Design and Implementation of a Cooking GasGauging System using STM32F411CEU6 Microcontroller

ABSTRACT

In Nigeria, many Liquified Petroleum Gas (LPG) users face two common issues due to their inability to gauge the gas level in cooking cylinders. First, they often get defrauded by either LPG vendors or their assistants, leading to the purchase of less gas than paid for. Second, they experience the inconvenience of running out of gas while cooking, especially during odd hours. To address these problems, this paper introduces an LPG gauging system utilizing Internet of Things (IoT) technology. Key components of the system include load cells for weight sensing, an HX711 amplifier, and an STM32F411CEU6 microcontroller (MCU) that acts as the device's central processor. When the load cell detects weight, it sends a signal to the HX711 amplifier, which amplifies the signal and forwards it to the MCU for processing. The MCU then triggers the Liquid Crystal Display (LCD), showing the LPG level from the time of purchase until it is depleted. Users can also set a refill reminder to be triggered via SMS or call when the gas reaches a preset level. Additionally, a custom mobile app has been developed for remote monitoring and control of the LPG cylinder. The system is powered by a battery, a 5V power pack, and an 18W solar panel. Implementing this system will prevent LPG users from being defrauded and avoid the inconvenience of running out of gas while cooking.

Keywords: Liquified Petroleum Gas; Internet of Things; LPG gauging; STM32F411CEU6 microcontroller; Load cell; HX711 amplifier.

1.0 Introduction

Liquified Petroleum Gas (LPG), a fuel gas, made primarily from butane, propane [1-2] and unsaturated hydrocarbons [3], is gotten either as a product of refining of petroleum or from the extraction of natural gas [4]. LPG, as a cooking fuel, is bottled and marketed in pressurized cylinders in liquid form [3]and usually filled to about 80% to 85% of its capacity to allow for thermal expansion of the gas [2].

In a world where convenience is key and efficiency paramount, the monitoring of LPG in cooking cylinders stands in the forefront of innovation. As the primary source of cooking fuel for millions of households worldwide, ensuring a seamless gauging of LPG in cooking cylinders is not only essential for daily life but also critical for economic development.

In Nigeria, the inability to gauge the level of LPG in the cooking cylinder is accompanied by two unwholesome scenarios. First, most users are defrauded by the LPG vendor or the ward who is assisting the user to make the purchase. The end up having LPG of a lesser quantity than what they paid for. Second, the scenario of having an empty cylinder while cooking, especially during odd hours, is quite embarrassing. To put an end to this fraud and embarrassment, researchers have designed various systems [5-20].In this section, look into existing literatures, summarize their shortcomings and propose a concept that will curb these scenarios.

Mariselvam & Dharshini [5] developed LPG gauging and automatic booking system using an integrated sensor which was developed using a transducer. The sensor,interfaced with the NODE microcontroller (MCU), continuously monitored the level of LPG in the cooking cylinder, transferring same to the MCU.Data received by the MCU was used for decision making, as the MCU triggered to inform the gas vendor to come for a refill when the gas level was low. This system could not be remotely monitored and controlled.Oyubu*et al*., [6] proposed LPG level monitoring system, designed to gauge the quantity of the gas in cooking cylinder and also inform the user and the LPG vendor when the quantity of LPG in the cylinder reaches a preset level via the GSM module which was pivotal to the communication between the system and the user/LPG vendor. The system was designed to prompt LPG level at the following thresholds; low (50%), very low (25%), critically low (12.5%) and empty (6.25%). The Node MCU/Wi-Fi module accepted inputs from the load cell and controlled the output devices based on pre-defined logic. This system could not provide the user on LPG level after purchase, therefore, failed to handle the fraud scenario that could be perpetuated by either the LPG vendor or the user’s ward. Also, the system could not be remotely monitored and controlled.Sabitha *et. al*., [7] developed a system that monitors continuously, the weight of the gas in the cooking cylinder. The system is designed such that when theweight of the gas falls below the threshold value of 0.5kg, a logic high pulse is fed to the microcontroller. As this pin goes high, the microcontroller sends aShort Message Service (SMS) to the user and the gas vendor, requesting for a refill. The disadvantage of the system is that it could not be remotely monitored and controlled.This research aims at deploying the concept of IoTto develop an LPG gauging system, suitable for the monitoring of LPG in the cooking cylinder.

