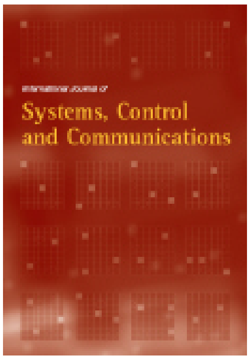

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Smart LPG usage and leakage detection using IoT and mobile application

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Abstract: Liquified petroleum gas (LPG) is one of the most popular home cooking sources in Brunei and other parts of the world where gas price is cheaper than electric price. However, LPG is highly inflammable and can easily cause fire and explosion if there is a leakage. When the gas finishes at an odd time, it will be difficult to order and get a new cylinder. There are two main objectives of this IoT-based research project. The first one is to monitor the usage of the gas and place an order through a mobile application when the gas level goes below a threshold value. The second one is to detect any gas leakage and close the knob of the cylinder when the gas leakage level goes above a threshold value and activate an alarm. This system also sends an automatic alert notification to the user through the mobile application. Apart from the mobile application, a simple web interface was also created to record the values from the sensors.

Keywords: LPG leakage; LPG usage; LPG fire; LPG properties; internet of things; IoT; gas sensor; load cell sensor; mobile application.

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1 Introduction

Liquified petroleum gas (LPG) is used by millions of people in different parts of the world for a variety of applications. According to LPG exceptional energy report, agriculture, industrial, professional and commercial, domestic, transportation, recreational and energy and power are the different application areas of LPG. For example, in the transportation area, the LPG is called autogas (automotive LPG). LPG is one of the popular sources for heating and cooking at home in Brunei and also in countries where LPG price is cheaper than electric price. LPG has a high calorific value, low emission rate and lower harm to the environment (Khan, 2020). The use of clean fuels like LPG and electricity is important to bring down household air pollution especially in developing and under-developing countries (Gould and Urpelainen, 2018). As per the report of the Multiconsult Group by Norad (2020), LPG helps to achieve access to clean fuels and technologies which contribute to achieving Sustainable Development Goals (SDG) in developing countries. There are also risks in using LPG because it is highly inflammable and can easily cause explosion and fire if there is a gas leak. This can cause injury and even death to human beings and also property loss. Old regulator, defect hose, low-quality and unmaintained hose, improper installation of the gas regulator and poorly connected hose to the gas stove are the common causes of the accident (Khan, 2020; Tamilselvi and Ghafar, 2018).

Internet of things (IoT) is defined by International Telecommunication Unit (ITU) as follows:

> "A global infrastructure for the information society enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies." [ITU-T Recommendation ITU-T Y.2060, (2013), p.1]

There are many definitions for IoT. Another definition is, IoT is a fast-emerging technology that makes things and machines in our surrounding environment connect, communicate, act and react with each other autonomously without human intervention (Kumar et al., 2020). The applications of IoT keep expanding due to its advantages. It can be used for simple smart home automation to complex industrial automation. IoT-based smart systems are not only used for monitoring and controlling but can also be used to predict future events using data analytics.

1.1 Problem statement

The following are the problems faced by the users in Brunei who use LPG cylinders for home cooking. This information is gathered from Brunei Shell Marketing (BSM) and our research:

- LPG leakage, explosion and fire which created accidents, loss of lives and properties.
- Difficulties in knowing when the gas finishes especially in night time (in Brunei, LPG cylinder distributors operation time is from 9:00 A.M. to 6:00 P.M. and most of the shop closes at 10:00 P.M.).
- Difficult in LPG cylinder order processing. Brunei still uses the manual cylinder ordering process and it is time-consuming and not efficient.

To address the above problems faced by the users, we started this research. The research objectives are provided in Section 3. This paper is organised as follows. Section 2 covers a detailed background study. Section 3 describes our proposed system. System design is covered in Section 4 and implementation is explained in Section 5. Section 6 analyse the results, and finally, this paper ends with a conclusions in Section 7.

2 Background study

LPG is obtained during natural gas and crude oil extraction (Synák et al., 2019). It can also be generated from fossil fuel sources. LPG was initially used as motor fuel in 1928. It was first produced by an American Chemist, Dr. Walter Snelling in 1910 and he also identified that propane and butane in the gasoline cause its evaporation (Zloty, 2013; Momin et al., 2016). LPG refrigerator was made in 1928 (Zloty, 2013). LPG was first used for cooking and heating during the Olympic Games in Los Angeles in 1932 (Zloty, 2013). According to Zloty (2013), a form of LPG called Blau gas was used in airships. Due to the increase of petroleum prices in 1970, LPG-fuelled vehicles were on the rise (Ryskamp, 2017). This paper focuses on how to improve the safety and service of LPG cylinders usage at home through mobile applications in Brunei Darussalam.

2.1 Properties of LPG

LPG mainly consists of propane (C_3H_8) and butane (C_4H_{10}) with an equal combination (Momin et al., 2016) and in some cases, it also consists of a small percentage of ethane (C_2H_5) and pentane (C_5H_{12}) (Adolf et al., 2015). The percentage of propane and butane varies a bit in winter and summer, with a higher percentage of propane in winter (El-Morsi, 2015; Setiyo et al., 2017).

Propane has a gravity of 1.56 is heavier than air and it is colourless, odourless and flammable (Sriwati et al., 2018). According to BSM, an odorant (ethyl mercaptan) is added to LPG when there is a leakage. Propane catches fire at higher temperatures in the air and produces carbon dioxide and water as end products (Sriwati et al., 2018). Propane boiling point temperature is –42°C or –44°F (ELGAS, 2021a). On the other side, butane has a gravity of 2.01 and it is also heavier than air and it is colourless and flammable (Sriwati et al., 2018). Butane is flammable when ignited in the air or oxygen. Both propane and butane are heavier than air and it stays close to the ground level when there is a leakage. Table 1 summarises the important properties of LPG (ELGAS, 2021a).

