Monoxide Sensor Device Prototype Development and Implementation in a Mechanic Shop Building

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Abstract *— Carbon Monoxide is a dangerous component that primarily comes from incomplete combustion of carbon containing fuels. Is a gas with no odor, color or taste , have approximately the same density as air. Is often called "the silent killer". At lower levels of exposure can have the same effects of a flu. This project will investigate the development of a carbon monoxide sensor monitor prototype, to be applied over a proposal for a diesel fumes vacuum extraction system. Carbon Monoxide is one of the components in diesel exhaust emissions. The application area is a mechanic shop building with multiple working bays.*

Key Terms — Carbon Monoxide (CO), Environmental Protection Agency(EPA), Particles per Million (PPM), Permissible Exposure Limits (PEL).

INTRODUCTION

Safe and healthful working condition for our fellow maintenance soldiers aligned with the Occupational Safety and Hazard Agency's vision and its requirements is also the United States Armed Forces safety requirement standard that will be proposed with this project. So permissible exposure limits according to OSHA's requirements will be the set points over the monitoring system prototype.

The quantitative investigation and data gathering of a carbon monoxide exposure to then apply it to a fumes extraction logic system, is consulting service that will be developed locally with the help of co-workers and supervisors, avoiding the high cost of an external consulting firm.

RESEARCH OBJECTIVES

The main goal of the project is to obtain a sensor module able to monitor carbon monoxide exposure levels (to OSHA's PEL), to obtain a quantitative measurement of this dangerous component and how much time the worker is exposed to those fumes. If the worker is exposed to carbon monoxide then is also exposed to other dangerous components that are part of the diesel exhaust mix. The bottom line goal is minimize fumes exposure to workers and at the same time creating a system which can be maintained locally, consume the less energy possible with the better cost efficient investment.

RESEARCH CONTRIBUTIONS

Employers have a general duty under section 2 of the Health and Safety at Work Act 1974 to ensure, so far as is reasonably practicable, the health, safety and welfare of their employees at work. Better quality of working live, will give the company a lot of productive years from each worker without paying the cost of absences and loosing experienced workers because of health factors.

This project will give an option to provide the less possible exposure to harmful chemical components that, in the short or long term, affect the health of each worker. Other contributions like the cost implied in the research of appropriate equipment for a fume extraction system and a local implementation of the prototype monitoring system, are also cost reductions implied on the project development.

BACKGROUND

The following topics, describe few theory about, the installation description, diesel exhaust composition, which OSHA's rules are directly involved and also brief information on EPA's rules.

Installation Description

These kinds of facilities in the ARMY are known as MATES- Maneuver Area Training Equipment Site. The primary mission of the facility is to receive, store and maintain equipment, so all units will have a main central facility to maintain and repair their vehicles floats and other military equipment. Twenty four bays are aligned receiving different types of military heavy truck vehicles for maintenance and repairs. Each vehicle is parked to perform different tasks and some of them require being on at the time of being parked and some times during other maintenance or troubleshooting check operations.

The working area is divided by three groups called teams. Team 1, 2 and 3 are the working groups. Team1 works in one sections of the building while Team 2 and 3 works in the other opposite bay area. Each team specializes on certain family of vehicles and equipment. The final experiment will take this groups as a consideration.

Generated Fumes

All of the vehicles over these facilities are diesel engines, which generates fine particulate matter (diameters less than 2.5 µm) and large number of ultrafine particles (diameters less than 0.1 µm). This small size makes them easily respirable and able to reach deep inside the lungs (Figure 1) [1]. NIOSH-National Institute for Occupational Safety and Health, has classified diesel exhaust as a potential occupational carcinogen since 1988. The emissions from diesel engines consist of both gaseous and particulate fractions.

The gaseous constituents include carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide, oxides of sulfur, and hydrocarbons (e.g., ethylene, formaldehyde, methane, benzene, phenol, 1,3-butadiene, acrolein, and polynuclear aromatic hydrocarbons).