2.0 Methodology

This system comprises of the hardware, firmware and software components. For ease of explanation, this research is being broken down into various sections for detailed discussion.

2.1Materials

The major materials used for the development of this system's hardware is been described below.

2.1.1 STM32F411CEU6 Microcontroller: This is a high-performance microcontroller from STMicroelectronics, part of the STM32 family, which is based on the ARM Cortex-M4 core with Floating Point Unit (FPU), running at up to 100MHz. It has a flash memory of 512 kilobyte (KB) and a Static Random Access Memory (SRAM) of 128KB. It operates at a voltage of 1.7V to 3.6V, temperature range of -40 to 85°C and has low power consumption with multiple power-saving modes. This microcontroller is designed to offer high processing power and rich peripheral interfaces, making it suitable for a wide range of applications, ranging from consumer electronics to industrial automation and more.

Figure 1: STM32F411CEU6 Microcontroller

2.1.2 HX711 weight sensor amplifier: This is a precision 24-bit ADC that is designed to amplify signals from the load cell and reporting them to the microcontroller. It contains an on-chip low noise programmable amplifier with an optional gain of 32, 64 and 128. The HX711 chip integrates a regulated power supply, an on-chip clock oscillator, and other peripheral circuits, which have the advantages of high integration, fast response, and strong anti-interference. With the grove I2C connector and 4-pin screw terminal, it becomes quite easy to connect the load cell to the microcontroller, with no soldering required. The HX711 uses a two-wire interface (Clock and Data) for communication. Load cells use a four-wire wheatstone bridge configuration to connect to the HX711. These are commonly coloured and each colour corresponds to the conventional colour coding of load cells: red (Excitation+ or voltage common collector (VCC)), black (Excitation- or GND), white (Amplifier-, Signal- or Output-), green (A+, S+ or O+) and yellow (Shield). The yellow pin acts as an optional input that is not hooked up to the strain gauge but is utilized to ground and shield against external electromagnetic interference. However, some load cells have variations in colour coding. Since the output of the load cell gives a weak signal, the amplifier is used to amplify the signal and to convert the analogue data to digital data by using the ADC [21].