Table 1 LPG properties

Properties	*Values*
LPG (propane boiling point)	–42°C or –44°F
LPG melting-freezing point	–188°C or 306.4°F
Propane flame temperature	1,967°C or 3,573°F
Propane ignition temperature in air	470°C–550°C or (878°F–1,020°F)
Limits of flammability	2.15%–9.6% LPG/air
Propane auto ignition temperature	470°C–878°C

LPG is in the gas form in the normal atmospheric pressure. LPG is normally supplied in pressurised steel vessels because its boiling point is below room temperature and will evaporate quickly at normal temperature and pressure (Momin et al., 2016). The flammable range of propane is between 2.4% to 9.6% while the butane is between 1.9% to 8.6% (Sriwati et al., 2018).

World LPG Association Annual Report 2019 says that the global LPG production has increased by 3.6% (WLPGA, 2019). This WLPGA (2019) report also says that IoT can be employed to make the LPG business safer, smarter and more accessible. LPG bottlers follow safety measures throughout the bottling process and generally the accidents happen in the end user's place like home and restaurants mainly due to poor handling of gas cylinders and not following the guidelines given by the LPG suppliers. The 2017 annual report from The High-Pressure Gas Safety Institute of Japan (KHK) on LPG related accidents says that there are still accidents that happen due to gas leakage and explosion, however, the total number of accidents is reducing compared to previous years. This report also says that in 2016 and 2017, there were still injuries with no reported deaths (KHK, 2017).

2.2 LPG statistics in Brunei

In Brunei, 76% of the energy demand is catered by electricity, in the remaining 24%, LPG accounts for 13% and natural gas accounts for 11% (ERIA, 2019). According to this report, the LPG is mainly used for home cooking and heating. Kuala Belait district mainly uses natural gas because it is close to the gas fields and the processing plants. In addition, the gas price is fixed at $5.00 per house per month (ERIA, 2019). According to this report, Brunei's national average consumption of LPG per household was 0.23 m^3 and Kuala Belait recorded the national highest average consumption of LPG household at 0.3039 m^3 (ERIA, 2019). The following are the few recent LPG gas related accidents in Brunei according to the local newspaper, *Borneo Bulletin*. A recent LPG gas leakage and the fire were reported in a house at Kampong Sungai Tampoi due to leakage from an LPG gas hose on 2nd April 2021 (https://borneobulletin.com.bn/gas-leak-sparks-house-fire/). On 26th August 2019, another incident was reported in which two women suffered burn injuries due to gas leakage and explosion at Kampong Katok. And again, on 12th November 2018, a 17-year-old boy suffered 40% burns due to gas leakage and explosion at his home in Tutong district. There could be other LPG related accidents that happened in past in Brunei and the data are not available. With IoT-based gas leakage detection system, LPG related accidents can be avoided and can save people's life and properties. A report from BSM says that exposing people to LPG at high concentration can cause fainting, headache, nausea and in the worst-case loss of life. Touching the gas leak will cause cold burns to the skin and damage the eyes if it comes into contact.

2.3 Existing systems

With the proliferation of mobile devices especially smartphones and the emerging era of IR4.0, we see more IoTs and smart devices gaining a strong foothold in monitoring and maintaining domestic health and safety issues. One area is the detection of toxic and highly combustible gases from LPG to prevent fire at home. In Subramanian et al. (2020), the authors used the MQ-5 gas sensor, Arduino controller, and cloud storage in the proposed system. In the system, MQ5 is used for the detection of gas. The collected data were stored in the cloud and Arduino Uno with a Wi-Fi module was used to monitor and process data to a certain extent and to send data to the internet. The cloud data collection system is done through open-source software, ThinkSpeak. In the proposed system, all the information including recorded data, warnings and alerts can only be seen from a web-based interface and through mobile phones. There is no alarm or any form of indicator to inform users/owners on the premises if the users do not have mobile devices.

In Bhoi et al. (2018), the authors proposed a smart domestic fire detection system through data analytics. The system used historical records and classification performed on K-nearest neighbour (KNN) to distinguish between, fire, light fire and no fire conditions. Once predicted, the alert message is sent to the users/owners through mobile phones for evacuation and to take precautionary actions to prevent fire. MQ series of sensors are used for the detection of smoke, CO_2 and CO. DHT-11 was used in the system to measure temperature. 20,000 instances of a dataset from the sensors for CO_2, CO, smoke and temperature were generated for the three possible conditions required in a controlled environment. The experiment proved that the accuracy was 93%. The drawbacks of the proposed system were that it may be overfitted as the generated data were simulated, the system only pushed alerts to mobile devices to owners or the fire department and there was no alarm on the premises to alert owners.

In Shrestha et al. (2019), IoT-based smart gas management system was proposed by. The system consisted of gas leakage detection, fire detection and gas cylinder load notification. The system was using Arduino Uno as the main controller. MQ-2 sensor was used for detecting gas leakage. Load cell and fire sensors were proposed but no specific devices were recommended. A SIM900A GSM module was also proposed for sending alerts to phones. A buzzer was also proposed but with no specific device recommendation. When the system was on, gas leakage would be monitored regularly, the fire detector would detect any occurrence of fire, and the load cell would continuously weigh the weight of cylinder gas. Any anomaly detected would trigger an SMS to be sent to alert the owners. The proposed system however did not show how a load of the gas cylinder could be measured using the load cell. The system also uses a GSM module which may not be practical now as many GSM networks in many countries are obsolete and may not be sustainable.

