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Implementation of Gas Scathe Admonisher and Control System Prototype

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Abstract

With the advent of and rapidly increasing use of organic, chemical, hazardous, non-hazardous, natural and man-made gases into various industrial processes like food processing industries, oil and gas sector, domestic usage and etc., the detection of sophisticated gas leakage system has become a concern and need of the hour. Chernobyl and Bhopal gas tragedies are some of the horrible examples that lay the foundations for the significance of this project. This paper is based on working model of an automated, low-cost, simple design, computer-based embedded instrumentation system**,** which can detect leakage of Liquefied Petroleum Gas and Carbon Dioxide Gas in surrounding environment using fast and accurate gas sensing technologies and then provide control action over the surrounding using final control elements to maintain the gas concentration within levels that human body can bear. To accomplish this objective a Graphical User Interface has been developed on LabVIEW™ that is interfaced with the gas sensor modules through Arduino (controller and data acquisition device) to track the real-time gas concentration and energize actuator mechanism to lower down the concentration by turning ON exhaust fans and hence perform function of a **'**Control System'**.** The controlling action is effective and the results are promising. The energizing action is further used to generate alarms of gas leakage and hence this paper is aptly entitled as 'Gas Scathe Admonisher'. Data Acquisition System used in this process overcomes the human intervention and increases the overall efficiency and safety of the system. The Graphical User Interface with detailed information of prototype makes it useful for teaching purposes in laboratories for experimentation.

Index Terms: Automation, Virtual Instrumentation, Embedded system, Gas leakage, Graphical User Interface, Laboratory prototype, LabVIEW™.

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1. Introduction

This paper discusses the implementation of a prototype model meant to monitor air quality and to control gas concentration levels, thereby keeping the surroundings safe for humans. This system generates an alarm as a warning signal, whenever gas concentration exceeds normal limits, hence entitled **'Gas Scathe admonisher and control system'**. The paper organization begins with the introduction and interface of electronic components and novelty of approach used in the prototype model, followed by method of implementation, LabVIEW algorithmic flowchart and front panel description. Finally, the results section brings into light the promising outcomes of this model.

Various Gas leakage detection systems have been designed worldwide so far. An economic gas leakage detector was designed and implemented [1]. This prototype alerts the user by issuing audio-visual warning signal by detecting low and high gas leakage levels. Also, Global System for Mobile (GSM) application based gas leakage detection system was designed to monitor gas concentration [2]. This detection kit, when placed at vulnerable places, automatically detects and alerts the user by Short Message Services (SMS) in no time. These prototypes were able to warn the user but were unable to control the increased concentration and reduce it back to permissible levels.

This project work was undertaken to devise a proactive safety mechanism for important gases such as Liquefied Petroleum Gas (LPG) and Carbon Dioxide Gas (CO2) that invariably affect human lives. Undoubtedly, exposure to high concentration of these gases causes adverse health effects; the predominant ones being complaints of stiffness and odour, drowsiness or even asphyxiation under higher concentrations. Table 1 lists the effects of increased concentration of LPG and CO_2 on human health.

Over the years, LPG has become a de-facto standard for cooking gas and is an important resource for every kitchen [3]. Nevertheless, being inflammable in nature, leakage of LPG at times can cause fatal accidents or health problems. This raises the concern to initiate an effective and practical solution to detect and control LPG leakage. CO2 is another important gas that is the main cause of indoor and outdoor air pollution. Anthropogenic emissions of CO_2 gas have increased significantly due to the cutting of trees, smoking in the public areas, pollution from transportation system, burning of trees for energy or exhaust from industry, which adversely affects the human health [4] [5] [6]. Continuous increase in the concentration of CO_2 gas in the atmosphere is a significant contributor to the global warming [7].

Apart from this, the appropriate concentration of CO_2 is suited for proper photosynthesis process in plants to grow and produce yield, especially in controlled environment farms where plants are grown in greenhouses. Modern agriculture looks forward to monitor and control CO_2 using a CO_2 injector [8]. The necessity to monitor and control CO_2 in diverse commercial or industrial applications described above is the driving force to choose CO_2 gas for surveillance in small-scale industries and in public areas.

Table 1. Effect of Increased CO2 and LPG Concentration Level on Human Health [9] [10]

Gas	Concentration	Impacts
CO_2	350-450 ppm	Normal outdoor level
CO_2	< 600 ppm	Acceptable levels
CO_2	600-1000 ppm	Complaints of stiffness and odour
CO_2	1000-2500 ppm	General drowsiness
CO_2	2500-5000 ppm	Adverse health effects expected
CO_2	5000 ppm	Maximum allowed concentration within an 8-hour working period
LPG	350-500 ppm	Normal outdoor level
LPG	< 1000 ppm	Acceptable levels
LPG	>1000 ppm	Asphyxia

The work addresses in particularly the design and implementation of working model on embedded platform along with computer interface and virtual instrument to monitor and to control the concentration of LPG and CO_2 gases with the designed gas leakage detection system using LabVIEW for data acquisition and communication [11].