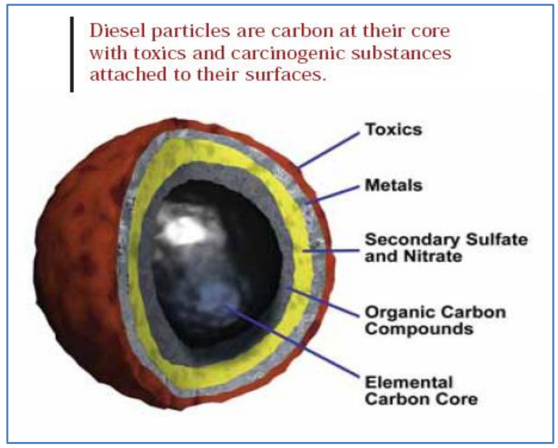

Figure 1
Particle Composition generated by Diesel Exhaust

Permissible exposure limits (PELs) established by the Occupational Safety and Health Administration (OSHA). Below (Table 1) [2] is a list of few the chemicals associated to the diesel exhaust and their health factors.

Table 1
Major components for Diesel Exhaust, their OSHA's PEL's (8 hours) and their Health Factors

Chemical compound	*OSHA GENERAL INDUSTRY* PEL'S		HEALTH FACTORS
	PPM	mg/m^3	
Carbon Dioxide CO_2	5000	9000	SYMPTOM(s): Headaches, dizziness, restlessness, paresthesia; dyspnea; sweating; malaise; increased heart rate, elevated blood pressure, pulse pressure; coma; asphyxia; convulsions; frostbite (dry ice) HEALTH EFFECTS: Simple Asphyxiant (HE17) ORGAN: Lungs, skin, CVS

Carbon Monoxide *CO*	50	55	Potential Symptoms: Headaches; tachypnea; nausea; weakness,dizziness, confusion, hallucinations; cyanosis; depressed , ST segment of electrocardiogram; angina; syncope. Health Effects: Asphyxiation, Chemical anoxia. Affected Organs: CVS, lungs, blood, CNS
Nitrogen dioxide NO_2	5	9	Potential symptoms: Irritation of eyes, nose, throat; cough, mucoid frothy sputum, decreased pulmonary function, chronic bronchitis, dyspnea (breathing difficulty); chest pain; pulmonary edema, cyanosis, tachypnea, tachycardia; eye, skin burns; dermatitis, frostbite (upon contact with liquid); INGES ACUTE: Burns in mouth, throat and stomach. EXPOS CHRONIC: Headache, weakness, loss of appetite, nausea, sores in nose and mouth, erosion of teeth; emphysema. Health Effects: Irritation-Eye, Nose, Throat, Skin---Marked (HE14) Lung edema or bronchiolitis obliterans (HE11); Dental erosion (HE3) Affected organs: Eyes, respiratory system,
			cardiovascular system

OSHA Regulations

Below is a summary list of the sections that apply to air contaminants [3].

General Industry (29 CFR 1910)

- 1910 Subpart N, Materials handling and storage.
- 1910.178, Powered industrial trucks.
- Appendix A, Powered industrial trucks.
- 1910 Subpart Z, Toxic and hazardous substances.
- 1910.1000, Air contaminants.
- Table Z-1, Limits for air contaminants.
- Table Z-2.
- 1910.1200, Hazard communication.
- Shipyard Employment.
- 1915 Subpart Z, Toxic and hazardous substances.

EPA Regulations

The Clean Air Act (CAA) requires EPA to identify a list of at least 30 air toxics that pose the greatest potential health threat in urban areas, and for the Strategy, the agency identified a list of 33 air toxics [4].

The agency established an environmental limit of 10 mg/m3 (9 ppm) of carbon monoxide in air averaged over 8 hours and not to be exceeded more than once per year.

