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Wireless Sensor Network (WSN) Based Smart and Safe Home

Thangavel Bhuvaneswari, J. Hossen, C. Venkataseshiah and Lee Wei Xiong
Faculty of Engineering and Technology, Multimedia University,
Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia

Abstract: Negligence or failure to detect gas leakage from LPG cylinder in kitchen may lead to dangerous situations. Several accidents due to gas leakage at homes have been reported. A need also exists for early detection of gas level for ordering cylinder refill. The objective of the study is to design and develop a Wireless Sensor Network (WSN) (radio frequency) based gas leakage detection and gas level monitoring for smart and safe home. The system detects the leakage of the LPG and alerts the user using buzzer and LEDs. It continuously monitors the level of the gas present in the cylinder using load sensor and alerts the user when the cylinder level goes <25%. A prototype has been developed for gas leakage detection and level monitoring and tested. The tests results confirmed the satisfactory performance of the system developed. The proposed design ensures safety and prevention of accidents due to LPG leakage in smart homes. This also alerts the consumer when the gas level falls below 25%.

Key words: Microcontroller, LPG leakage detection, LPG level indicator, wireless sensor network, accidents

INTRODUCTION

The LPG is used in kitchens everyday which makes it vital to have a ready supply of LPG at all times. This leads to a necessity of an indicator that tells the user how much LPG is remaining in the cylinder. Negligence or failure to take reasonable steps in monitoring the gas level in the LPG cylinder may lead to unwanted situations such as outage of gas supply or in more severe cases, leakage and explosion of LPG cylinders. By including a level indicator, a user can periodically check on the remaining level of LPG remaining in the cylinder and replace it with a new unit whenever necessary.

Recently, several accidents due to gas leakage at homes have been reported: One such case is LPG cylinder explosion in a housing area located not far from Salem, India (Ananth, 2013). The statistics related to LPG leakage and accidents revealed that majority of the accidents happened in the morning, a time when residents are not aware of surroundings. The hypothesis made regarding the cause of the explosion was that the LPG cylinder has been leaking for the whole night (Kumar, 2013). Although, these accidents are categorized as the fault of the user's negligence, the presence of a leakage indicator such as a gas sensor could have notified the user and enable prevention of the accident.

Sovlukov and Tereshin (2004) have proposed LPG level measurement using radio frequency techniques. This design implements three measurement sensor, two RF level sensors and one gaseous phase dielectric permittivity sensor. This method provides accurate measurement of both the level and mass of gas in a LPG cylinder. However, the implementation of this design requires a custom designed and built LPG cylinder. This is not practical for domestic usage as standard C14 Model cylinder for households already exists.

Chang and Wu (2010) have applied LPG measurement based on acoustic principles. Different frequencies are produced when an LPG cylinder is knocked at different liquid levels inside. This frequency is then compared to a Bernoulli-Euler beam to achieve an estimate of the liquid level based on the frequency measured. The drawback of this design is the necessity of a knocking device to be used on the LPG cylinder that can be a cause of hazard in the case of metal on metal that may cause sparks. LPG is highly flammable and can easily catch fire in the presence of spark and subsequently lead to an explosion.

Hossain *et al*. (2015) performed gas leakage detection using micro controller and the data are sent to the computer for analysis in future. The analytical operation is modelled and simulated using MATLAB. LPG leakage is automatically detected and alert is sent as SMS using GSM technology and PIC microcontroller by Amsaveni *et al*. (2015). The same idea using ARM7 processor is developed by Shyamaladevi *et al*. (2014). Sahani *et al*. (2015) designed an interactive kitchen monitoring system for monitoring environmental parameters such as light intensity, room temperature, fire

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Corresponding Author: Thangavel Bhuvaneswari, Faculty of Engineering and Technology, Multimedia University,
Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia

detection, motion detection and LPG gas level. This system can monitor the status of kitchen and send an alert SMS via GSM network and/or an E-mail automatically to the concerned authority if the conditions become abnormal.