In Cekova et al. (2018), a mobile sensor network system was developed to detect toxic gases in Macedonian mines. The system was designed using a mobile controlled robot using a mobile phone. The sensors used were DH11 for temperature measurement, MQ-2 to detect methane gas, MQ-7 to detect CO and MQ-135 for measurement of CO_2. The system was implemented using an ESP8266 Wi-Fi module attached to a microcontroller and connected to mesh topology for TCP-IP communication. The controller processed sensor data transformed them from analogue to digital data and sent the data to the server through the Wi-Fi interface module. A threshold value of the gas was set and would generate an alarm when the threshold value was crossed. Cloud computing was also used to store data to allow remote monitoring anytime and anywhere. The system was rigorously tested, even 100 m from an explosion at surface mines in Probistip, and proven to be suitable for deployment, especially in underground mines.

Mohammed et al. (2021) proposed a system that detects a range of toxic and flammable gases using IoT. The system would detect release evacuation alarms once harmful gases were detected and sent SMS for emergencies. The system used different MQ series of sensors for detecting different types of harmful gases and connected to an Arduino Uno controller. A SIM800A quad-band GSM module with an RS232 interface was used for SMS emergency notification. A piezo buzzer was used for the system for releasing alarm if toxic gases were detected. Although the system can detect different types of gases, it is lacking in terms of capability in recording and storing raw data from the many sensors, a reasonable web interface, and using a diminishing and almost obsolete GSM system for the SMS emergency alerts.

Many IoT-based gas leakage detection and gas usage systems were done as part of the research projects (Khan, 2020; Suma et al., 2019; Dwibedi et al., 2020; Debnath et al., 2020; Leena et al., 2018; Sriwati et al., 2018; Tamizharasan et al., 2019; Tamilselvi and Ghafar, 2018; Anandhakrishnan et al., 2017). Another research project prototype is developed using wireless sensor networks (Murugam, 2020). An IoT-enabled toxic gas detection and alarming system using WSN was developed to detect toxic gases in hotels and resorts (Praveen et al., 2021).

In Brunei, LPG gas cylinders are supplied by BSM approved distributors. They supply 12 kg cylinder for the home sector and 44 kg cylinder for the commercial sector. Brunei is involved in IoT-based research studies in poultry farm (Hambali et al., 2020) and in environmental monitoring (Syazwan et al., 2020). To the best of our knowledge, this is the first initiative in Brunei to monitor the usage of LPG and gas leakage detection in the residential sector. If the gas finishes at odd hours, it may not be possible to order and get a new cylinder immediately as most of the gas distributors close their operations at 6 P.M. Thus, this makes it difficult for people who are highly dependent on LPG cylinders for cooking as it affects the cooking process. A mobile application is developed as part of this research to enable the user to order the gas cylinder using e-mail, phone call (if it is daytime) or SMS. This research also proposes a solution to detect the gas leakage early and close the gas valve when the gas leakage level is above the threshold value. This prevents gas explosions and improves the overall safety of the LPG home users.

3 Proposed system

This research project has two important objectives. The first objective is to safeguard the people and their properties from being damaged in case of fire and explosion due to LPG leakage at home. The second one is to improve the service by checking the remaining gas level and ordering the next cylinder when the gas level is below a threshold value. The safety parameter is incorporated by using a gas sensor to detect the gas leakage and close the valve using a micro servo motor. At the same time, it alerts the user through a mobile application and an alarm is raised. This ensures the safety of the home users and their properties from being damaged. The service is improved by incorporating a load cell sensor which measures the weight of the cylinder and when the weight goes below a certain threshold value, it will notify the user through the mobile application and give the option for the user to e-mail, SMS or call the vendor to supply the cylinder.

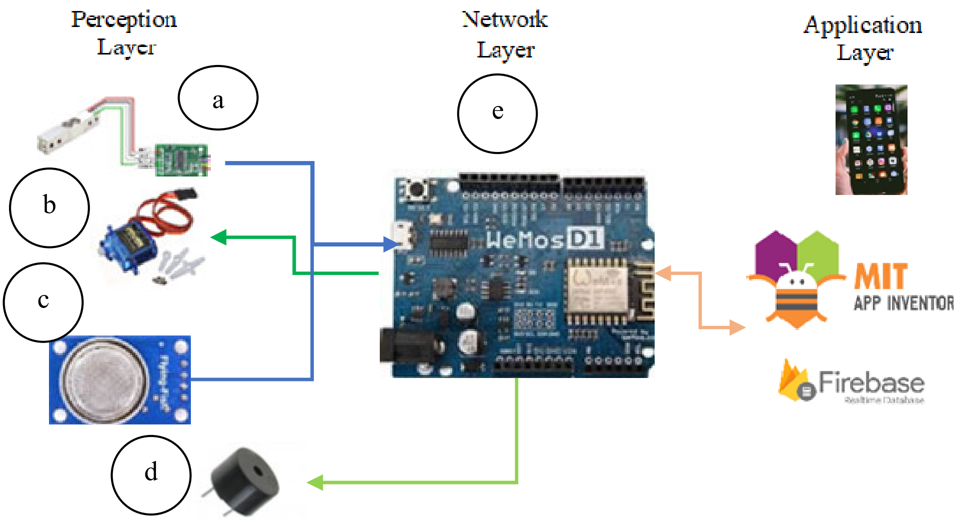
LPG cylinders bottlings and the safety guidelines are provided by BSM during our online discussion. The backbone of the prototype is the WeMos D1 IoT development kit. It has built-in Wi-Fi based on ESP8266 12E, similar to NODEMCU. There are two sensing units used in this system. The first one is HX711, a load cell sensor for calculating the weight of the cylinder. The second one is the MQ5 gas sensor to detect gas leakage. Two actuators are also used in the system, the first one is a piezo buzzer, which is used to generate an alarm sound to alert the home users and nearby people when there is gas leakage. The second actuator is a micro servo motor which is used to close the valve of the cylinder to further stop the gas leakage and thwart a major accident. This IoT-based smart system improves the overall safety of the LPG cylinders at home and allows the user to book a cylinder in advance to avoid any interruption of gas supply for home cooking. The next section describes the system design of the prototype.

