EMBEDDED AUTOMATIC GAS CIRCULATION MONITORING SYSTEM THREAT AND LEAKAGE DETECTOR

R.A.D.M.P.Ranwaka[1]

[1] Department of Mechatronics, Faculty of Engineering,
South Asian Institute of Technology and Medicine (SAITM), Sri Lanka.
Email: piyumalranawaka@gmail.com

ABSTRACT

This paper presents the design and implementation of an embedded system to detect fluid leakages irrespective of the chemical and physical nature of the fluid. Since LP gas is extensively used in households and there has been serious safety concerns relating to its domestic usage, LP gas leakage is a key application of the developed system. The system automatically monitors the gas circulation; detect gas leakages or a possibility. The system includes a fool proof operations to mitigate consumer ignorance, operation of the buzzer and the indication lamps as an alarm to the consumer and automatic lockdown of the gas cylinder at a controllable gas leak. The objectives is to ensure maximum safety for the consumer from all the gas related accidents and to improve the efficiency of gas consumption by cutting down the wastages due to gas leakages The system has been designed based on three inputs of three sensors which corresponds to three physical parameters namely an IR Flame Sensor to sense the presence of the flame, a Gas Flow Sensor to sense the presence of the gas flow and a Pressure Sensor to sense the rate of pressure variation. These three inputs are processed using the control unit in the embedded System which generates the outputs signals to drive the outputs. This system could be extended to an industrial control system or could be used in automobiles as well. Low cost, Reliability, Fast real time response and high sensitivity are other key advantages.

Key words: *Embedded Systems, Industrial Control, Automation, Leakage Detection, LP Gas Detection, Fluid Detection*

1. INTRODUCTION

Liquid Petroleum(L.P Gas) Butane and Propane is a vital source of energy at present. Although it is been a useful energy source there are two main problems in relation to LPG [1]. It associates high accident possibility. Then as it is very expensive and rare, effective and efficient usage is essential.

In surveying in to the related designs which are available at present following conclusion could be made[1]. Smoke sensors and combustible gas sensors which are based on sensing the gas leaked out would not be very effective in terms of the reliability and the threshold concentration needed for operation and therefore is not extensively used.

So the main challenges were to Identify/detect the gas leakage and to take autonomous actions to control and indicate it. Finally it yielded successful minimization of gas related accidents and the energy wastage due to carelessness.

System comprises of many features to serve the objective. If it is a Leakage from the devices beyond the regulator, the gas cylinder is locked up and gas supply cut down automatically to ensure the safety and it is indicated to the user in the indication panel together with the notification alarm. Then if it is a leakage from the cylinder a quick loud awareness buzzer/alarm is rung to the consumer as the gas emission could not be controlled. Then a gas leak could also happen from the burner after the going away of the flame(non combusted gas) so to prevent such a condition The gas cylinder is locked up and gas supply cut down using a solenoid valve to ensure safety and it indicated to the user. Another very common accident possibility arises when the opening of the gas control valve and the ignition are not simultaneous as in some gas cookers. There may be a delay between the opening and igniting or sometimes it would not be ignited after opening due to carelessness or the valve may be opened without sense. In such instances no gas leakage would happen as the gas will not flow to the burner due to the solenoid valve controlled by the system which is normally closed. For initial ignition user has to press the ignition hold up button which operates the valve independently and that mechanism acts as a fool proof operating feature. The other very special feature in this system is the automatic real time detection of the runtime sensor failures and the corresponding notification to the user.

2. DESIGN METHEDELOGY

In coming to the design of the system infrared sensor focused at the flame monitors whether the flame is there or not, the pressure sensor and the gas flow sensor monitors whether there is a pressure reduction in the cylinder and whether there is a gas flow or not. These three are continuous voltage signals which are proportional to the intensity of the flame, internal pressure of the cylinder and the rate of gas flow.
Then these signals are fed in to the control unit and are digitalized and processed to get digital output signals which actuate the outputs. The locking of the gas flow is done by the solenoid valve which is fixed next to the regulator and the gas reaches the cooker through it. Alarm has separate tones and indicator panel has separate lamps to indicate the specific conditions.
The Sensors and the embedded controller are assembled as follows;