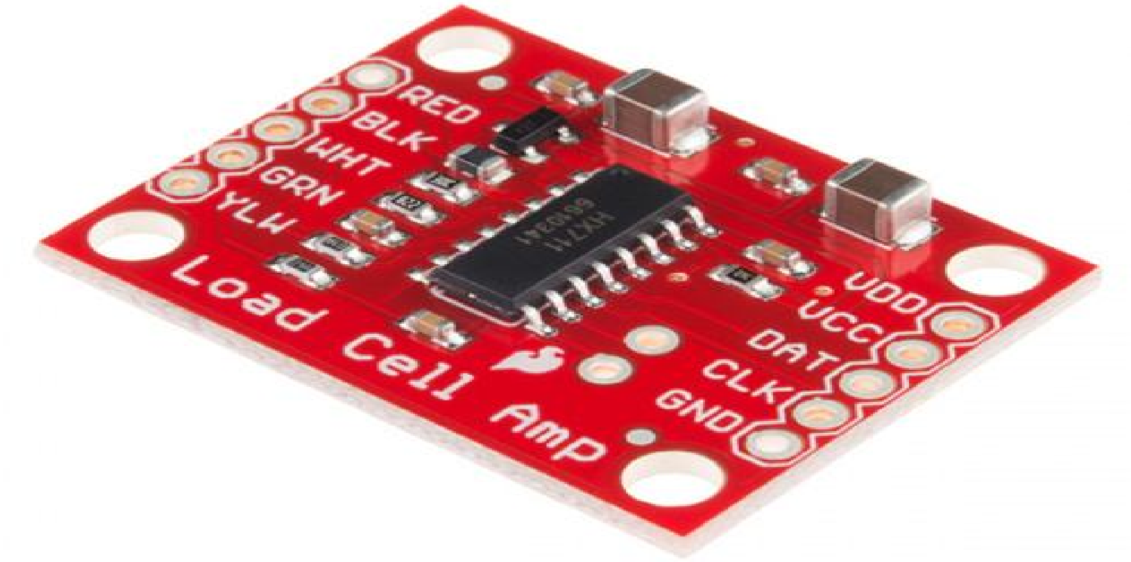


Figure 2: HX711 weight sensor amplifier

2.1.3 Load Cell: A load cell is a non-active transducer or sensor used for measuring weight by converting the applied load into electronic signals. Depending on the circuitry, this signal can appear as a change in current, voltage, or frequency. Load cells utilize strain gauges, which are small resistor patterns that work on the principle of resistance change. When a load is applied, the strain gauges bonded to a deformable beam experience strain, resulting in a change in resistance proportional to the load. Load cells provide highly precise and linear measurements, have excellent fatigue characteristics, and are not significantly affected by environmental changes, although they can be slightly sensitive to temperature variations. They have a long operational life due to the lack of moving parts that generate friction and are easy to produce because of their few components.

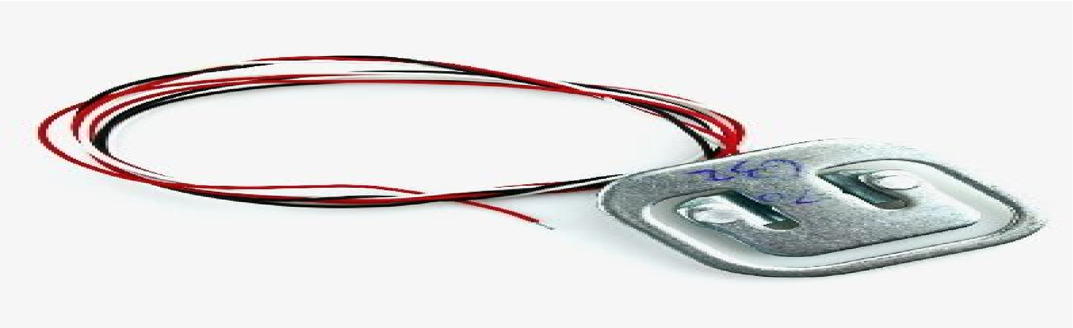


Figure 3: Diagram of a Load Cell

2.2System Design

Figure 4 illustrates the system's block diagram. In this setup, the MCU acts as the central processing unit, overseeing the load cell readings, processing the data, and generating outputs. The input section of the MCU includes a gas weight sensor that detects changes in the weight of the gas cylinder. The output section comprises a driver, a multicolor Liquid Crystal Display (LCD), and a communication module. The driver amplifies the power needed to run the system, the LCD provides a graphical display of the system's status, and the communication module enables internet connectivity, making the device an IoT device.

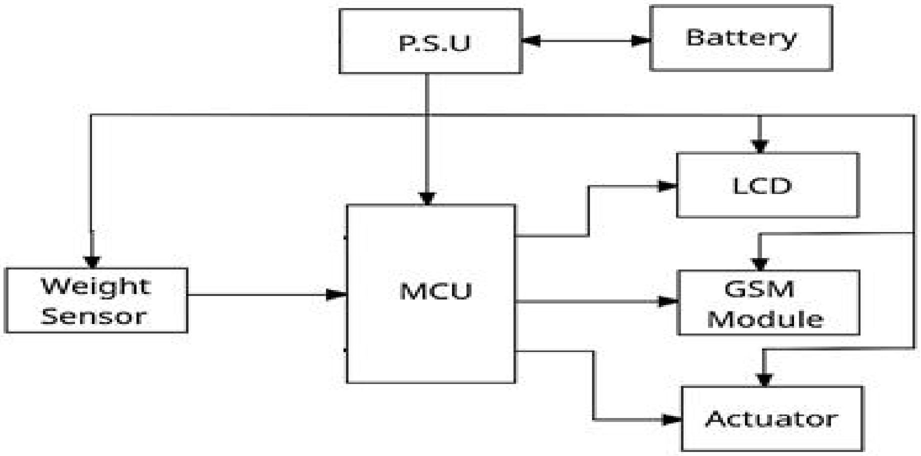


Figure 4: Block Diagram of Gas Gauging System

All hardware components require specific voltage levels as specified in their datasheets. The Power Supply Unit (PSU) handles the conversion of the input voltage into the various voltages needed by the system. The PSU is powered by either a 5V power pack or an 18V solar panel.