The novelty of approach lies in the integration of smart digital gas sensors on embedded platform with the PC-based control system. Control action works by actuating the final control elements (powerful exhaust fans or solenoid valve fitted within the pipeline) using Proportional Integral Derivative (PID) control scheme. Final control element is actuated in response to variation in gas concentration from permissible levels, to ventilate the excess gas leakage within the working space (kitchen or room) or in an industrial environment. LabVIEW™ based virtual instrument executes reliable dual-gas (LPG and CO_2) to monitor and control the action with timely audio-visual alarm annunciation. The other features include critical data logging, Liquid Crystal Display (LCD) for local indication, LabVIEW™ Graphical User Interface (GUI) with built-in functionality for simulation, data acquisition, instrument control, measurement analysis, and data presentation.

The end goal is to design and develop a portable, easy to use, multi-functional, fast and reliable gas sensing and control system. This system is devoid of complex traditional development environments, with self-explanatory and interactive graphical interface for public areas, laboratories, industries, and homes, wherever gas leakage is an active problem. It can also be used as an experimental setup in laboratories for teaching LabVIEW™ based Control and data acquisition.

2. Gas Scathe Admonisher And Control System

Designed prototype of dual-gas control system as shown in Fig. 1 is a the closed loop feedback system, where gas concentration data as measured by the smart sensors is interfaced to the suitable controller, for generating control signals, to actuate the final control elements, in order to maintain the healthy concentration of gases in ambience. The data acquisition and communication is performed by embedded microcontroller that interfaces smart gas sensors and actuators to drive exhaust fan and activate audio and visual alarm.

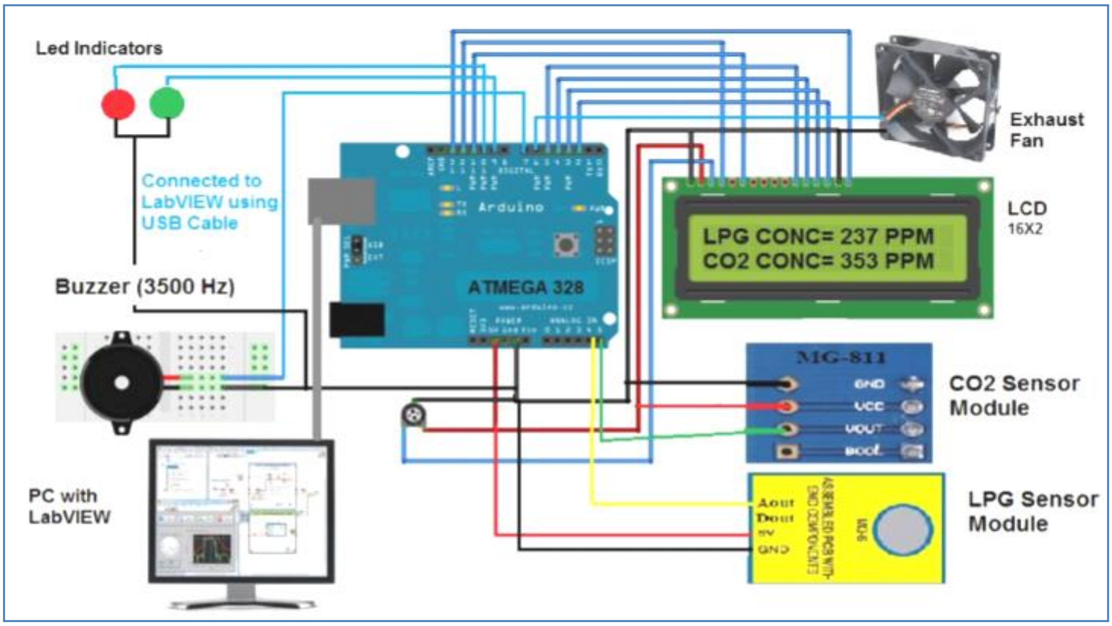


Fig.1. Complete System Schematic

Fig.2. Gas Scathe Admonisher and Control System Prototype

The application GUI developed in LabVIEW™ is tested in the real time with the real time hardware and software simulation in LabVIEW™. The indicators, LCD, and graphs show the real-time results of the gas concentration in ambience.

The Arduino ATMEGA 328 is loaded with the logic, created in LabVIEW™ "Block Diagram Window". Arduino evaluates the GAS concentration using algorithms. Any deviation from ideal data will result in control action by Arduino. Arduino generates the visual, audio alarms for indication and actuate the actuator for process normalization. Arduino is interfaced with LabVIEW™ loaded PC using Arduino Interface toolkit software. The Process is displayed on PC by creating "Graphical User Interface" in LabVIEW™. The system prototype is shown in Fig. 2.

The raw gas sensor data as acquired by the processor is serially communicated to host PC over Universal Serial Bus (USB) port. The Virtual Instrument (VI) program running on the host PC processes the sensor signals to get reliable concentration values at the predefined sampling time interval. It executes the PID control and leakage detection algorithm and communicates the control signals to the microcontroller to drive the actuators.

The well designed and intuitive graphical user interface of VI displays time variation of concentration of the gases and many vital parameters. Also, sensor data on the microcontroller is preprocessed to display the level of concentration in Parts per Million (ppm) of LPG and CO_2 on LCD.

The following sections discuss the important components of the system such as gas sensors used herein and their technological aspects, data acquisition and communication module (microcontroller), sensor and actuator interfacing, functionality and development of the virtual instrument.