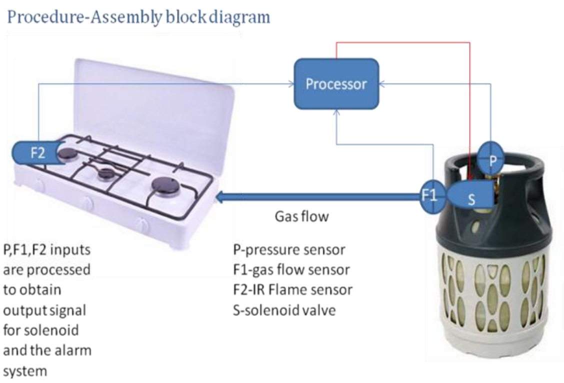

Figure 1: Assembly Diagram

The overall block diagram is illustrated in Figure 2.

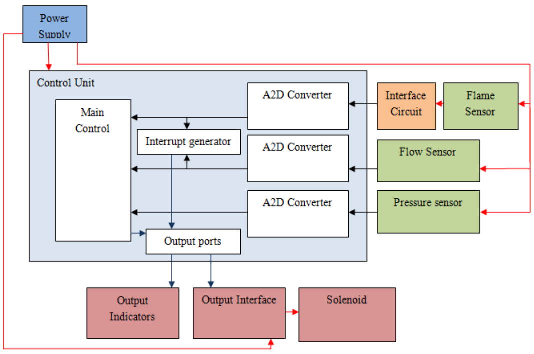

Figure 2:System block diagram

2.1 Sensors, Transducers and Mechanisms

2.11 Flame Sensor: Two successful mechanisms were implemented namely IR flame sensor and the plasma flame sensor. Even the combination of the two sensors could be implemented for best results. In IR flame sensor the intensified leakage current across the reversed biased PN junction of an IR LED due to the IR heat radiation was utilized. An operational amplifier in differential mode was used to filter the inputs from two such LED's one focused on to the flame and other to the surrounding. Then the final output from the amplifier would be proportional to the difference of the IR intensities on the IR LED's. Therefore the sensor did not respond to non of the free radiations in the surrounding. Then as an IR led is used to would be responding to the same frequency bandwidth that it emits and it was non-responsive to the other electromagnetic radiations in the environment. To increase the gain of the sensor lenses and reflectors could be used accordingly. Instead of this a plasma sensor could also be used which would be based on the conduction trough the free electrons in a flame.

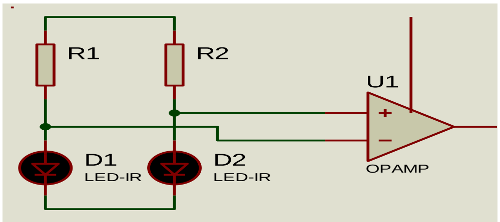

Figure 3: Sensor interface amp circuit

2.12 Gas Flow Sensor: A small silicon deformation pressure sensor was placed within the tube. As the gas flow increases the static pressure drop which is almost inversely proportional to the gas flow. So the pressure output could be mapped with the flow.

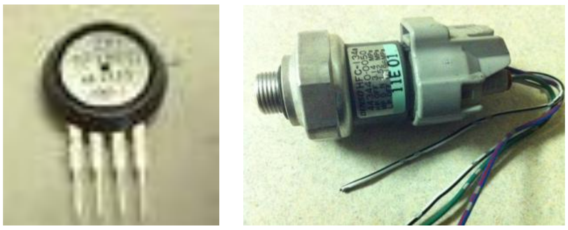

Figure 3: Silicon deformation sensor and metal strain pressure sensor

2.13 Pressure Sensor: A metal strain pressure sensor which is capable of handling a high pressure up to 27Psi was used sense the internal pressure of the cylinder. The continuous output voltage was proportional to the pressure exerted according to the manufacturer specification.

2.2 Outputs

2.21 Solenoid valve:As shown in figure 1 as well the gas reaches the cooker through this valve which could be opened or closed using an electric signal. This is used to control the gas flow based on the output from the control unit which is operated trough an additional switching transistor with protection diodes to ensure protection.