2.3System Design/Overview

Figure 5: System Overview

Figure 5 gives a picture of how the system interacts. The control unit, made up of the HX711 amplifier and the MCU, gathers data from the load cell, controls the charging/discharging of the battery and transmits/receives data to and from the ThingsWeb IoT service. The load cell works by sensing the weight of the gas cylinder. This weight varies with and without content. Using four 50kg load cells, it is possible to create a weight sensor that varies its output current as the cylinder's weight varies. The signal from the load cells, being too low to feed directly to the MCU, is first sent to the amplifier (HX711) which amplifies and sends the amplified signal to the MCU. The MCU reads the signal in digital form, as the amplifier outputs a pulse train.At the user end, an android smartphone running a custom app is used to monitor, control and manage the system operations remotely.

2.4Circuit Description of LPG Gauging System

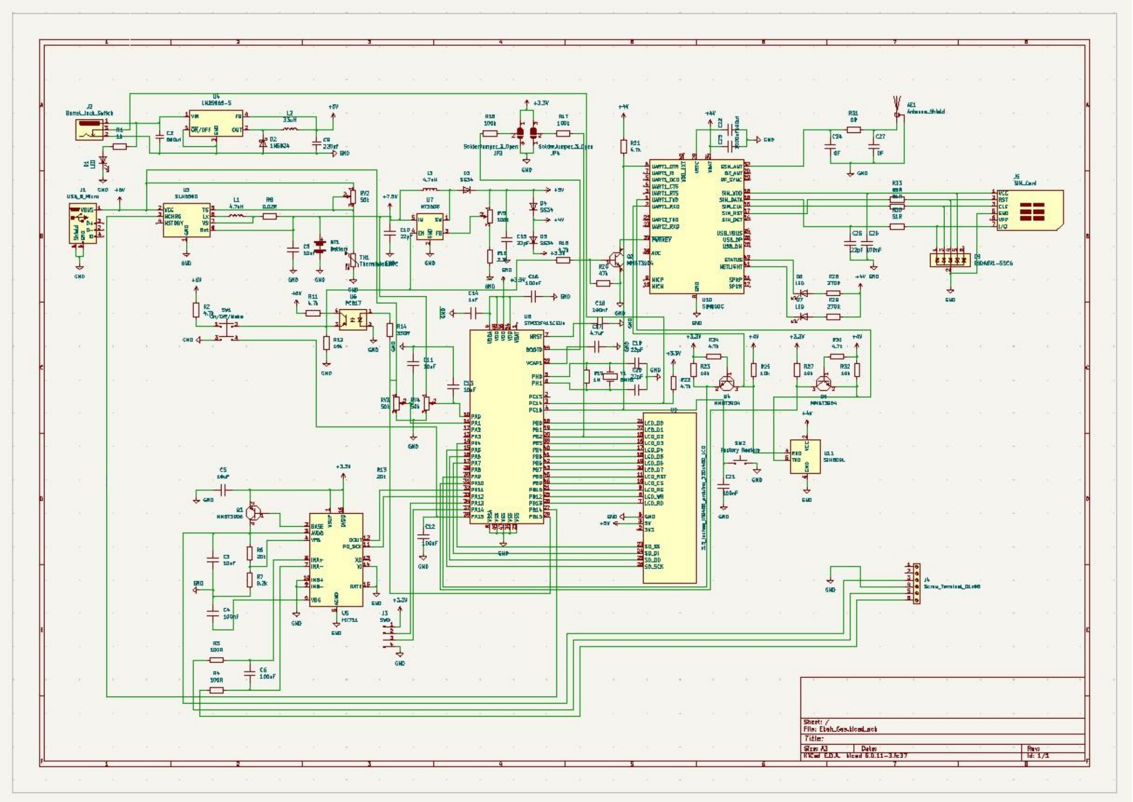


Figure 6: Circuit Diagram of LPG Gauging System

Components needed were load cell, HX711 load cell amplifier, STM32F411CEU6 microcontroller and jumper wires. The load cell typically has four wires: Excitation+ (E+), Excitation- (E-), Signal+ (S+), and Signal- (S-). The signal from the load cell, being too low to feed directly to the MCU, is first sent to the HX711 amplifier. Connecting the load cell to the HX711, E+ of the load cell is connected to the E+ pin on the HX711, E- of the load cell is connected to the E- pin on the HX711, S+ of the load cell is connected to the A+ pin on the HX711 while S- of the load cell is connected to the A- pin on the HX711.