2.1. Gas Sensing Technologies

The gas sensor is a subclass of chemical sensors. Gas sensor interacts with a gas and measures the concentration of gas in its vicinity [12]. Each gas has a unique breakdown voltage i.e. the electric field at which it is ionized. The sensor identifies gases by measuring these voltages. Gas concentration can also be determined by measuring the current discharge in device [13]. Gas sensors are based on various gas sensing technologies such as metal oxide sensors, Semiconductor gas sensor, NDIR based sensors, Electrochemical gas sensors. The Use of gas sensing technology is based on availability, economic conditions, and applications [14]. This project utilizes the semiconductor technology to measure the concentration of LPG and CO_2 gas because semiconductors based sensors and integrated on board signal conditioning provides compatible output to be interfaced with the Data Acquisition system. It is also economical, reliable and small in size.

2.2. LPG Sensor Module

LPG sensor module as shown in Fig. 3 is MQ-6 semiconductor based smart sensor. It uses Tin Oxide (SnO_2) semiconductor layer which adsorbs LPG and detects LPG by a chemical reaction that takes place when the gas comes in contact with the sensor [15]. SnO_2 is the most common material used in semiconductor sensor. The electrical resistance of the sensor decreases when it is exposed to the gas [16]. The resistance of the SnO_2 is typically around 50kΩ in air but drop to around 3.5kΩ, which is used to calculate the gas concentration. In-built signal conditioning circuit of smart sensor gives 0-5 V output. The characteristics of MQ-6 sensor are shown in Table 2.

Fig.3. LPG MQ-6 Sensor Module

Table 2. Characteristics of MQ-6 Sensor [14].

Model No	**MQ-6**
Sensor type	Semiconductor
Detection gas	Iso-butane, LPG, Butane
Concentration	30-10000 PPM

From the data sheets of the sensors [15], equation (1) is derived to calculate the concentration of gas with respect to the change in the resistance as given below. This equation is used for the formula implementation in LabVIEW^{TM}.

$$\text{Log}(C) = \frac{\text{Log}(R_S)-\text{Log}(R_O)-1.194}{\text{Log}(0.4)} \quad (1)$$

Where,

R_s: - sensor resistance at LPG gas concentrations C;
R_o: sensor resistance at 1000ppm of LPG in the clean air.

2.3. CO2 Gas Sensor Module

The MG-811 sensor as shown in Fig. 4 is highly sensitive to CO_2 and less sensitive to alcohol and CO. The smart gas sensor module has MG-811 highly sensitive CO2 gas sensor with on board signal conditioning circuit and sensor component. The output voltage of module falls in between the range of 100 – 600mv as the concentration of CO_2 increases, which corresponds to 400-10000ppm concentration of CO_2. There is onboard signal conditioning circuit to amplify output signal. The CO_2 gas smart sensor output is 0-5 V analog output. Sensor is widely used in air quality control, ferment process and indoor air monitoring application [16].

From the data sheet of the sensor [17], equation (2) is derived to calculate the concentration of gas with respect to the change in the voltage.

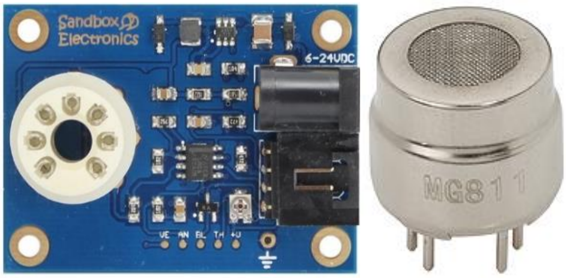


Fig.4. CO2 Sensor Module with MG-811 Sensor

$$V_s = V_o + \Delta V_s \frac{\mathrm{Log}(CO_2) - \mathrm{Log}[400]}{\mathrm{Log}(400) - \mathrm{Log}[1000]} \tag{2}$$

Where, Vs is the output voltage corresponds to the Log (CO_2) concentration of gas ΔVs = sensor output at 400 ppm – sensor output at 1000ppm and V_O = Zero point voltage.

2.4. Data acquisition and communication module

The LPG & CO_2 sensors are installed in the prototype model in their respective chambers. The analog outputs of both sensors are connected to the analog input pins of Arduino as given in Fig. 5. Arduino is a microcontroller board based on the ATMEGA328, which is used as a data acquisition and Control and communication device. It is an embedded device that interfaces to the sensors and actuators and also communicates data serially to the host PC, running virtual instrument programmer. Device has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, and a reset button. It is powered simply by connecting to the computer with a USB cable. The device operates at 1.8-5.5 volts.

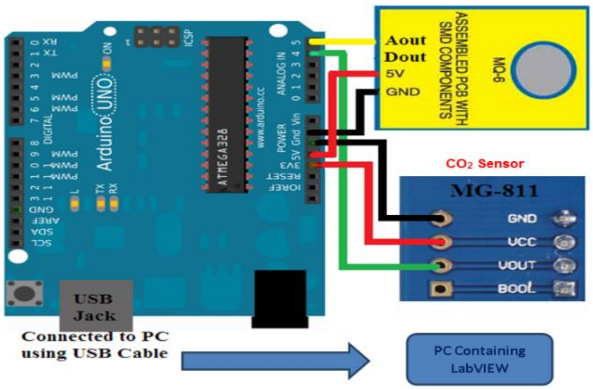


Fig.5. Dual Sensor interfacing with Arduino

The LPG and CO2 sensor output received from the sensors at analog input pins is converted into 10-bit digital data using inbuilt Analog to Digital Convertor (ADC) of 10-bit resolution. The ADC data (0-1024) corresponding to the sensor signal is sent to PC running virtual instrument through USB port of PC using

FTDI232 as serial to USB converter.