In conclusion EPA requirements are even more rigid than OSHA. For investigation purposes we took 50ppm as the standard for investigation. This concentration will be the one we pretend to set as our exposure limit concentration.

Methodology

There is a lot of different products in the field already designed for carbon monoxide monitoring. Good to know is that when you read information about some of these sensors they specify that are not for complain to OSHA's regulations. The intent of the project is to build a really low budget prototype to monitor and tell what is currently happening with carbon monoxide emission levels. Also to have an equipment calibrated to detect our target concentration of 50ppm or more. After having a picture of the carbon monoxide exposure to the minimum level required by OSHA, we can design a more robust energy efficient system where is most required and turned on only when required.

The prototype sensor project will be accomplished by establishing a set of phases and description of each step described through the rest of the project report (Figure 2).

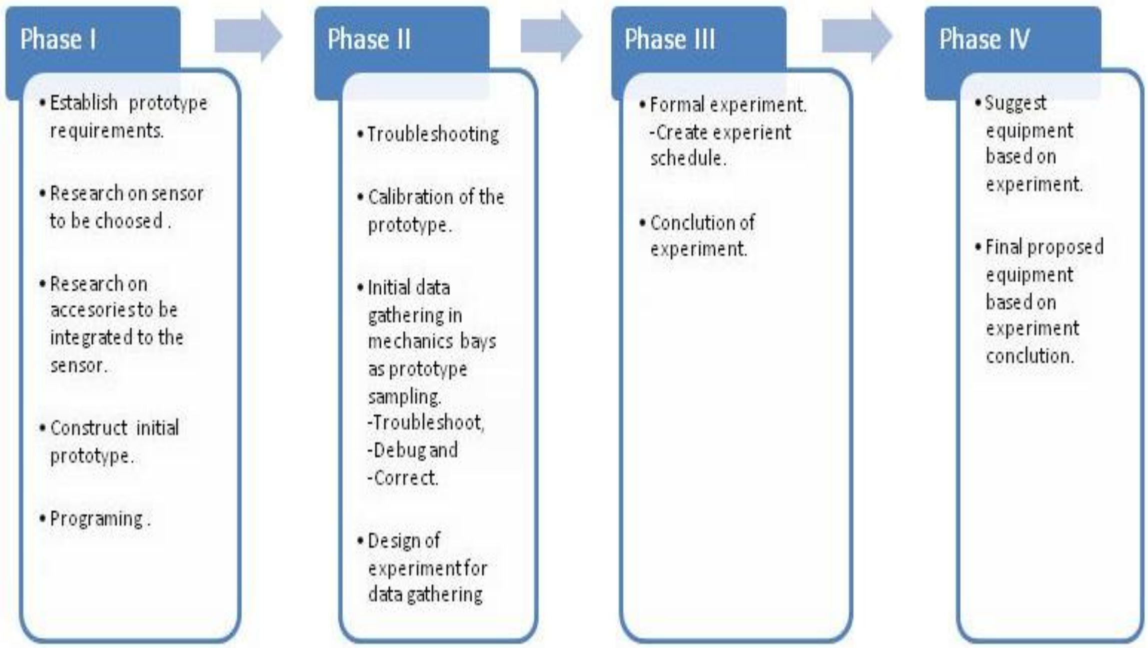

Figure 2
Project Development Phases

Phase I

First phase will be composed from five sub steps. From the basics of establish requirements thru the programming development step. Once finished first phase, the prototype should be constructed and programmed (Figure 2).

- Establish Prototype Requirements: The prototype should be a small portable box, able to be attached and removed from its base, so it can be disconnected easily and sent to calibration. It should have light emitting diodes and or sound status display when dangerous thresholds levels have been reached. Easy connections to external devices such as power supply, data connection. For cost matters, it should be the cheapest available so it can be locally developed with not much budget.
- Research on Sensor to be Chosen: There are many different types of sensors in the market, but in our case the goal is a low cost. Below (Table 2) is a table of the different type of sensors. We choose the semiconductor type because of the pricing accessibility, stability and good performance. Is relatively low cost and long time maintenance free, gas detection sensor device.