2.22 Indication and alarms: Separate LED's and buzzer tones with different beeps were used to indicate different conditions to the user.
The output ports are defined as follows from the control unit.
Once activated these output variables/ports are activated they would be retained until the consumer resets the system.

Table 1: Definition of outputs

output	On result
Controlled gas leak(S)	The solenoid valve close down, lock the cylinder and controls the gas leak and the specific alarm rings with the indication lamp
Uncontrollable gas leak from the cylinder(A)	A loud emergency alarm goes on with a splashing threat indication lamp . and solenoid is also closed down for better safety to stop the continuation of the flame at the burner which may lead to an accident by being an igniter for the leaked up gas.
IR flame sensor failure(Ff)	Specific indication with the alarm and the lamp
Pressure sensor failure(Pf)	Specific indication with the alarm and the lamp
Gas flow sensor failure (Gf)	Specific indication with the alarm and the lamp

2.3 Interfacing and Digitalization of sensor outputs as inputs to the controller

Analogue to digital converters in the micro controller were utilized to digitalize the sensor outputs. The reference voltage levels were set to nearest minimum and maximum readings from the sensors. To the maximum and minimum values the sensors were tested with 5 different cases. The maximum and minimum voltage ranges of the inputs were 1.57V -5.48V in flame sensor, 0.03V-2.09V in the flow sensor and 3.62V -12.63 in the pressure sensor. Therefore real-time register values were assigned to the sensor readings which ranges between 0-256 for the. Then a Boolean variable F was defined to represent the presence of the flame and it was set to 1 for register values greater than 25 and else 0 which acts as a tolerance margin. Then the pressure reading which corresponds to the flow, reduced with increasing flow. So the Boolean variable G which represents gas flow was set to one for the register values less than 230 and else zero which denotes whether there is a flow or not. Here also the 230 to 256 range acts as a tolerance to the sensor reading. Finally the internal pressure reading was differentiated with respect to time using a numerical method. As the clock of the microcontroller was used a 0.1 micro seconds was used as the delta t for the differentiation. So at minimum gas consumption the d(Pressure reading)/d(time) was experimented to be 2.14. Then the upper value varied to an undefined high value depending on the rate of pressure drop. So the Boolean variable P was defined to denote pressure reduction rate and it was set to 1 for values higher than 2.00 and zero otherwise. Therefore the final Boolean variables could be summarized as follows;

Table 2: Input Signals

Input device	condition	If	else
Pressure sensor(P)	Pressure reduction (dP/dt)>0	1	0
Gas flow sensor(G)	Gas flow	1	0
IR flame sensor(F)	Flame on	1	0

2.4 Control Logic

The truth table which governs the basic control logic of the system is given below which could be implemented using a dedicated logic circuit(CMOS logic) as the embedded system, but due to the convenience a microcontroller was used as it's Analogue to Digital converters would be used for sensor input digitalization anyway.
In following truth table P,G,F represents the inputs pressure, gas flow and flame respectively while S,Pf,Gf,Ff,A are output variables.
S corresponds to the solenoid valve which is an active high output, therefore solenoid valve would be open and facilitate gas flow when S reaches the high state. Then when it is zero the solenoid is closed down stopping the gas flow from the cylinder to the cooker.P_f,G_f,F_f are the sensor runtime failure indicators. In case a sensor fails while it operates it would be intelligently detected by the system and would be indicated to the user. Then A is the indication corresponding to a gas leakage.In sequence 1, all the inputs are zero that means pressure is constant, no gas flow and flame is absent which corresponds to a