The signal received by the HX711 is then amplified and forwarded to the MCU. In connecting the HX711 to the STM32 microcontroller, the HX711's VCC is connected to the 3.3V pin on the STM32, the HX711's GND is connected to the GND pin on the STM32, the DT (Data) pin of the HX711 is connected to a GPIO pin on the STM32 (PA11), while the SCK (Clock) pin of the HX711 is connected to another GPIO pin on the STM32 (PA12).

2.5 Circuit Analysis of Gauging System

i. Load cell output voltage

The output voltage is directly proportional to the load applied.

Therefore, $V_0 = \dfrac{S.\,V_e.\,F_l}{F_m}$ Equation 1

Where V_o = output voltage

V_e = excitation voltage

F_L = load applied to the load cell

F_m = Maximum rated force of the load cell = 200kg

S = Sensitivity of load cell in mV/V = 1mV/V

ii. HX711 amplification of load cell output voltage

$V_a = GV_o$Equation 2

Where V_o = Output voltage of load cell

G = Gain of the amplifier = 124

V_a = Amplified voltage

iii. Digital output from HX711 amplifier

$$D = \frac{V_a}{V_5}\ (2^N - 1)\text{Equation 3}$$

Where D = Digital output value from HX711

V_a = Amplified voltage

V_r = number of bits for HX711 amplifier = 5V

N = number of bits for HX711 = 24

2.6Firmware Development

The step-by-step process involved in firmware development are the User Interface (UI) design, program plan or flow chart development, sectional code test, coding, debugging and testing.

The UI design was necessary since the hardware has an LCD intended to display graphically appealing information. This was followed by a program plan developed in flowchart form, to guide in the process of development. The HX711 sensorwastested separately to find out the code that worked best with them. This code snippet was used in the final code development. With the sectional experimental code test perfectly working, the actual coding of the specific firmware for the system commenced. Here, the concern was how to arrange the process flow in such a way that the MCU resources are managed effectively without any issue and all parts appearing to run concurrently. The code was written in C language, using STM32CUBEIDE.

The coding process began, after which a machine code file was generated which was sent to the MCU during the chip writing.

Before generating the writable file, the code was run to check for bugs. If there is none, it starts generating. The first debugging started with clearing of syntax errors and then during testing. At this point, the hardware is ready and the very first version of the software is run on the MCU and observed for any possible runtime error. All these errors were cleared before having a final revision version of the firmware.

2.7Development of the Mobile App

The development of the mobile app involved the following stages: UI design, flow chart, sectional code test, coding, debugging, and testing.Mobile development assumed with designing the UI. This involved creating a visually appealing and user-friendly layout for the app. The design tool used to sketch and prototype UI elements is an Android Studio UI designer that uses an Extensible Markup Language (XML).

To map out the logical sequence of actions within the app, a flow chart was used. This outlined how users will navigate through different screens and interact with the various features. This visual representation was useful in planning the app's architecture and user experience. A sectional code test was then conducted before implementing the entire app. This involved testing individual components or sections of the code to ensure they function correctly and meet the specified requirements. It helped in identifying and fixing issues early in the development process.After the sectional code test, the actual source code for the mobile app was written in C language. This was necessary to implement the functionality, integrate APIs, and handle data storage which brought the app to life based on the UI and flow chart. We then proceeded to identifying and fixing errors in the code. This iterative process ensured a stable and reliable application.

2.8Cloud Server Integration: For the IoT cloud service, the ThingsWeb IoT service was used. This service was able to save and retrieve files in normal file format or list format. It appeared in string data type format to either the GPRS module or the android device.

2.9Testing of the Mobile App: After developing the mobile app, it was tested to evaluate its functionality, performance, and usability. This was done to ensure that the app behaved as expected, and to rectify any issues that may have been overlooked during the app development.Here, the developed app was uploaded and tested on a real device. The Android Package (APK) file which contains the compiled code and resources necessary for installing and running the app was then generated to enable installing it on all android devices. The app was installed on a few devices to confirm the UI of the app being responsive and visually appealing across different screen sizes and resolutions. This is done to ensure a consistent user experience for diverse users.