The chosen semiconductor sensor where supplied by Parallax Inc., the first one on the list, because of the price and the buying availability with the company that also sell the microcontroller and prototype board.

The sensor detects calibrated concentrations of carbon monoxide in the air and changes it resistance according to the concentration. The sensor can measure concentrations of 20 to 200 ppm. The sensor can operate at temperatures from -20to 50°C. It is recommended by the manufacturer to have the sensor for 48 hours.

Table 2
Different Sensor Manufacturers

Sensor Manufacturer	Model	Picture
Hanwei Electronics Co., LTD	MQ-7 Gas Sensor	
Alphasense Ltd	C0-AX Carbon Monoxide Sensor	
Dräger	XXS Drager Sensor Part Number: 540-6810882 $145.00	
Sensidyne	Sensalert 195272-D-1	

- Research on Accessories: The chosen company supplies a prototype board that can be easily fixed over any case. Some other accessories where bought at a RadioShack (Figure 3), the most easy local common electronics parts and accessories store. Other accessories like power supply, resistors and light emitting diodes where got (recycled from bad electronic equipment) from the shop where the prototype construction took place.

Figure 3
Prototype Box from RadioShack

- Construction of Prototype*:* The first prototype will be the board itself in order to have access and be easy access to measuring points and programming and troubleshooting (see Figure 3). Then the prototype will consist of a prototype board with the sensor module (see Figure 4) connected to the microprocessor controller outputs.

Figure 4
Sensor Module

Figure 5
Microcontroller Board

- The initial base program will be provided by the example program posted by the company. From there we are going to add whatever is required to our application. With this code we can start communication testing and start becoming familiar with the microprocessor programming.

After testing communications and programming downloads, the next step is to add a data gathering. For this purposes the more inexpensive data collection interface found was a free application from the same company called Parallax Data Acquisition (PLX-DAQ[4]). Parallax data acquisition tool software is an application that interfaces the microcontroller commands and data gathering through a serial port with excel. So the alarms status gathering data base will be excel with the help of PLX-DAQ. The goal will be to collect in a log table , every time the sensor detect that the CO ambient level is at or over 50ppm(the maximum permissible level eight hours exposure permitted by OSHA).

- Construction of Prototype: The final built prototype where a small box with light emitting diode status display (see Figure 6) power connection and a serial data connection. The box have status display light emitting diodes and other peripherals described in Table 3.

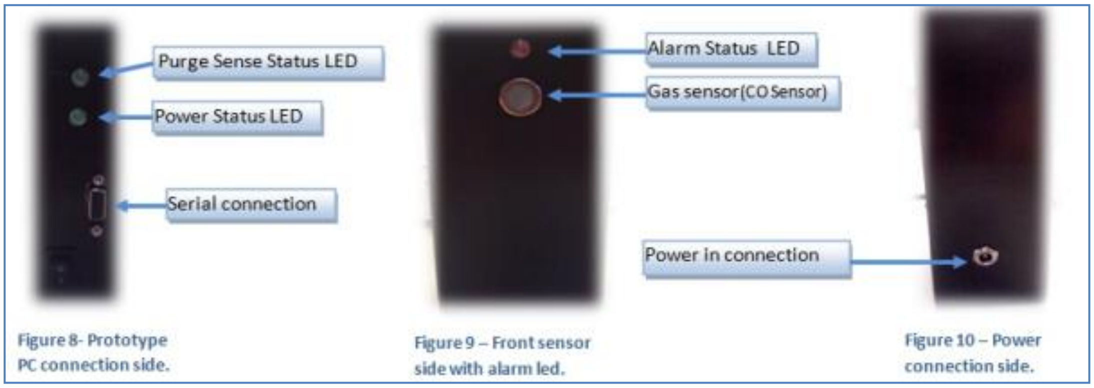

Figure 8- Prototype PC connection side.