4 System design

IoT can be implemented based on three-layer, four-layer or five-layer architectures. The architecture can be selected based on the application, domain area and functionalities required by the IoT-based systems. In our research prototype, we used three-layer IoT architecture (Kumar et al., 2020) as shown in Figure 1. The first layer, which is also called as perception or physical layer, where all the sensors (load cell sensor is labelled ‘a’ and gas sensor is labelled ‘c’ in Figure 1), IoT development board (labelled as ‘e’) and actuators (micro servo motor is labelled as ‘b’ and piezo buzzer is labelled as ‘d’) are located.

The input and output devices are connected in this first layer. The second layer is called as network layer. The Wi-Fi module, which is part of the WeMos D1 IoT board (labelled as 'e' in Figure 1) is located in this layer. This WeMos D1 IoT development board is shown in the network layer because it has built-in Wi-Fi. Lastly, the third layer called as application layer processes the data received from the sensors through the network layer. The processed data are displayed through the mobile application and the actuators are controlled through the program according to the value of the threshold.

Figure 1 Three-layer IoT architecture of the proposed system (see online version for colours)



This system consists of two important modules, namely, the load cell sensor module and the gas sensor module. All the sensors, the piezo buzzer and the micro servo motor are connected to the development board. The sensing module passes the data to the application layer through the Wi-Fi controller. The IoT board collects the weight of the cylinder from the load cell and the gas leakage from the gas sensor continuously (shown in the blue arrow going in to the IoT board in Figure 1) and sends it to the Firebase database through the built-in Wi-Fi controller. The data are processed in the application layer and the notifications are sent to the mobile phone through the mobile application program. After processing the data, the mobile app sent the control to the actuators to take the necessary action (shown in the green arrow coming back from the IoT board in Figure 1). Table 2 shows the summary of the hardware components used in the system.

Table 2 Summary of the hardware components

Hardware	*Used as*
WeMos D1 R2	IOT development board with Wi-Fi
HX711	Load cell sensor with amplifier circuit
MQ5	Gas sensor
Micro servo motor 9g	Gas regulator on/off
Piezo buzzer	Alarm sound

4.1 Load cell sensor module

A load cell is a transducer that translates an input mechanical load, weight, pressure, tension or compression into an electrical signal (Ganorkar et al., 2018). There are different types of load cells. The load cell we used in our prototype is bar-type resistive load cells (Yida, 2019). It works based on the piezo-resistivity. This load cell sensor module collects the weight of the gas cylinder at a regular interval and passes it to the database through the Wi-Fi controller (network layer). HX711 with an amplifier circuit is used as a load cell sensor. The load cell has a strain gauge, and the strain gauge generates an electrical signal on deformation (Saddam, 2017). The electrical signals generated by the load cell are further amplified by the amplifier circuit, converted into a digital signal by the analogue to digital converter (built-in amplifier circuit) and sent to the WeMos controller to derive the weight. Load cells come with different weighing ranges from 5 kg to 100 kg. We used only a 10 kg load cell in our prototype because the other load cells which can weigh higher weights are not available in the local market. The threshold kept for the cylinder weight is 2 kg. If the cylinder weight goes below 2 kg (in our setting), it alerts the user to order a new cylinder. The specification of the HX11 load cell sensor is shown in Table 3.

Table 3 HX711 load cell sensor specifications

Feature	*Specification*
HX711	Six pins for load cell, four pins for connection to the board
Load cell wire	Four wire only from loadcell (red connected to E+, black connected to E–, white connected A–, green A+)
HX711 to board wire	Ground, serial data output, serial clock input and VCC
Data accuracy	24 bits (24 bit analogue-to-digital converter chip)
Refresh frequency	10/80 Hz
Operation supply voltage	4.8–5.5 V
Operation supply current	1.6 mA

4.2 Gas sensor module

Gas sensors are used in many industries especially in oil and gas, chemical industries and also other industries where the gas poses a significant threat to human beings and their properties. There are four basic types of gas sensors available (Cory, 2020). They are:

- catalytic sensors
- electrochemical sensors
- infrared sensors
- photoionisation (PID) sensors.

There are several gas sensor modules available in the market. We selected the MQ5 sensor for our prototype which is an infrared type of sensor. This gas sensor module collects the leaked LPG gas level inside a home at a regular interval and passes the data to the database through the Wi-Fi controller. In the application layer, the data are processed and when 800 ppm and above leakage is detected, the users are alerted through the dashboard in the mobile app and the alarm is raised by the buzzer. At the same time, the cylinder valve is closed through the micro servo motor. When the gas level goes below 800 ppm, the valve is opened. This MQ5 sensor is made up of SnO_2 which has lower conductivity in clean air (Sharma, 2012). It can detect LPG, isobutane, methane, alcohol, hydrogen, smoke and so on. It is highly sensitive to LPG gas (Sharma, 2012). It can detect concentrations from 200 ppm to 10,000 ppm. Table 4 shows the specifications of MQ5 sensors (Amin et al., 2018).