2.10Testing and Calibration of the Gauging System:

The load cell was calibrated to measure the weight of the LPG cylinder. The calibration accounted for the weight of the empty cylinder (the minimum limit) and when the cylinder was filled (maximum limit). This was done while the app was running and the calibration was also noted on the app.

In this research, a 12.5 kg was used. With the hardware properly connected,the empty LPG cylinder was set at zero while the full LPG cylinder was set at 12.5 kg. A two-point calibration was performed. This involved adjusting the readings so that they correspond accurately to the known weights of the empty and full cylinders**.**

The basic reading code was uploaded to the MCU with zero reading and full reading set to 0. The reading displayed with the empty cylinder on the load cell was recorded as the zero load reading and the value updated to the code. The full LPG cylinder (12.5 kg) was placed on the load cell and the reading displayed was recorded as the full load reading and the value updated to the code. The readings obtained from the empty and full cylinders were used to calculate the scale factor and was been incorporated into the code and updated.

While taking measurement, the load cell was placed on a stable and flat surface, free from vibrations.The load cell's ability to accurately measure the level of LPG in the cylinder and trigger appropriate alerts was then tested and these involved various usage scenarios. The reliability of data transmission from the load cell to the monitoring system was assessed to check for any latency issues or data dropout that could affect near real-time monitoring. Once these was done, the software handled the job from there, notifying and displaying the gas level data.

3.0 Results and Discussion

To monitor the level of gas in the cooking cylinder, the system utilized four 50kg load cells integrated into the IoT device. Through testing, the system was observed to effectively gauge gas levels in the cooking cylinder with high accuracy and reliability and provided timely notifications when the LPG level exceeded the predefined threshold.This allowed users to track gas usage and anticipate refills.

A user-friendly interface was developed for the system, which allowed users to visualize the level of LPG in the cooking cylinder through the LCD. The interface was designed to be intuitive and accessible on smartphones, tablets, and computers. The system was able to establish a secure connection with a cloud-based platform (ThingsWeb) for data storage and analysis. This facilitated remote access data to the level of LPG in the cooking cylinder and enabled the user to gauge the cooking cylinder from anywhere via the mobile app. This enhanced convenience and safety and provided users with greater control and peace of mind.