	P	G	F	S	P_f	G_f	F_f	A
1.	0	0	0	0	0	0	0	0
2.	0	0	1	0	0	0	1	0
3.	0	1	0	0	0	1	0	0
4.	0	1	1	0	1	0	0	0
5.	1	0	0	0	0	0	0	1
6.	1	0	1	0	0	1	0	0
7.	1	1	0	0	0	0	0	1
8.	1	1	1	1	0	0	0	0

normal condition with no consumption. So all the outputs are made zero therefore the solenoid is closed as well. Therefore the system could not be ignited initially as no gas is supplied. For initial ignition user has to press the above mentioned ignition holdup button which would open the valve independently and light up the flame to get the system to the 8th sequence. This works as a good fool proof operation feature because the opening of the gas without sense/consumption is avoided.In sequence2, pressure is constant and the gas doesn't flow then it's not possible to have a flame which should probably be a failure of the flame sensor, Therefore that error is indicated and the solenoid is closed to ensure safety.In sequence3, pressure is constant and the flame is not there. So it's not possible to have a flow which should probably be a failure of the flow sensor, Therefore that error is indicated and the solenoid is closed to ensure safety.In sequence 4,It's not possible for the pressure to be constant if there is a gas flow and a flame. It's possibly a failure of the flame sensor. In Sequence 5, Pressure reduces with no flow or flame .which corresponds to a gas leakage from the cylinder which is uncontrollable and as it extremely dangerous to maintain the flame with the presence of a severe gas emission the flame is put off by cutting off the gas supply using the solenoid valve. Additionally the consumer is notified with the notification alarm. In sequence 6, It is again a failure of the gas flow sensor as it is not possible to have a flame and a pressure drop without a gas flow. There for indication and the solenoid cutoff is done.In sequence 7, It is a situation where the flame is not there with a gas flow and a pressure variation. It might be a condition where the flame has blown off with the non combusted gas leaking through the burner continuously or a non ignited situation after igniting. So to save the fuel wastage and in order to prevent the risk the solenoid is automatically locked to stop the leakage and indication is done. In sequence 8, It is a normal gas consumption with a pressure drop, a gas flow and a f lame .And the solenoid is kept on to facilitate the gas flow and all other indication should be deactivated.

2.41 Interrupt controls: Basically the above logic could be implemented to govern the control of the system but has draw back if a gas leakage originates when the system is operating with a normal gas consumption where the excess gas leakage , and the flow due consumption both represents the same logic state. To overcome the above drawback the following solution was implemented. The variation of the gas flow with the flame was plotted by considering the average of several instances and different cooker models. The x axis represents the digital count of the flame and the and the y axis represents the digital count of the flow.

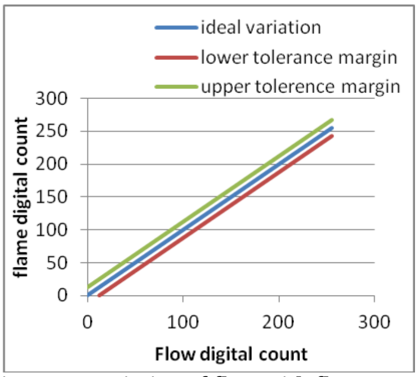

Figure 4: Variation of flow with flame count

A 5% tolerance range with the original function was defined as the operating region and any instance where the system operates in a higher region was discovered as a gas leakage simultaneous to the consumption and the microcontroller interrupts are activated to generate the same results as in sequence 5 and 7.That is s=0 and A=1. Same way if the system operates at a lower region than the defined operating region it could be identified as a failure in the sensors.

2.42 Delay elements for stability: As a measure to avoid the fluctuations and oscillations due dynamic conditions during state transition of the system the outputs would be actuated only if the state remains constant for a period of 700ms, which is an experimentally fine tuned value.

3.0 CONCLUSION

This is an embedded technology based control system which could guarantee the detection of a gas leakage, autonomous control of the leakage and indication which could be further extended as a system applicable to detect any fluid leakage irrespective of the chemical and physical properties of the fluid.

4.0 REFERENCES

[1]http://en.wikipedia.org/wiki/Gas_leak_detection

[2] W. Chung, and D. Lee, "*Real time muti-channel gas leak monitoring system using CPLD chip*," Sensors and Actuators B, Vol. 77, pp. 186- 189, 2001.

[3] Ho-Jung Ryu, Seung-Yong Lee, Young Cheol Park, and Moon-Hee Park, “Solid Circulation Rate and Gas Leakage Measurements inan Interconnected Bubbling Fluidized Beds”, World Academy of Science, Engineering and Technology, vol. 4, pp. 169-174, 2007