MATERIALS AND METHODS

The proposed system consists of Arduino Nano microcontroller, load cell/weight sensor for the LPG weight measurement, gas sensor for leakage detection and output device. The output device includes a LCD display unit, LEDs and buzzer. The inputs, the cylinder gas level and the status of gas leakage are fed to the microcontroller for processing and the output is shown in LCD display, along with two LEDs and a buzzer as shown in Fig. 1. The portable LCD display unit is to indicate the gas remaining in the cylinder. A LED is programmed to light up once the level of LPG is below 25% to notify the user that a replacement cylinder should be ordered soon to avoid running out of gas during usage. To ensure that the user is promptly alerted in case of a gas leakage, a buzzer will be triggered together with a flashing LED to provide both audio and visual warnings of the hazardous situation.

One of the common problems faced by all previously reported LPG level indicator models is the necessity for the user to occasionally lift/shift the cylinder from the storage to check out the level. This problem is solved by adding a wireless transmission to transmit data read from the LPG cylinder to the user.

An empty C14 LPG cylinder weighs 16.5 kg on an average. Every full cylinder is loaded with 14 kg of LPG making the total weight 30.5 kg. The significant difference between the full and empty cylinder can be translated into level indication. The weight of LPG remaining in the cylinder can be converted to the level of gas remaining by using the relationship:

$$\frac{\text{Weight (current)}}{\text{Weight (full)}}\times 100\% = \text{Level of LGP} \qquad (1)$$

Using this Eq. 1 the level of the LPG can be calculated as given in Table 1. Therefore a sensor that is capable of sensing force or mass is necessary to be integrated along with a microcontroller that is capable of performing calculations.

Hardware design and software development

Gas leakage detection: The MQ2 sensor is used as the leakage detector in this design. The MQ2 gas sensor senses the presence of gas leakage. A digital HIGH signal is sent when the leakage is sensed and low signal during normal conditions where no leakage is present. By adjusting the sensitivity of the sensor, it can be triggered at different concentrations of LPG. The Digital Output pin (DOUT) from the gas sensor module is connected to the microcontroller via digital input pin 3 (D3). The input value at pin D3 is constantly monitored to detect any leakage sensed by the gas sensor module.

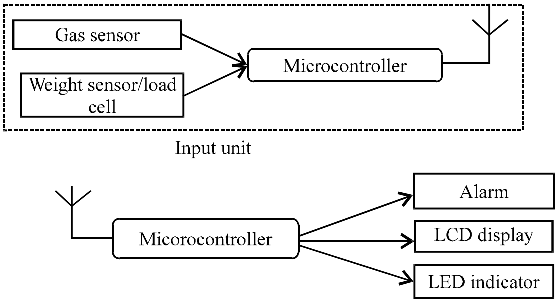

Fig. 1: Block diagram of proposed design

Table 1: Weight of LPG converted to level

Weight of LPG remaining (kg)	Level of LPG (%)
14.0	100
10.5	75
7.0	50
3.5	25

The 16×2 blue backlight LCD display is used in this design. The display serves as a visual indicator of the current gas level corresponding to the input received from the weight sensor module. The display is programmed to show both the current weight as well as the percentage of LPG remaining. The buzzer is used as a means of alerting the user when a leakage is sensed by the gas sensor. The sound produced is a loud and high pitched beep that is easily recognizable and clear. In case of a gas leakage, the user is alerted promptly and the chance the user not noticing warnings given out by the system is minimized. Ideally when the buzzer is heard, the standard steps of handling a gas leakage should be taken which includes: Opening all doors and windows, not turning on/off any electrical appliance, unplug the regulator from the LPG cylinder outlet and if leakage is still persists by smell contacting the LPG cylinder supplier.

In this design, LEDs are used to indicate two situations: Firstly when the level of LPG is below 25%, the user is alerted by a flashing LED. Secondly, when a leakage of LPG is detected, the user is alerted by a blinking LED synchronous with the beeping of the buzzer. To differentiate the two different states of operation, different colours of LED are used. Dangerous conditions are symbolized by a red coloured light and a yellow light is used in the case of an unusual situation. Adapting this