Figure 9 – Front sensor side with alarm led.

Figure 10 – Power connection side.

Figure 6
Prototype Peripherals

Table 3
Prototype Box Peripherals Description

Box peripherals	DESCRIPTION
ALARM LED	CO level alarm - Located at the front side of the box. This red color led will be red solid red every time the CO level is at 50ppm. Off when no alarm level is detected.
Gas sensor	Located at the front side of the box.
Purge Mode/ Sense Mode LED	Located at the lateral side of the box. This green led have two operating modes: ON(solid green): no alarm, purge mode. This status remain for 60 seconds. On(Blinking,) -The sensor is scanning for a concentration of 50ppm. This mode duration is 90 seconds.`
Serial Port connector	Communication port with the computer. Serial port used for programming and data gathering to the computer.
Power LED	Power status display. Green led display of the power status of the module. Solid green: power is present at the microcontroller.
On/Off switch	Used to turn on the sensor module.
Power connector	Power connection to the sensor module box. Power required 9-12 V dc

- Functioning: The sensor box will run in cycles of 60 second off (purge mode) and 90 seconds on (sensing mode). During the sensing mode is where the alarm light is activated (red led solid), when it detects a concentration of 50ppm. At this point the time data will be logged to an excel table. The excel table will contain alarm status with stamped time of the event (alarm on). Following Figure 6 is a flow chart of the final program.
- Excel Data Base: The Parallax PLX-DAQ[4] Excel macro application inputs serial data to a excel table and stamps time of the acquisition. The macro program where modified to our application, trying to make it the most simple as possible. An extra button where added to scroll down to the last data input. Below (Figure 8) is a screenshot of the running application.
- Schematics: Two figures (Figure 9 and 10) display the schematics of the microprocessor connections with all the peripherals. The Figure 9 shows the modified sensor module from Parallax Inc [5].
- Cost: Below is a table which gives a detailed price list of the whole prototype module cost.

Table 4
Prototype Components Price List

Item #	Description	Vendor	Price	*Recycled
1	Microproconreoller Carrie	Parallax Inc.	$31.51	NO
2	BASIC Stamp 2- Microco	Parallax Inc.	$65.52	NO
3	CO Gas Sensor Module, F	Parallax Inc.	$30.49	NO
4	LED's, 2 green, 1 red	Digikey	$2.10	YES
5	LED, 1 red	Digikey	$2.13	YES
6	Coaxial DC Power Jack	RadioShack	$4.59	NO
7	Project Box Enclosure (6x	RadioShack	$5.02	NO
8	Snap-In on-off Switch	RadioShack	$3.44	YES
9	Relay SPDT , 5V, 1AMP	RadioShack	$5.87	NO
10	Diode	RadioShack	$0.17	YES
11	Fuse Clip	RadioShack	$1.61	YES
12	Fuse	RadioShack	$0.80	YES
13	Resistor 1kW 0.5W, 5PK	RadioShack	$0.30	NO
14	Resistor 220W 0.5W, 5Pl	Digikey	$0.42	YES
15	Resistor 470W 0.5W, 5Pl	RadioShack	$0.30	NO
16	Capacitor 1mF	Digikey	$0.30	YES
17	Transistor 2N3904	RadioShack	$1.49	NO
18	Rectifier	ElectronicGoldM	$0.69	YES
19	Cables	n/a	$0.00	YES
20	10KW 15-Turn Potentior	RadioShack	$3.41	NO
21	Computer power supply	RadioShack	$34.99	YES
		TOTAL	***$195.14***	
		PRICE WITH RECYCLED ITEMS	***$148.49***	

