3 Operational flow chart of the system

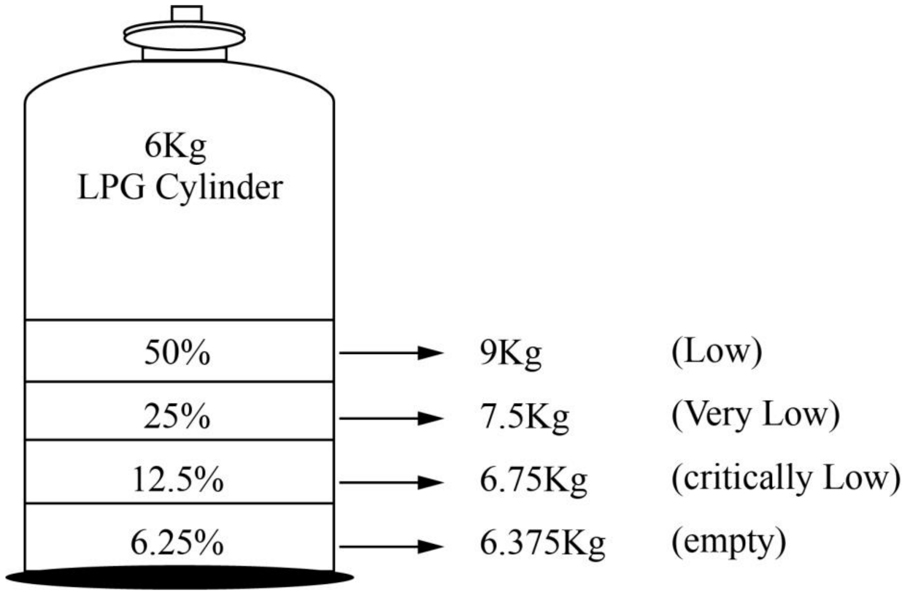

Fig. 4 Thresholds and their corresponding quantity of LPG for a 6kg LPG cylinder

Table 1. Thresholds for various LPG cylinders

3Kg Cylinder			
PERCENTAGE OF LPG CONTENT	**QUANTITY OF LPG**	**NEW WEIGHT**	**STATUS**
100%	3L	6KG	FULL
50%	1.5L	4.5KG	LOW
25%	0.75L	3.75	VERY LOW
12.5%	0.375L	3.375KG	CRITICALLY LOW
6.25%	0.1875L	3.1875KG	EMPTY
6Kg Cylinder			
100%	6L	12KG	FULL
50%	3L	9KG	LOW
25%	1.5L	7.5KG	VERY LOW
12.5%	0.75	6.75KG	CRITICALLY LOW
6.25%	0.375L	6.375KG	EMPTY
12.5Kg Cylinder			
100%	12.5L	25KG	FULL
50%	6.25L	18.75KG	LOW
25%	3.125L	15.625KG	VERY LOW
12.5%	1.5625L	14.0625KG	CRITICALLY LOW
6.25%	0.78125L	13.28125KG	EMPTY
25Kg Cylinder			
100%	25L	50KG	FULL
50%	12.5L	37.5KG	LOW
25%	6.25L	31.25KG	VERY LOW
12.5%	3.125L	28.125KG	CRITICALLY LOW
6.25%	1.56265L	26.56KG	EMPTY

The second phase of the operating procedure involves the calibration of the device. Here, the user clicks on the calibrate button on the dashboard and inputs the cylinder's size, placing the filled cylinder on the load cell platform of the device to get the weight. The different thresholds are also set at this stage, and the calibration setting is saved thereafter. This procedure is carried out once, except another cylinder with a different weight other than the one previously configured in the system has to be used. In such cases, a recalibration becomes necessary.

Once the calibration is accomplished, the system starts its monitoring operation. The node microcontroller using its written program, interprets the signal it receives from the load cell amplifier (HX711 load cell amplifier module). It compares it with the different weights and thresholds stored in its memory. If, upon comparison, the weight corresponds to the weight of any of the thresholds, the GSM module is triggered to send a preinstalled message with the customer's Id, date and time stamp to the user/vendor. Each threshold has a peculiar message: 50% (Id_2012_LPG Low), 25% (Id_2012_LPG Very Low),12.5%(Id_2012_LPG Critically Low) and 6.25 %(Id_2012_LPG empty).

4. Results and Discussion

The performance evaluation of the developed system was done to ascertain conformity with the design aim and objectives. The result obtained is discussed in the following subsections.

To access the control dashboard of the designed system, a phone or pc with enabled Wi-Fi was connected to the device hotspot using the pre-assigned password. Then the device address, 192.168.4.1, was entered on a choice browser. This was followed by calibrating the system. Once the system is calibrated, it shows the gross weight of the LPG cylinder (i.e. the weight of the cylinder with LPG content), calculates the current level of LPG from the measured parameters, and displays all parameters, including the user's profile which contains the vendor's phone number on the dashboard. The dashboard of the developed system has an integrated slide to allow the user to set the thresholds at which level alerts will be sent.

The test was carried out to ascertain different thresholds representing quantities of LPG remaining in the cylinder. The results were shown on the LCD and sent as SMS to registered phone numbers.

Samples of the SMS alert for various thresholds for the studied LPG cylinders based on their information in Table 1 are shown in Figure 5a-d.

5. Conclusion

The IoT LPG quantity monitoring device essentially measures the quantity of LPG in an LPG cylinder in real-time. The device leverages the load cells, HX711 amplifier, and GSM module to monitor the weight of LPG and alert the user /vendor through SMS whenever the quantity falls below a preset threshold. The integrated Wi-Fi module allows the user to connect to the device dashboard via a suitable Wi-Fi interface and calibrate the device accordingly. The user is provided with the functionality to set the threshold for alert, which he desires. The designed system performed in consonance with the design aim and objectives.

12:55. 23/03/2023

Id_2012: LPG low

5a

11:55. 24/03/2023

Id_2012: LPG very low

5b

14:58. 24/03/2023

Id_2012: LPG critically low

5c

16:15. 23/03/2023

Id_2012: LPG empty

5d

Fig. 5(a-d): Samples of SMS alert reporting different LPG thresholds/status

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