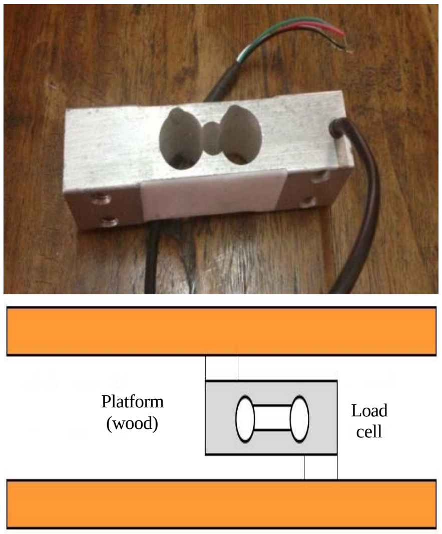

Fig. 2: Load cell and its implementation in wood platform

standard, the red LED is assigned to indicate leakage and the yellow LED serves to warn the user of impending low level of LPG remaining in the cylinder. This serves as a double warning in case the buzzer fails the user is still notified about a leakage by the blinking red light. Besides that if the LPG cylinder level is not checked regularly the user is still able to know that the gas is running low by the flash of yellow LED.

Gas level monitoring: Electronic weighing scales operate by using a load cell to accurately measure the mass placed on its platform. For this design, a simple binocular dual beam load cell is used as the sensor that measures the mass. The binocular beam load cell is made of an aluminium body with two strain gauges attached on the top and bottom of the load cell. When the force is applied on the free end of the load cell, the upper side of the load cell experiences a shear force that causes a deformation or displacement to its shape. This force stretches the strain gauge attached to the body of the load cell contributing to a change of resistance of the strain gauge. The load cell is shown in Fig. 2.

As illustrated in Fig. 2 the platform attached to the free end of the load cell should be centred to provide the best reading during operation. However, it is said that the load cell will be able to sense a force equally regardless of application directly at the centre or at any distance away from the centre.The resultant voltage difference from the wheat stone bridge is in terms of millivolts. This change in voltage can be translated into the amount of the force applied on the load cell. But this small change in voltage may not be significant enough to be sensed directly by the microcontroller's built-in Analog-to-Digital Converter (ADC). Therefore, an intermediate signal processor has to be included between the load cell and the microcontroller. The HX711 module, a 24 bit ADC is used to amplify the input signal from the load cell and convert it to digital signal which is then transmitted serially to the microcontroller.

Software development: Programming of the Arduino Nano microcontroller is done using the Arduino 1.0.5 IDE (Rashid *et al*., 2010). The functioning of the transmitter board is illustrated in flowchart in Fig. 3. The transmitter receives input from two sensor modules-the MQ2 gas sensor and the HX711 weight sensor module. By using the digitalRead ( ) function, the status of the gas sensor (pin D3) is continuously monitored. In case of no leakage is detected, the condition of pin D3 is "HIGH" and returns nothing. When leakage is sensed, pin D3 is set to "FALSE". In this situation, a character 'A' is transmitted wirelessly to the receiver board to indicate that a leakage has been detected. This action will repeat infinitely until the gas sensor no longer sense any gas leak.

In contrast, the input from the weight sensor module serves three purposes-to be used to calculate the level of LPG to indicate an overload on the weight sensor and to indicate a low gas situation when the level reaches 25% and below. The input received is stored in a buffer labelled temp 'C' which is then multiplied by a correctional factor. In normal operating conditions where there is no overload or gas low status, the corrected weight reading is transmitted directly to the receiver board to be displayed. At the same time, the weight measured is constantly compared to the threshold set for overload and low gas conditions. When an overload is detected, the character array 'OVERLOAD' is sent to the receiver board. Once the weight is reduced below the limit of 15 kg, the 'OVERLOAD' status will stop sending. Similarly, when the level of LPG drops below 25%, a character 'C' is transmitted.

The receiver board function is shown as flowchart in Fig. 4. The receiver receives its input solely from pin D11 on the microcontroller. When the controller is powered up, the necessary initializations for LCD display as well as the receiver module is declared. Once the receiver starts to receive data, it is stored into the buffer 'BUF' as a character array. 'BUF' is then continuously checked to find the characters 'A' and 'C' that are a short form for gas leakage and also gas low status from the receiver.