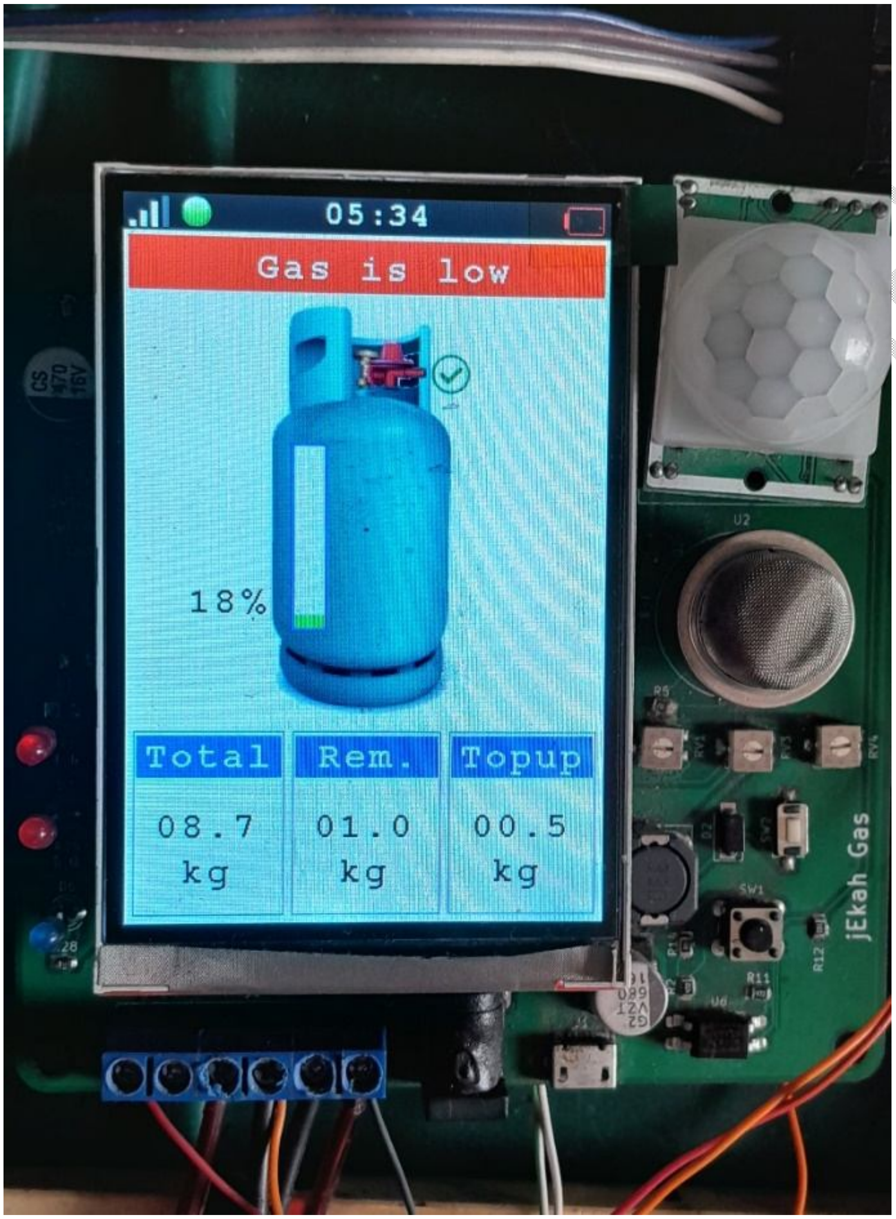
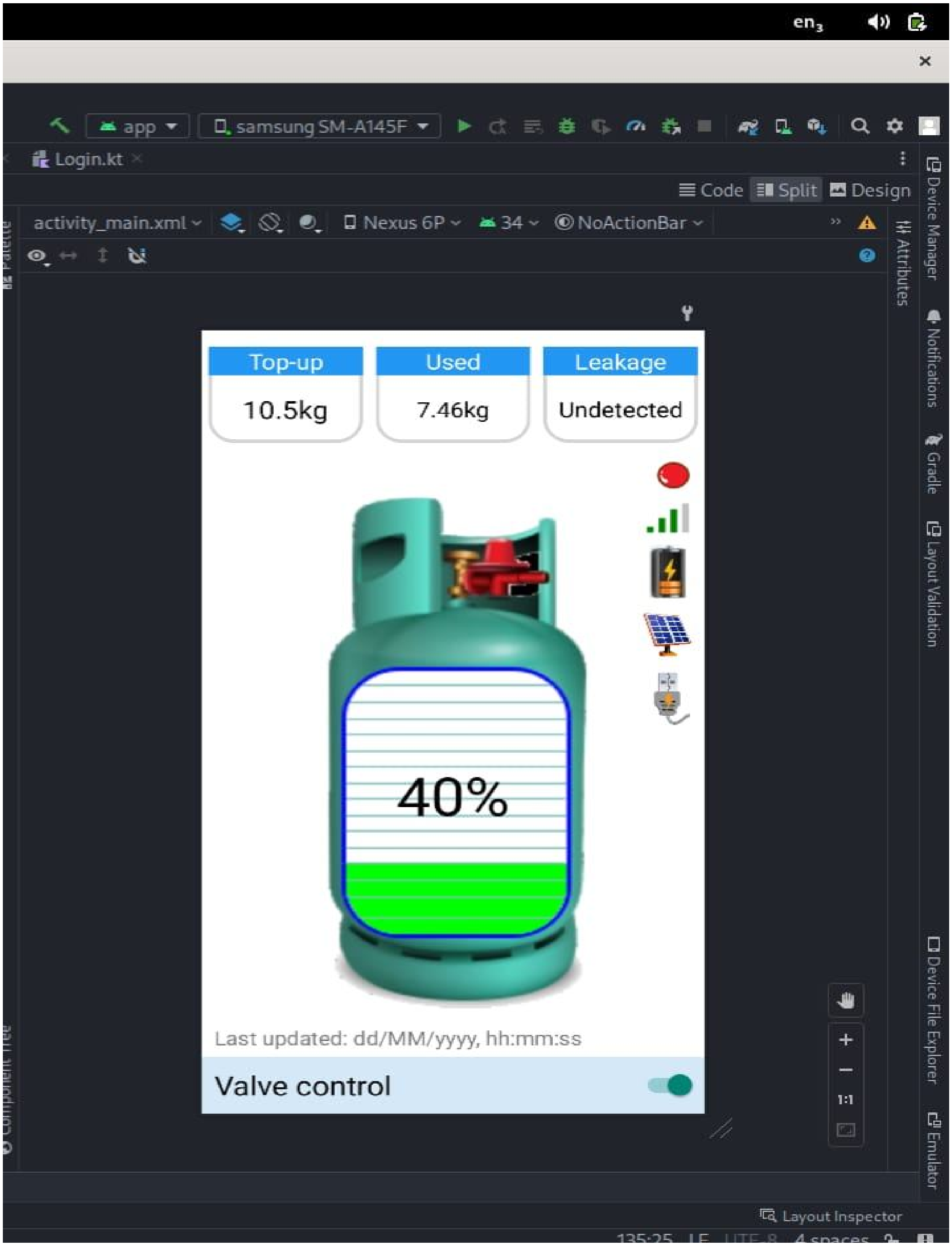