Table 4 MQ5 gas sensor specifications

Feature	*Specification*
Pin number	Four pins
Pin name	1-VCC 2-GND 3-DO 4-AO
Detect gas	LPG, natural gas, town gas
Detect concentration	300–10,000 ppm
Working voltage and current	5 V and 150 mA
Sensitivity adjustment enabled	Yes
Preheat time	Over 20 s

Table 5 Micro servo motor 9g specifications

Feature	*Specification*
Modulation	Analogue
Torque	4.8 V: 25.00 oz-in
Speed	4.8 V: 0.12 sec/60°
Weight	9g
Operating voltage	3–6 V DC
Motor type	3 pole
Rotation/support	Bushing

Table 6 Piezo buzzer specifications

Feature	*Specification*
Pins type	Two pins, positive pin and negative pin
Rated voltage	1.5 VDC
Buzzer type	8 ohms, 0.5 W
Rated current	Less than or equal to 60 mA
Sound type	Continuous beep
Resonant frequency	2,048 Hz
Output	85 dB

This gas sensor module also includes two actuators, namely micro servo motor 9g and piezo buzzer. The micro servo motor 9g is a small form factor that is used to control the gas regulator valve. It can rotate 180 degrees (90 in each direction) and it is used to open and close the gas regulator valve of the cylinder. The second actuator piezo buzzer is used to make an alarm to alert the people at home and the neighbours when the gas leakage level is above the threshold value. Table 5 shows the important specification of the micro servo motor and Table 6 shows the important specifications of the piezo buzzer.

4.3 Software used

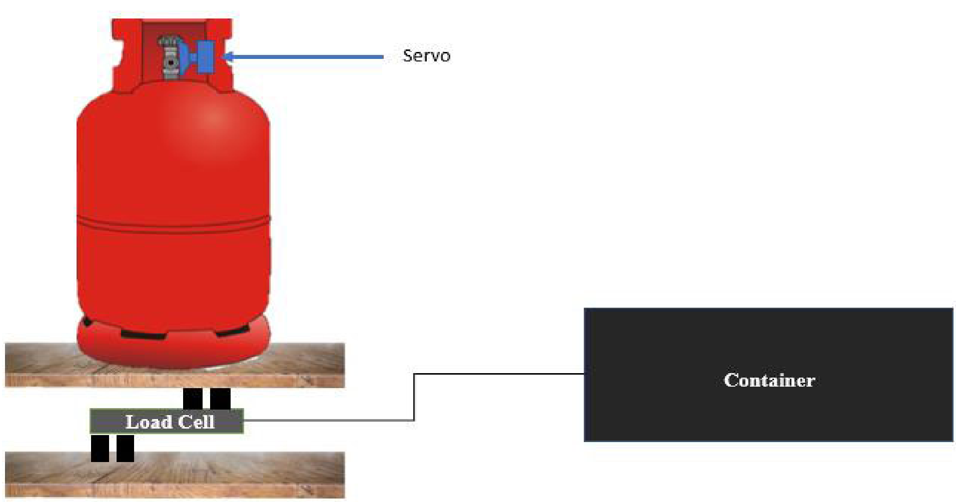
Arduino C++ is used to create a simple web interface which collects the data from the sensors and stores it in a Firebase database. Firebase is known as BaaS which are backend-as-a-service and it is a Google platform that support both developments, which are mobile application development and web-based application. Firebase is a cloud database and a NoSQL database, to update and sync the data store in real-time. Also, Firebase is connected from WeMos and to mobile application by JSON data reference.

MIT App Inventor 2 is used for mobile application development. It is initially created by Google but then handled by MIT Institute. This platform allows helping the low level or new programmer to create mobile applications either for Android or IOS. Also, this platform supports the Firebase database that eases the process of developing the mobile application.

4.4 Overview of the full system design

Figure 3 shows the overall design of the system which shows an LPG gas cylinder, load cell and container. The gas sensor, WeMos IoT board, buzzer and the micro servo motor are installed inside the container. The gas sensor needs to be installed close to the ground level because the LPG gas is heavier than air (ELGAS, 2021b) and when there is a leak, the LPG goes down close to the ground level and stays there. The load cell sensor is placed separately outside in between two wooden pieces so that the cylinder can be kept on top when in actual use as shown in Figure 2.

Figure 2 Overview of the system design (see online version for colours)



5 Implementation

Due to limitations, our prototype was developed using a small form factor. The hardware used is shown in Table 2 and the software used is shown in Section 4.3. Table 2 consists of all the hardware components with the breadboard. There are many factors for choosing the threshold value of the LPG gas leakage. LPG to air ratio level is one of the important parameters and if it is 1.8% above, there is a possibility of fire and explosion (Sriwati et al., 2018). According to Occupational Safety and Health Administration (OSHA), 1,000 ppm is the allowed limit for eight hours working. To be safer, 800 ppm is initially selected as it is the allowed range for the LPG gas leakage. When the leakage level goes above 800 ppm, the micro servo motor closes the regulator valve, an alarm sound is generated and the warning message will be sent to the user mobile through the mobile app. Experiments by Yan and Rahayu (2014) in their research suggest that LPG leakage 1,000 ppm and above is dangerous. For the cylinder weight, we kept a threshold value of 2 kg. The threshold parameter values are shown in Table 7.