When 'A' is detected, the buzzer and red LED will synchronously be turned on and off to form a beeping sound flashing light effect. If 'C' is detected instead, the yellow LED will be flashed. The character 'A' represents

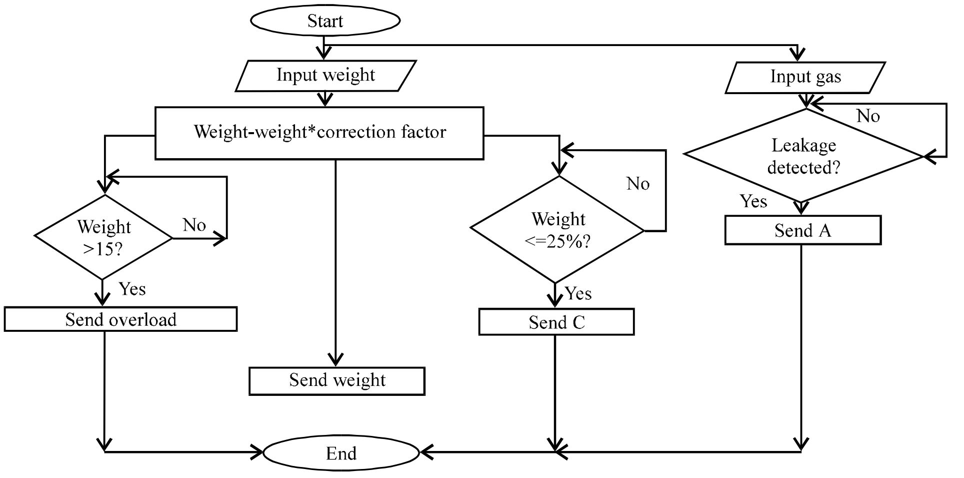

Fig. 3: Flowchart of transmitter board

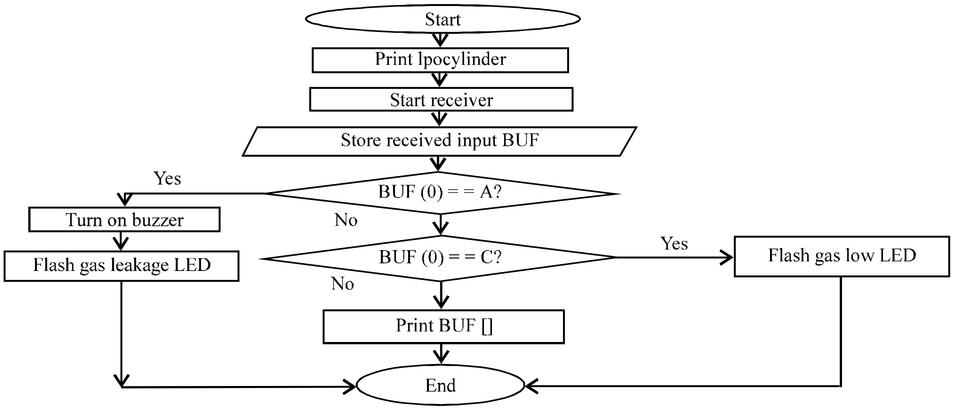

Fig. 4: Flowchart of receiver board

the status of gas sensor when leakage is sensed. The character ‘C’ represents the level of LPG below 25%. In normal conditions where ‘A’ and ‘C’ are not detected, ‘BUF’ will contain the weight measurement that was received from the transmitter. The program will then loop to receive data from the transmitter and checking repeats again.

Table 2: Actual weight versus measured weight

	Reading per region				
Weight plate (kg)	A (kg)	B (kg)	C (kg)	D (kg)	E (kg)
2.5	2.50	2.50	2.51	2.50	2.51
5.0	4.89	4.88	4.89	4.88	4.89
7.5	7.39	7.39	7.40	7.39	7.40
10.0	9.67	9.66	9.68	9.67	9.68
12.5	12.18	12.18	12.19	12.18	12.19

RESULTS AND DISCUSSION

A prototype has been developed. After interfacing the load cell and the microcontroller, the performance of the device is tested by using weight plates of different values and given in Table 2. It is observed that the displayed reading was not the real weight of the plate placed on the device to be measured. Therefore, a correction constant, K has to be multiplied to the input from the load cell in order for the device to display the correct weight values. The data is collected using weight plates in the Gym. For each weight category, two different plates of the same weight are measured. The correction constant is then calculated as follows:

$$\text{Correction constant (K)} = \frac{\text{Sum of weight}}{\text{Sum of average weight}} \qquad (2)$$

$$K = \frac{37.5\ \text{kg}}{10282\ \text{kg}} = 0.003647 \qquad (3)$$

The reading from the load cell was calibrated by applying the correction constant, K. After calibration, the