2.5. Actuator interfacing with Arduino

In order to regulate the concentration of gases within the safe limit, the final control elements used in the project prototype are Brushless DC motor exhaust fans of 1.8W (12V, 0.15A). The important feature of these exhaust fans is their unidirectional rotation. Speed of the exhaust fan depends on the controller output, programmed to work on the variable speed. The exhaust fans are interfaced to the driver IC (L293D) as shown in Fig. 6 to actuate the control signals to the exhaust fans from PC. It is used either at the inlet or at the outlet.

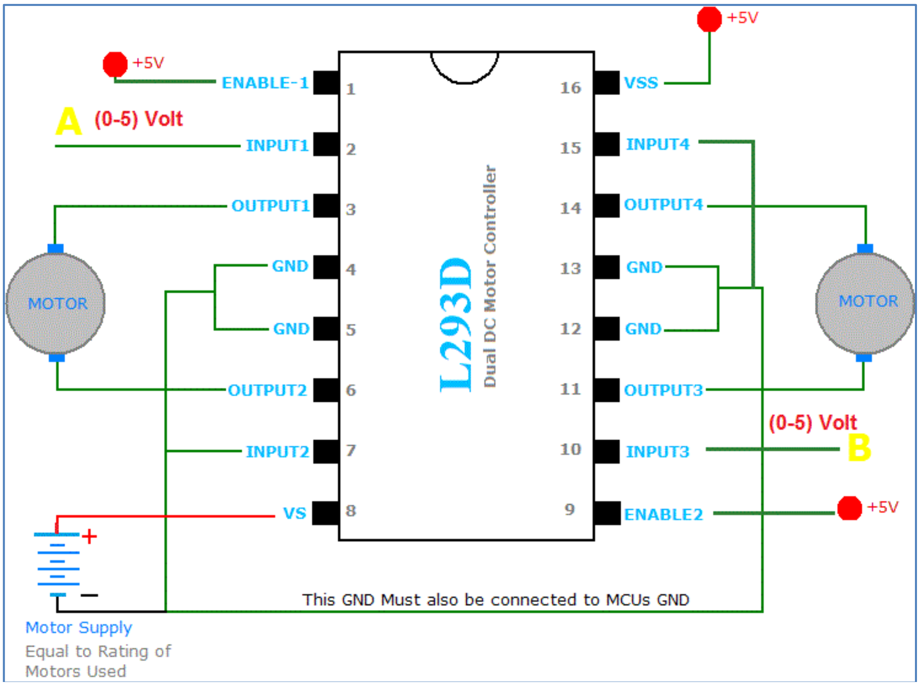


Fig.6. Actuator Interfacing with L293D

L293D is used to drive two motors simultaneously each to regulate CO2 and LPG concentration in the closed chamber in the prototype model. It is a quadruple high-current half-H driver. It maps control signal the 0-5V control signal output from Arduino output to variable speed of motor in the range 0-1200RPM of exhaust fan speed.

2.6. Virtual Instrumentation

The software for system prototype has been developed as virtual instrument (VI) on the platform of LabVIEW^{TM}. The virtual instrument allow the user to start the operation, feed the required set limit for concentration of CO_2 and LPG and online visualize the monitoring and controlling of LPG and CO_2 gas concentration with annunciation of alarm indicator. The project has been developed on LabVIEW^{TM} 2011. Fig.7 and Fig.8 shows the GUI and flow chart indicating functionality of the VI for gas scathe admonishor and control system. The actual data processing and data presentation work are carried out using advanced and sophisticated LabVIEW^{TM} toolkits [18].