Table 7 Threshold parameters for the prototype

Parameter	*Threshold value*
LPG gas leakage level	≤ 800 ppm
Cylinder weight	> 2 kg

The overall hardware architecture is shown in Figure 3.

Figure 3 Full hardware architecture (see online version for colours)

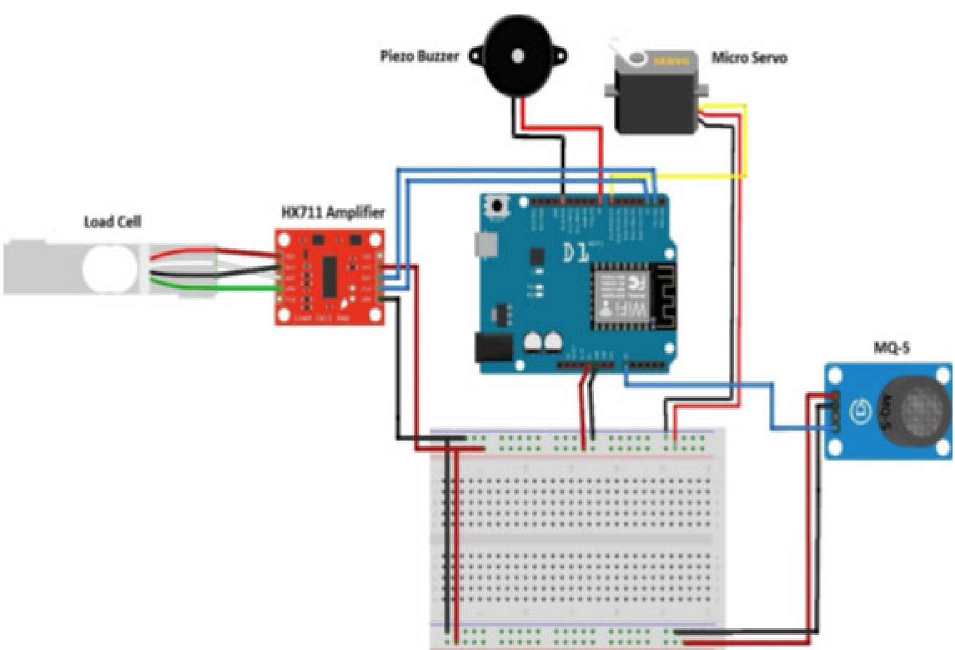


Figure 4 shows the side view of the prototype where the valve with servo motor and the wire from the load cell is shown. Inside the plastic container, an IoT development board with Wi-Fi, MQ5 gas sensor, piezo buzzer, breadboard for assembling all, jumper wires and other components are installed. On the side, a micro servo motor with a valve is installed. It is not safe to modify the cylinder valve. So, we used the valve with a servo motor and when there is a gas leakage of 800 ppm, it will close the valve. For power supply, the laptop power supply through USB is used. For implementation, solar panels can be installed near the gas cylinder outside of the house to supply the power for the IoT, sensors and other components since solar energy is abundant in this region.

Figure 4 Side view of the container containing processing board, input and output sensors (see online version for colours)

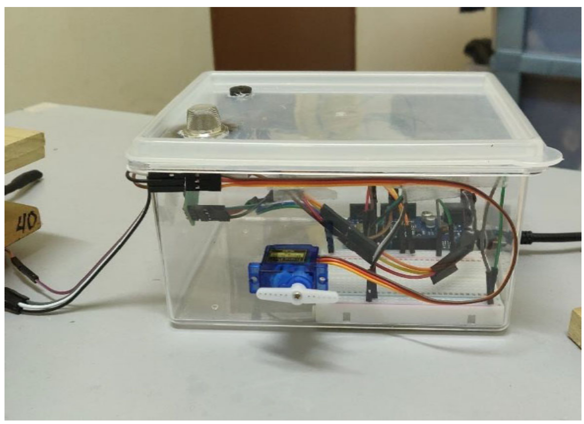


Figure 5 shows the load cell sensor with the wooden base which is used to weigh the cylinder. In the prototype, a hydro flask with water is used instead of an LPG gas cylinder because the load cell can weigh up to 10 kgs and also for safety reasons.

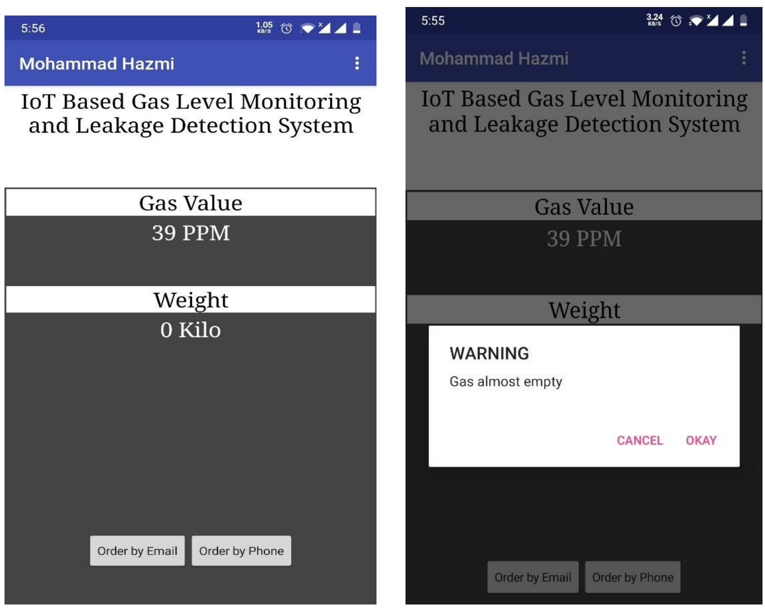
Figure 5 Load cell sensor with wooden base with flask as the cylinder (see online version for colours)

Gas leakage notification and the gas remaining level notification are done with the mobile application. When the LPG gas leakage is above 800 ppm, the mobile notification will pop up in the user's mobile phone with the message, 'Warning – LPG gas leakage at home – attention required'.