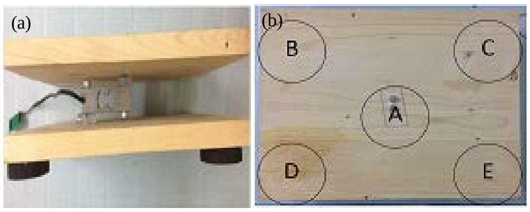

Fig. 5: a) Side view of weight measuring plarform and b) platform and marked regions

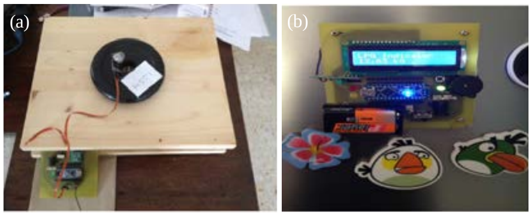

Fig. 6: a) Transmitter module connected and b) receiver module placed on ato a weight measuring platform refrigerator

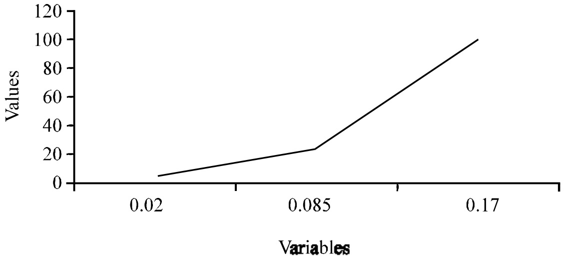

Fig. 7: Graph of range vs. antenna length

prototype is tested to determine its accuracy and effect of force acting on different regions. The platform can be divided into five portions namely: centre (A), top-left (B), top-right (C), bottom-left (D) and bottom-right (E). The weight plates are placed on the regions illustrated in Fig. 5 and the data are recorded in Table 2. Theoretically, the effective resistance change on each strain gauge with respect to mass applied must be the same regardless of position or direction the force is applied due to the resultant shear force. The resultant shear force acting on the surface of the load cell should be equal even though the weights are placed on different regions. The transmitter module connected to the weight measuring platform is shown in Fig. 6a and the receiver module is shown in Fig. 6b.

From the data recorded in Table 2, a 0.01-0.02 kg discrepancy is observed between readings. This shows that only a small effect is observed when force is applied on different region of the platform and can be considered to be negligible for the application meant for this prototype. However, as the weight of the plate increases, the discrepancy between the measured valued and the actual value seems to increase. This may be attributed to the inaccurate correction constant, K. Due to the fact that this design does not require such high sensitivity of weight measured, the data collected is accepted and no changes to the constant K is made.

The prototype involves wireless transmission through 433 MHz radio frequency which the manufacturer claims to provide range of over 100 m when antenna length is 17 cm. Since, data transmission is one of the most crucial elements in operation of the device, the range is tested to ensure it is functional in its intended environment. The test for range in open air for variable antenna lengths is conducted in the field. The receiver module is moved away from the transmitter 5 m at a time and the device is reset. Maximum range is considered at the point where the receiver last successfully manages to receive data from the transmitter.

From the data collected, the graph is plotted as shown in Fig. 7. It is observed that the antenna length does indeed affect the operating range of the prototype and hence the full length of the antenna should be maintained at all times. Another observation made during the experiment is the effect of supply voltage on the quality of transmission. When the battery supply at the receiver module runs low, it is observed that data received is noisy and the range is significantly reduced. Therefore, the battery or power supplied used should be checked regularly to ensure that sufficient power is supplied to the system to perform optimally.

CONCLUSION

In this study, a Wireless Sensor Network (WSN) approach of gas leakage detection and gas level monitoring is reported. Using this approach, a prototype has been designed and developed using Arduino nano microcontroller and sensors (MQ2 Sensor, load cells). The details of hardware design and software development have been discussed in the study. The experimental test results demonstrated the capability of the system to sense gas leakage and gas level successfully. The implemented wireless radio frequency transmission between the receiver and transmitter module provide ease of use and convenience to the user.

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