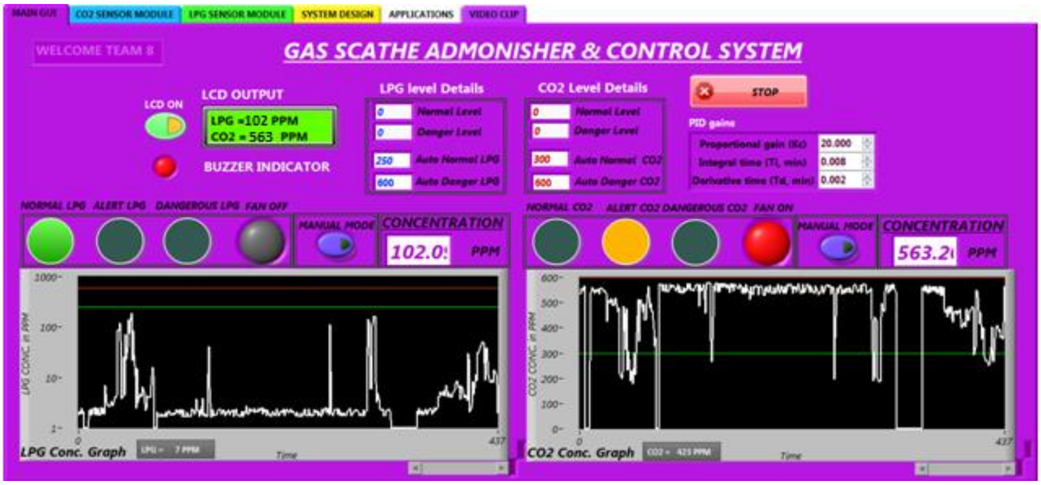


Fig.7. Project GUI in LabVIEW

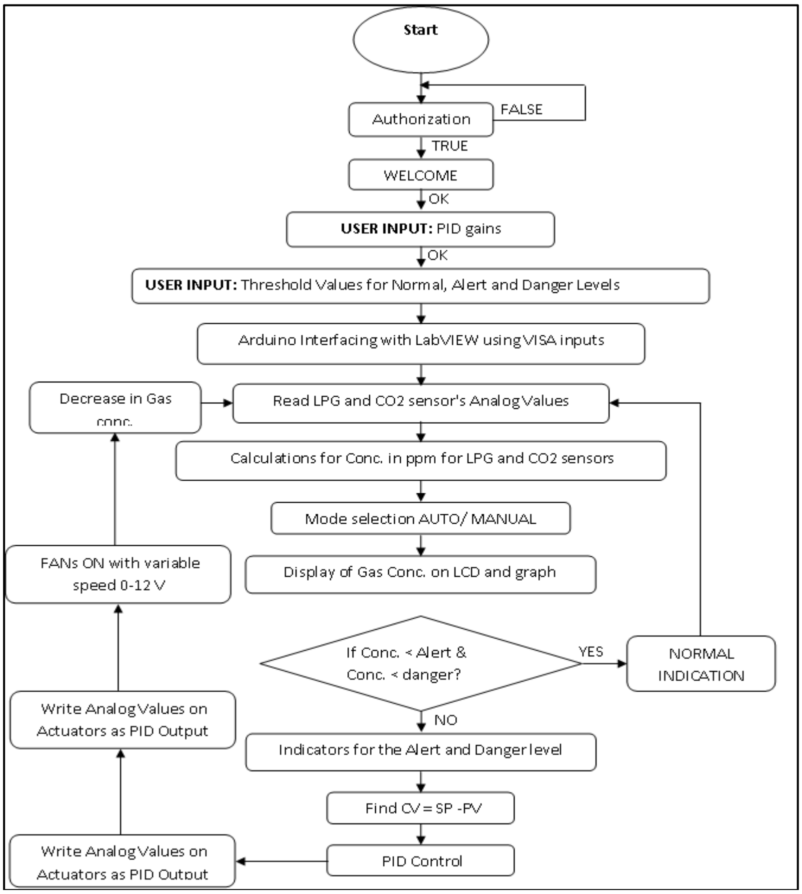


Fig.8. System Algorithmic Flowchart

The VI continuously acquires the raw sensor data and converts the digital information into concentration levels of CO2 and LPG in ppm. The concentration levels of individual gases are compared with the predefined threshold limits for normal alert and danger conditions to activate the respective alarm and issue a buzzer signal. The concentration of gases is also graphically displayed on the VI. Apart from annunciating alarm signals, VI implements ON and OFF control algorithm that activates the exhaust fans to ventilate the excess concentration of gases from the chamber. The raw sensor data signal as acquired by the virtual instrument program from the micro controller board is converted into respective gas concentration in ppm. LabVIEW™ acquires the processed digital data of sensors from Arduino and converts it into the gas concentrations in PPM for display. This conversion is carried out using the calibration equation of the individual sensors derived in equation (1) and (2). These equations are modeled in LabVIEW™ environment by using mathematical block diagram presentation of LabVIEW™. The concentration in ppm is logged on real-time trends on GUI and also this concentration is compared with the threshold normal, alert and danger level Set Points pre-defined by the user. Based on this comparison, a control signal is transmitted to the actuator.

To smoothen out the control action further, PID control scheme is being employed in this system. PID controller output of 0-100% is converted into 0-5 V analog output. This 0-5V analog output is in the form of Pulse Width Modulation (PWM) signal to derive the exhaust fan with variable speed in the range of 0-1200RPM.

The PID parameters are tuned to make the actuator action smooth and quick so that the concentration of the gases follow the check point and also minimize wear and tear loss of the actuator. This increases the efficiency of the control algorithm in regulating the concentration of the gases within the close vicinity. Process Value can follow Set Point perfectly and avoid wear and tear loss in the actuator. Thus, it increases the efficiency of this prototype.

3. Results

Performance of the prototype is evaluated under different conditions of gas concentration, by analyzing the real-time results obtained on GUI. Tests are conducted in the closed chambers of the prototype model filled with LPG and CO_2 gases above the permissible range or in locations (kitchens, automobile exhaust outlet) where LPG and CO_2 are released artificially/naturally.

Dual-gas sensors interfaced to embedded microcontroller continuously acquire the sensor signals at a fast rate, less than 10 sec and communicate the data to the host PC. The front panel of the dedicated virtual instrument as shown in Fig. 3(a) is started, configured and operated on the host PC for online monitoring and control of gas concentration and display of data on GUI.