5.1 Mobile application dashboard

The mobile application is developed using MIT App Inventor for the Android platform which interfaces with the prototype. The dashboard showing the gas value and the weight of the gas cylinder is shown in Figure 6(a).

Figure 6 (a) Mobile application dashboard (b) Low gas warning (see online version for colours)



(a) (b)

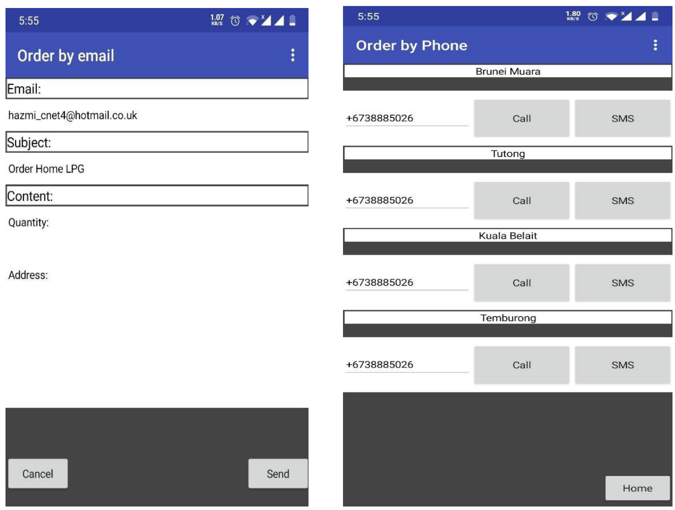
5.1.1 Low gas notification

This alert is generated when the weight of the cylinder goes below 2 kg and it can alert the user to order a new gas cylinder as shown in Figure 6(b). Our system provides three ways of ordering a gas cylinder for home users. They are through e-mail, mobile call and SMS. Users can choose according to their convenience. Figure 7(a) shows the screen for ordering the gas cylinder through e-mail. Figure 7(b) shows the screen for gas cylinder orders through the call or SMS option by users for the four districts in Brunei.

The user can choose either 'call' or 'SMS' to the LPG suppliers in their district. When the user presses the 'call' button, the Android phone call screen appears as shown in Figure 8(a). The phone number cannot be modified and can only be viewed. When the user chooses to call, he/she is only required to press the 'call' button as shown in Figure 7(b). In case, the user presses the SMS button, the following screen appears as shown in Figure 8(b). Here, the user can type the message and press the 'send' button.

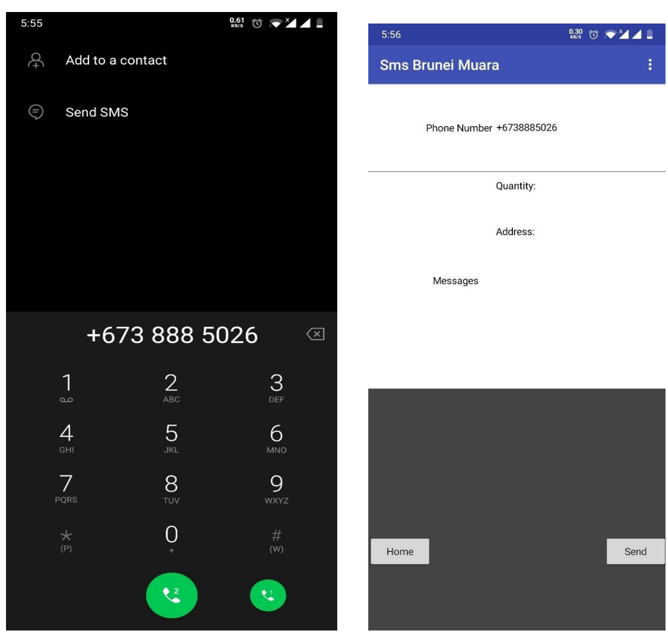
Users only need to enter the quantity of cylinder required and their home address, for the company to send the cylinder to the exact address.

Figure 7 (a) E-mail order (b) Call by mobile/SMS option (see online version for colours)



(a) (b)

Figure 8 (a) Android phone call or SMS (b) SMS order screen (see online version for colours)



(a) (b)

5.1.2 Gas leakage safety automation

The previous subsection shows how the low gas notification is handled by this system. This subsection deals with gas leakage safety. Apart from the alert notification when there is a gas leakage, this system automatically does the corrective action by closing the gas cylinder valve (in the prototype, the valve is attached to the servo motor) to prevent further leakage, fire and explosion. At the same time, the piezo buzzer makes an alarm to warn the users at home about the gas leakage, so that the users are deterred from switching on any electrical devices and the cooking stove. Figure 9 shows the simple web interface from Firebase real-time database. It shows only the leaked gas level if there is any and the cylinder weight. Firebase is a backend-as-a-service database, and it is a NoSQL database. The data is stored as a JSON object.