Figure 7: Diagram showing gas level on LCD screen



Top-up: 10.5kg

Used: 7.46kg

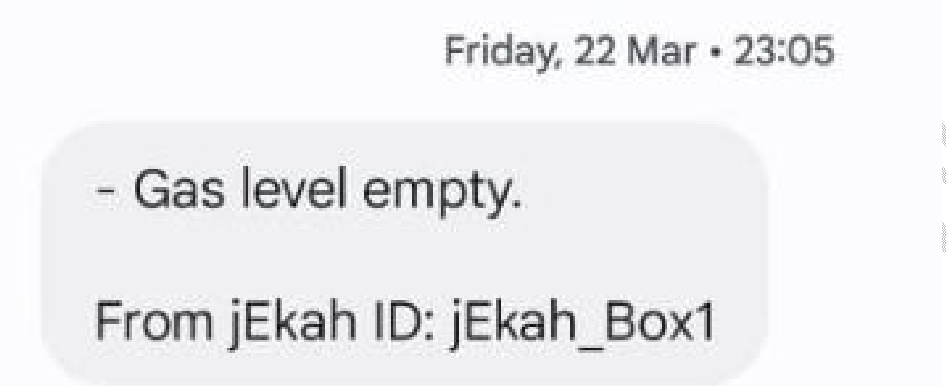
Leakage: Undetected

40%

Last updated: dd/MM/yyyy, hh:mm:ss

Valve control

Figure 8: Diagram of Gas level on mobile app



Friday, 22 Mar • 23:05

- Gas level empty.

From jEkah ID: jEkah_Box1

Figure 9: SMS Prompt of an empty Gas Cylinder

Conclusion

An IoT-based LPG gauging system has been developed. Developing the system involved design analysis, circuit construction, firmware development, mobile app development, cloud server setup and integration. The system consists of a load cell linked by cables to the control unit. The control unit consist of the MCU and the battery. The control unit gathers data from the load cell, controls the charging/discharging of the battery and transmits/receives data to and from the ThingsWeb IoT service.

The system is designed such that when the load cell sends the signal to the HX711 amplifier, the HX711 amplifies the signal and sends it to the MCU. The MCU triggers the GSM module to initiate the LPG value on the LCD. This will prevent the user from being defrauded by either the LPG vendor or the ward who is assisting in making the purchase. In addition, the user can adjust the system to a preset level for a refill reminder to be triggered through SMS/call. Owing to this, the system will be triggering a reminder to the user once the LPG gets to a level, as adjusted by the user. This will forestall the embarrassment of having an empty gas while cooking during odd hours.

More so, the system has a custom-developed mobile app thatwill isused to remotely gauge LPG level in the cooking cylinder at all times. Through this mobile app, gas level notifications will be triggered in the form of beeps to the user.

To arrest the issue of irregular power supply in Nigeria, the system will be powered by a battery, a 5V power pack and a 18W solar panel.

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