This virtual instrument allows the user to operate the system under manual or auto mode and set the limits (normal and danger) for different test conditions i.e. normal, alert and dangerous levels of LPG and CO_2 gas concentration. Under auto mode, the limits were predefined. Operating status of different visual and audio alarms varies at each time instant of data acquisition, based upon the level of concentration of gases detected.

Also, PID control action varies according to the variation in the concentration of the gases that changes the operating state of the actuator and the speed of exhaust fan accordingly. (Table 3) summarizes the test conditions for the two gases and operational status of audio-visual alarms and actuator. Continuous time variations in the concentration of gases are depicted on the respective graphs and dynamically logged in files. The following sections discuss the results of some of the preliminary tests/ experiments conducted using the developed prototype system under different situations of gas concentration.

Table 3. Results of Prototype

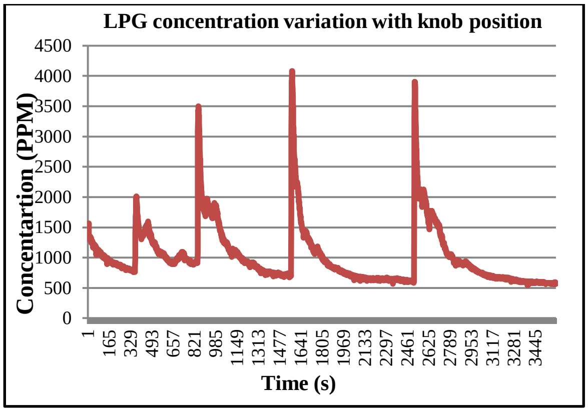
Test Conditions	Normal (PPM)	Alert (PPM)	Dangerous (PPM)
MANUAL Mode			
CO_2 Conc.	User Def.	User Def.	User Def.
LPG Conc.	User Def.	User Def.	User Def.
AUTO Mode			
CO_2 Conc.	< 300	300-600	> 600
LPG Conc.	< 250	250-600	> 600
Indication : Audio-visual Alarms and Actuator status			
GREEN	ON	OFF	OFF
YELLOW	OFF	ON	OFF
RED	OFF	OFF	ON
FAN	OFF	ON with speed(min)	ON with speed (max)
BUZZER	OFF	ON with frequency (400Hz)	ON with frequency (800Hz)

3.1. Variation in concentration (leakage detection) of LPG in kitchen

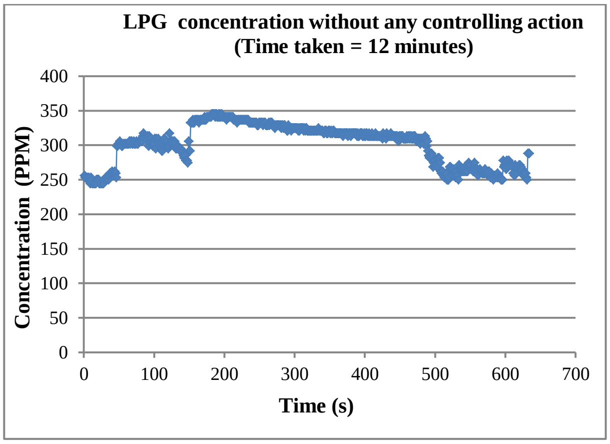
Leakage of LPG gas in a kitchen is a common problem and takes place when the gas knob is open but stove flame is switched OFF or the gas pipe or gas cylinder itself is leaking. An experiment is conducted to monitor LPG gas leakage in the kitchen. Pre-calibrated LPG sensor placed near to kitchen stove is connected to a microcontroller which was interfaced to the PC running with virtual instrument program. A controlled quantity of LPG was leaked in different concentration levels for a short period of time by changing the gas stove knob position. The instantaneous variation in LPG concentration as processed by embedded microcontroller was indicated on LCD panel and graphically shown on GUI in virtual instrument displayed on the PC screen.

Fig. 9(a) shows the time variation of concentration levels of LPG gas under a different operational state of the gas-stove knob. The graph depicts the peaks showing an abrupt increase and a decrease in concentration of LPG when knob at the particular position was opened and closed after a few second. As knob position was moved from lower to a higher level, a higher concentration of LPG gas was leaked into the environment thereby increasing the peak levels. Once the knob was switched OFF, the concentration of LPG within the kitchen area near to gas-stove started decreasing due to the natural process of convection and ventilation.

Higher is the gas concentration, more is the time required for gas concentration to decrease to acceptable levels. The results indicate that even in few seconds of LPG leakage, the concentration levels increased higher than acceptable levels. When LPG gas concentration level exceeded the pre-set limits, respective LED (alert or dangerous) alarms were activated on the panel.



(a)



(b)

Fig.9. (a) Variation in LPG Concentration with Time for Different Gas Stove Knob Positions under ON/OFF control scheme; (b) Variation in LPG Concentration within the Closed Chamber without Any Control Scheme.