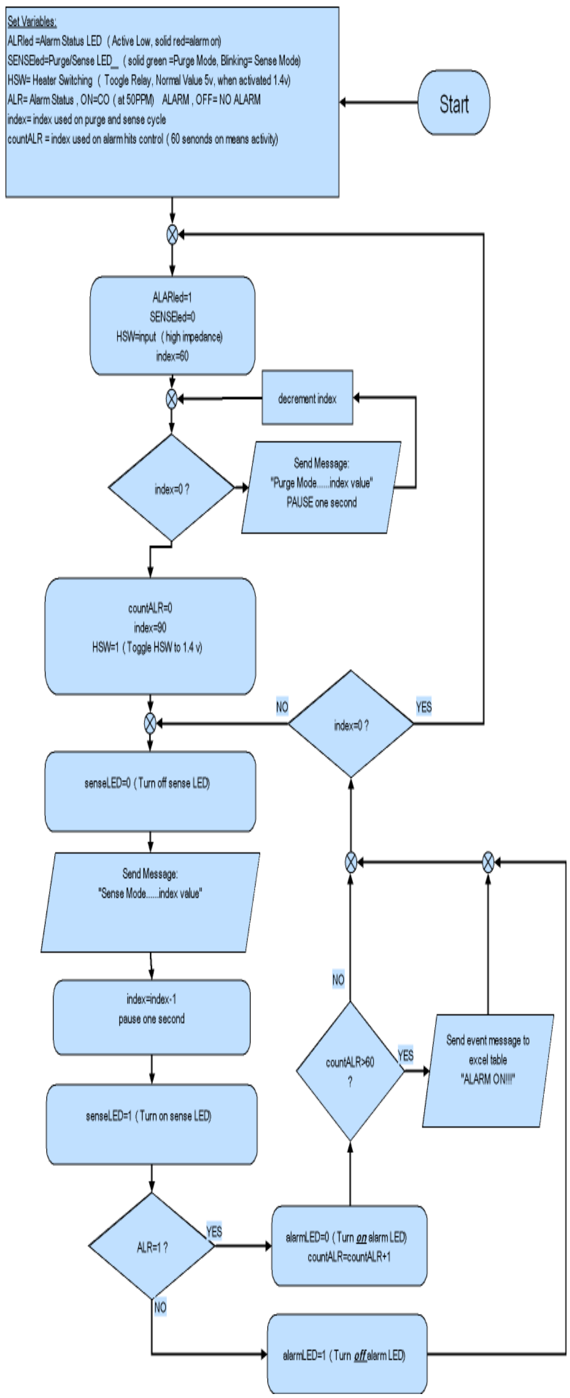

Figure 7
Program Flow Chart

A total cost of $195.14 was the cost for the Prototype Box. If we take in consideration all the items that were recycled, the cost drop down to $148.49.

The cost of the calibration gas cylinder where not included in this list, the price where $143.82. This item weren't able to buy it locally so where shipped and the price got twice the price of the item.

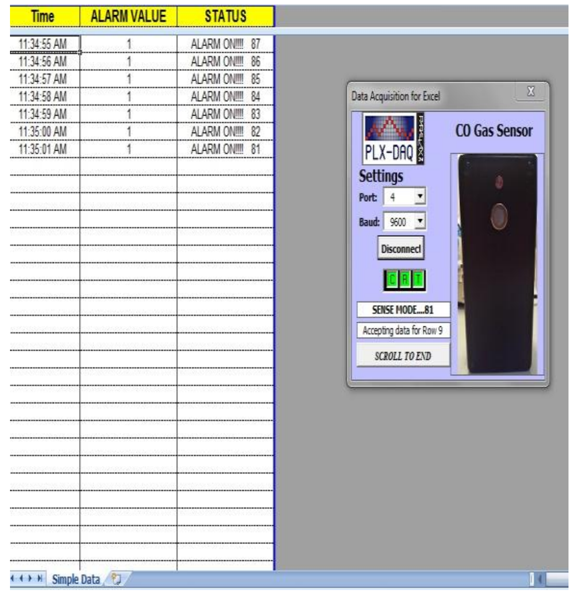

Figure 8
Excel Log Database and Parallax DAQ Macro Application

Phase II

Second phase contains troubleshooting part and, once all issues where corrected, the design of the final experiment.