Figure 9 Simple web interface with Firebase (see online version for colours)

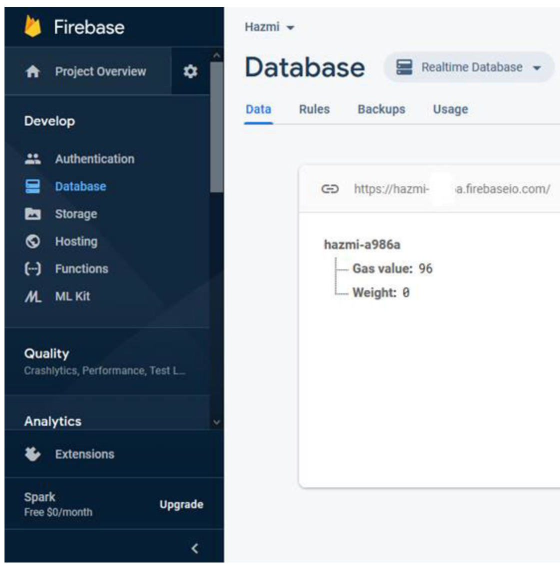


Table 8 LPG safety guidelines from BSM

Device	*Guidelines*
Regulator	• Use regulator with excess flow limiter
	• Change every 5 years
Hose	• Use fire retardant hose
	• Change every 2 years
Stove	• Maintain at least a distance of 1.5 m from the cylinder
	• Use hand-tightened clips to secure the connection
Cylinder	• Always keep the cylinders in an upright position
	• Keep LPG cylinders in well-ventilated areas
	• Never tamper the LPG cylinder valve
	• Do not drop/drag the cylinders

Apart from this technology, BSM (2021) recommends home LPG users to follow the safety guidelines to avoid accidents and property loss as shown in Table 8.

6 Results and discussion

These results in Figures 10 and 11 are taken before the project demonstration. Figure 10 shows the graphical representation of the readings taken from the load cell sensor HX711. We used the hydro flask with water for the gas cylinder and recorded the readings. When the weight goes below 2 kg, it generates a warning through the mobile app and asks the user to order a gas cylinder. Our main objective is to check the functioning of the load cell and the warning of low gas in the mobile app. Figure 11 shows the graphical representation of the readings from the MQ5 gas sensor from the prototype. The results in Figure 11 show the gas leakage level readings from the gas sensor taken at different times. In our prototype, we set the value of the gas leakage level as 300 ppm and if the gas level detected is 300 ppm and above, our system closes the valve of the container and the buzzer sounds the alarm. Our main objective here is to check the functioning of the gas sensor, alarm and gas valve. Both the load cell and the gas sensor produced the output as per our coding and the configuration.

Figure 10 Load cell sensor readings (see online version for colours)

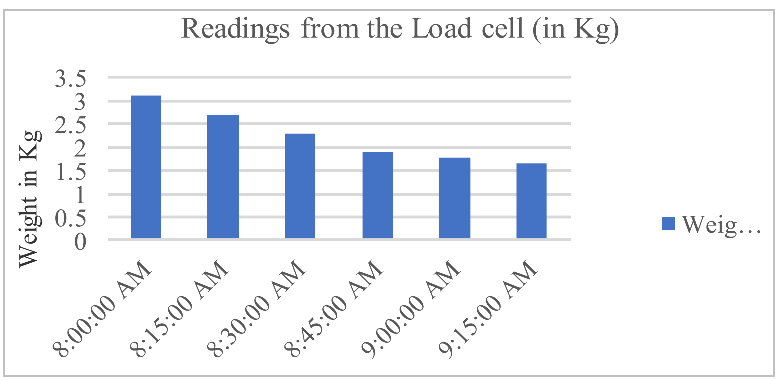
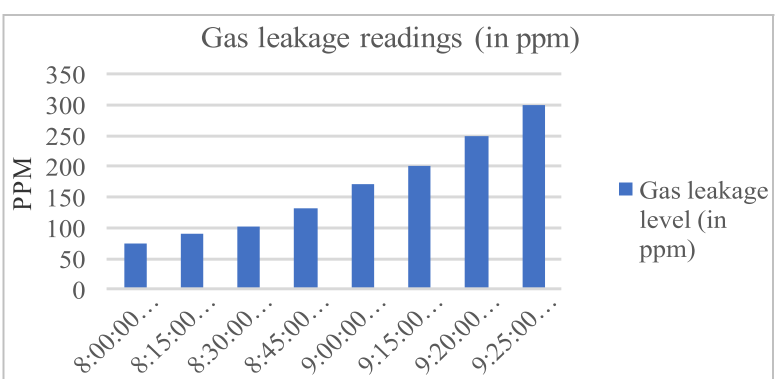


Figure 11 Gas sensor readings (see online version for colours)



7 Conclusions and future work

LPG gas cylinder is one of the commonly used cooking sources in Brunei and in other parts of the world where natural gas is abundant. LPG gas leakage related accidents happen at home and industrial sectors of developing and underdeveloped countries. These accidents can cause injury to human beings and even death. It can also result in damage to properties. Employing this simple gas leakage detection mechanism at home can provide safety to home users thus saving lives and properties. Also, with the inclusion of a load cell sensor and a mobile application, the supply and service of gas cylinders can be improved. Our research prototype proved that gas leakage can be detected, the gas valve can be closed automatically and also the gas cylinder can be ordered in advance before the gas runs out. This meets two of our research objectives, i.e., provide safety to the home LPG gas users and convenience for users to place the order before the gas is running out. A 50 kg load cell can be used in the future to weigh the gas cylinder and application can be extended to commercial sectors such as restaurants. Solenoid valves can be used to close the gas valve when LPG leakage of 800 ppm is detected and an alert sent to relevant people in real implementation. To power the IoT and sensors, solar panels can be used in the future.

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