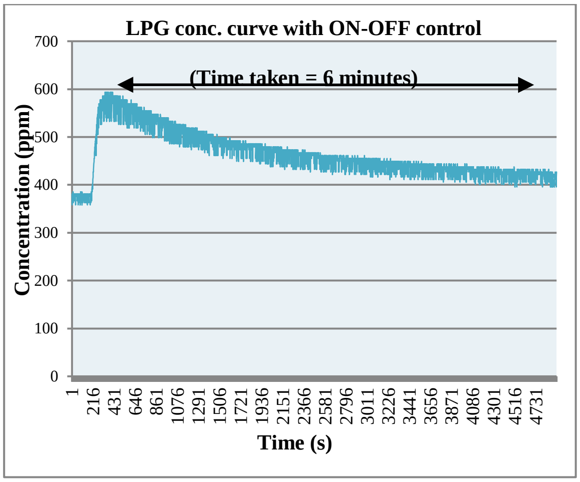
3.2. Monitoring LPG Concentration within the closed chamber under different control conditions

This experiment was performed by conducting three tests. In each test, initially, the closed chamber of the prototype model was subjected to LPG gas for some time. In the first test, no control algorithm was used. The virtual instrument only monitored the time variation of LPG concentration. Fig. 9(b) shows the rise and slow fall of LPG concentration with time in the closed chamber. Without any control scheme, the concentration of LPG in environment took more than 8 minutes to drop by 100ppm (fall from the level of 350ppm to 450ppm). The concentration of LPG gradually diminished with time due to the natural process of ventilation.

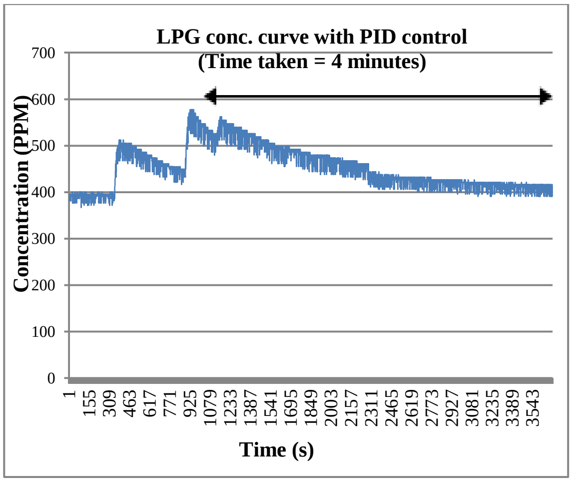
In the second test, the virtual instrument was configured to use ON/OFF controller. In response to variation of LPG concentration, the controller operated exhaust fan at fixed speeds to provide forced ventilation. Fig. 10(a) shows time variation of LPG concentration within the closed chamber with ON/OFF controller. This reduces the concentration of LPG within the closed chamber at a fast rate. The concentration falls by 200ppm (from 600 to 400ppm) in 6 minutes. Simultaneously, alarm was also activated.

In the third test, the virtual instrument was configured to use PID controller. Initially, PID controller was tuned and required parameters were fed. Based upon the level and rate of change of concentration of LPG, the controller operated the motor actuator with variable voltage to drive exhaust fan with variable speed to ventilate excess of LPG from closed chamber. Fig. 10(b) shows time variation of LPG concentration in the closed chamber with PID controller.

This reduces the concentration of LPG in the closed chamber at the much fast rate. The concentration falls by 200ppm (from 600 to 400ppm) in 4 minutes as compared to ON/OFF controller. The control objective of efficient control of gas concentration was henceforth achieved using PID control as it decreased the concentration of the LPG most effectively and in less time, thus saving energy cost of operating exhaust fan.



(a)



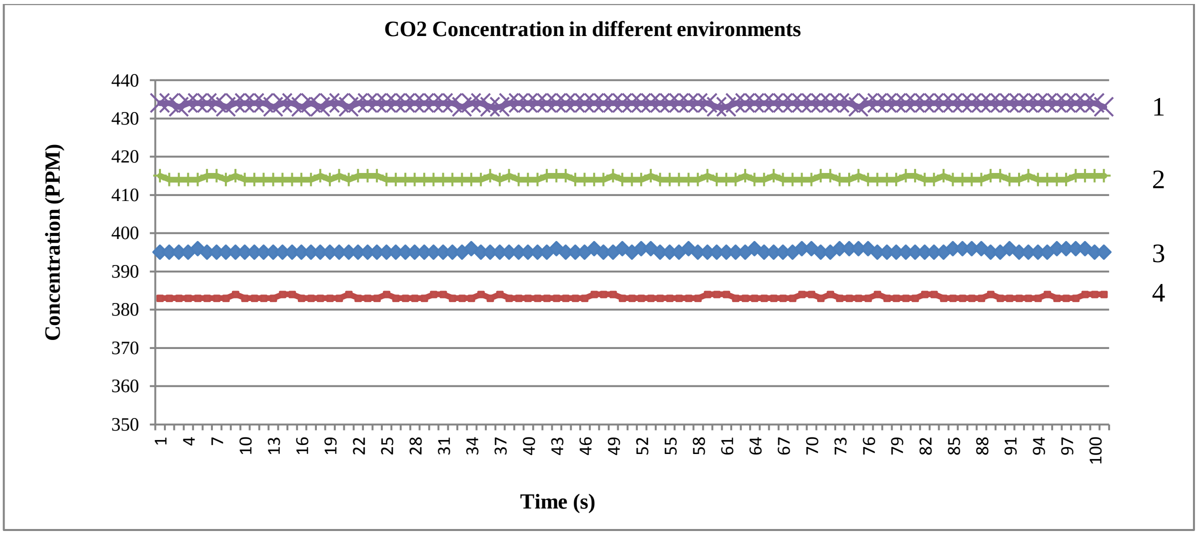
(b)