- Troubleshooting: The module presented some errors due to voltage levels. The solution to this errors where to add a computer power supply, able to manage a clean DC voltage. The system (CO Prototype Sensor Box module plus computer) where attached to a battery backup system to maintain a constant input voltage to the hole system.

The current demand where higher than expected, a relay and transistor driving circuit where added to supply correct voltage levels to the sensor (see schematics Figure 9). The sensor board module where also modified to use the relay directly on the supply of the high and low voltages. To avoid false alarms on the data gathering cycle, a counter where added to the program, this counter will aloud to control the when the alarm is on continuously for almost the whole sense cycle (60 seconds). At that time is when it starts to send data to excel. This extra programming where added as a final program revision.

Calibration of the prototype. The calibration instructions procedure where gathered from suppliers documentation. The procedure for setting these potentiometers is explained on the manufacturers documentation [5].

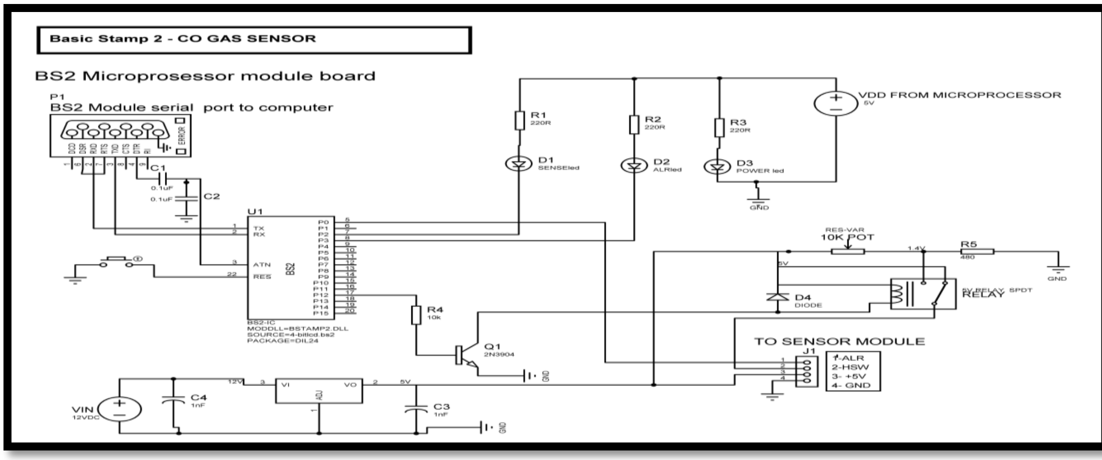

Figure 9
Prototype Board Schematics

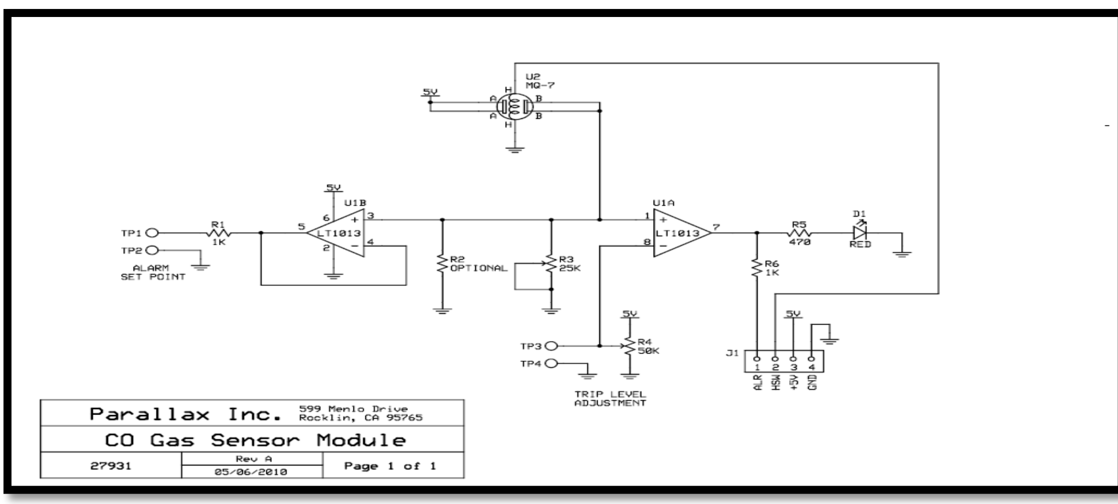

Figure 10
Sensor Board Module

Initial data gathering in mechanic bays: The prototype where placed over one of the bays for initial setup. Initial run of five hours where performed to test the prototype. The results for this fist five hours where that no alarm went on during this first run.

Formal Design of Experiment for data gathering: The experiment will consist of placing the prototype attached with a computer (for data gathering purposes, Figure 11). The working organization where used as the base of the experiment. The work team is composed as tree teams (Team 1, Team 2 and Team 3). Using that configuration, we are going to verify in each team working area, and at the same time verify the most used bay to perform the test on that bay. During one day in the Team 1 bay, then the next day on the other opposite section of the building (Team 2 area). The last day will be on the Team 3 area. The module will be placed at a low level (about three feet) height, because the mechanic spent much time working around that level. So each day will have eight continuous monitoring hours. The data will depend on the alarm status because the data is gathered only when the level reaches 50ppm and (at that instant) time is stamped on the computer table.

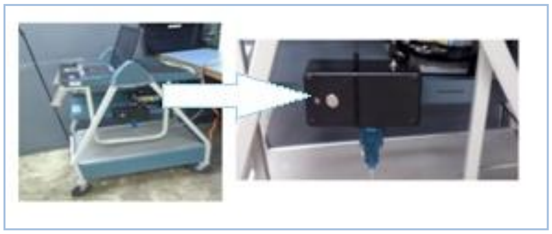

Figure 10
Prototype CO Sensor Box – Installed over a Movable Station

Phase III

Experiments results for each team are described below.

- Experiment Results:
  - Team 1 – The equipment where placed a full time shift. First time in the morning a test with calibrated gas where performed. After that no alarm occurred during the whole shift. The equipment where leaved for the hole night to the next day, no alarms found. Even a vehicle where parked over the bay and accelerated for one minute, the alarm didn't activate. The conclusion for this area is that no concentrations of carbon monoxide level at 50 PPM were detected.
  - Team 2 and Team 3 – Same procedure where performed and same negative results were obtained over these two areas.

Conclusion of the Experiment

The sensor module's experiment not found any exposure over the 50 PPM required by OSHA. The area is a well ventilated area, the bays are open in all times during working hours. The air is most of the time flowing. The facilities are located over an elevated area in the south coast, which helps to maintain the air flow most of the time.

Phase IV

Suggestions based on experiments results and proposed equipment based on those results.

Suggested Equipment based on Experiments

Because of the cero activation test results, taking in mind a low cost solution and OSHA compliance, the best affordable solution over that are, is to have a simple monitor system that warns the mechanics or supervisors by and visible and audible alarm. The extraction system as per experiments results is not required over this facility.

Final proposed Equipment based on Experiment and Conclusion

The final proposed equipment can be a local developed sensor module with an audible and visual alarm and located in the most used bays entrance. Further similar experiments should be performed over similar facilities (there are seven similar facilities around the island).

References

[1] *Diesel Soot Health Impacts*, Clean Air Task Force, http://www.catf.us/diesel/dieselhealth/faq.php?site=0.

[2] *Partial List of Chemicals Associated with Diesel Exhaust*, United Sates Department of Labor-Occupational Safety and Health Administration, Retrieved from: http://www.osha.gov/SLTC/dieselexhaust/chemical.html.

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