Fig.10. (a) Variation in LPG Concentration within the Closed Chamber with ON-OFF Controller (b) Variation in LPG Concentration within the Closed Chamber with PID Controller

3.3. Monitoring CO2 Concentration within the closed chamber under different environments

This experiment was conducted by placing the pre-calibrated CO_2 sensor in different environments where CO_2 gas was present in the atmosphere naturally or artificially emitted by different sources. The sensor was connected to the microcontroller which was interfaced to PC, running virtual instrument. Fig. 11 shows the variation in concentration of CO_2 gas in different environmental conditions.

The normal level of CO_2 gas concentration in the atmosphere was around 382ppm in the daytime and the level was high (415ppm) during the night when plant exhaled more of CO_2. In an isolated room, the concentration of CO_2 was slightly more (394ppm) than outside. But, the natural level of CO2 in the atmosphere increased to a high value (435ppm) near to vehicle exhaust. Vehicle exhaust tries to increase the level of CO_2 in the atmosphere causing air pollution. The increase of CO_2 levels above the permissible ranges due to any process make the ambience unhealthy and harmful for the humans and need to be controlled and detected for alarm conditions.



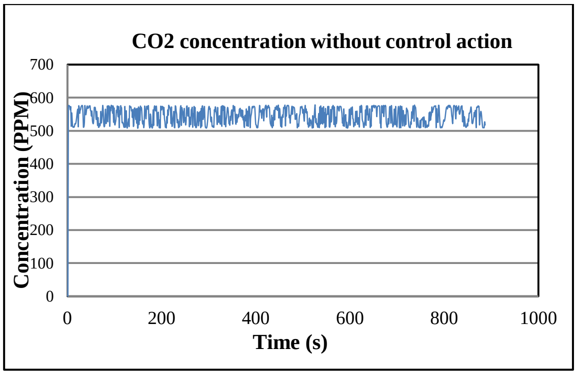
1- Vehicle exhaust 2- Under Tree (Night)

3- Isolated Room 4- Open Environment

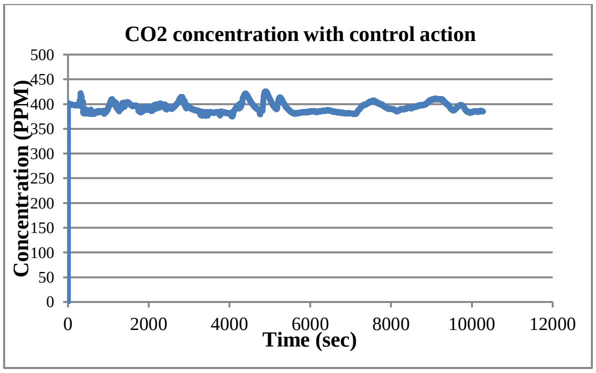
Fig.11. Variation in CO2 Concentration in Different Environmental Conditions.

3.4. Monitoring CO2 Concentration within the closed chamber under different control conditions

To test the prototype response to CO_2 gas concentration levels, the tests were first conducted without any control algorithm and then with PID control in a virtual instrument. When no control algorithm was used, the virtual instrument only monitored the time variation of CO_2 concentration. Fig. 12(a) shows the rise in CO_2 concentration with time in the closed chamber. Without any control scheme, the concentration of CO_2 in environment took just 60 sec to increase by 100ppm (500 ppm to 600 ppm). The concentration of CO_2 gradually diminished with time due to natural process of ventilation.



(a)



(b)

Fig.12. (a) CO2 Concentration Variation without Any Control by the Designed Prototype (b) CO2 Concentration Variation with Control by the Designed Prototype.

The experiment was conducted using PID control to check the response time of prototype for CO_2 gas concentration levels. Fig. 12(b) shows the decrease in concentration of the CO_2 gas from 600 ppm (non-permissible to human health) to 375 ppm (normal outdoor level) in around 200 sec. This time, period is less than the time when no damage occurs to human health in exposure to CO_2 concentration. Thus, the control objective is achieved using PID control as it decreases the concentration of the CO_2 gas in the ambience.

4. Conclusion

The integrated system consisting of the gas sensor modules, embedded control, PC based VI for monitoring and control has been successfully implemented and tested under different concentration of gases and environments. The performance of system was satisfactory with the display of reliable information about the instantaneous variation in the concentration of the gases with fast update rates. The data was indicated on the embedded LCD panel and also on the VI for continuously monitoring. The use of PID over ON-OFF control algorithm demonstrated the fast control of CO2 and LPG gas concentration with-in the closed chamber. The developed system is an automated, economical, multifunctional and reliable prototype that supports both embedded as well as online monitoring and control of dual LPG and CO2 gas concentration for different applications.

The indications are given by Light Emitting Diodes (LED) and buzzer as per as the normal, alert or dangerous concentrations of the two gases involved and the exhaust fan serves to control the gas concentrations by letting the gases out whose accumulation can lead to harmful and life threatening consequences. Using PID control the concentration of the LPG in the environment reduces in very less time and also offset is removed.

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