# Mobile Custom-made Handheld Chemical Detection Device

Iem Heng
Computer Engineering Technology Department
New York City College of Technology (NYCCT)
Brooklyn, NY, USA
iheng@citytech.cuny.edu

Andy S. Zhang
Mechanical Engineering Technology Department
New York City College of Technology (NYCCT)
Brooklyn, NY, USA
azhang@citytech.cuny.edu

Raymond Yap
Computer Engineering Technology Department
New York City College of Technology (NYCCT)
Brooklyn, NY, USA
raymond.yap@hotmail.com

***Abstract*— In today's society, there is a challenge to detect and to avoid exposure to harmful and lethal chemicals. This remains an issue to public health and has not been addressed adequately. To address this challenging issue, the objective of this paper is to provide a unique perspective in designing and building a custom-made mobile handheld chemical detection (CHCD) device that can detect harmful and lethal chemical gases ($NO_2$, $N_2$, CO, $CO_2$, LPG, $CH_4$, CNG, $C_2H_5OH$, $NH_3$, $H_2$ and others) in public and in private gathering places. This mobile handheld device can relay the information of the chemical concentration levels detected to smartphone or tablet or laptop in any place at any time. Applications of this useful mobile CHCD prototyping device include detection of harmful gases in public and in private gathering places such as subway stations, shopping malls, airports, and residential houses. Additionally, this mobile CHCD device provides an alternative and affordable resource for people to have and use it as an advance warning system within the proximity of dangerous areas.**

***Keywords- chemical detection; mobile communication; remote sensing.***

## I. INTRODUCTION

Over the years, chemical gases in the U.S. and around the world have caused and taken many innocent lives that could have been prevented. Of primary concern are the human health effects of chemical gas, including premature mortality and chronic illnesses such as bronchitis and asthma. Despite the tremendous economic costs and pervasive negative health impacts of bad chemical gas – chemical gas often goes unnoticed because it is largely invisible. Much of what happens in our immediate environment passes without being noticed by the public despite the fact that there are recording and crowd-sourcing devices installed in some neighborhood that monitor the air quality. A mobile CHCD device captures a spectrum of that lost reality and returns it to the users in real-time as the events unfold. By making these specific environmental events available to participants in real time and location, the CHCD supplements the qualitative information reported by government agency with quantitative information obtained from handheld sensing device that observes and records aspects of the environments that are either impossible to perceive directly (e.g., pollutant gas concentrations) or difficult to quantify and communicate in a consistent manner. A mobile CHCD device allows individuals to broadcast what is happening with their environment, crowdsource their own information with that from other participants, and identify patterns and commonalities. Thus, this mobile CHCD device makes the detection of chemical gas possible by concern citizens, thereby empowering communities to advocate for healthy environments.

Unlike the current commercial chemical detection devices, the mobile CHCD device is a unique and novel device in term of miniature size, provides an advance communication warning system accessed by other smart devices (smartphone, tablet, and laptop), and provides an affordable low-cost detection device for consumers. For instance, comparing the commercial hazardous vapor warning LCD 3.3 [1] and Nose Gas Sensor [2] devices to the mobile CHCD device, the LCD 3.3 and Nose Gas Sensor devices are designed as one unit with LCD screen used for displaying the gas concentration levels and are not capable of communicating with other smart devices. Additionally, both devices are not small and not cost effective for general consumers. Furthermore, many other commercial detection devices have similar features as the LCD 3.3 and Nose Gas Sensor. This is why the mobile CHCD device is a unique and novel detection device for an advance warning system to the public.

In this paper, we are going to provide a unique perspective in designing and building a CHCD device that can detect harmful and lethal chemical gases in public and in private gathering places. First, we look into how the chemical gas sensors work. Then a schematic of CHCD device is developed. Based on the hardware schematic of CHCD device, the custom-made physical prototype of this

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device is created. The CHCD device is capable of communicating to portable devices such as smartphone or tablet or laptop through the use of Bluetooth technology. We then have done several tests (indoor and outdoor scenarios) of mobile CHCD device with those portable devices. From those tests, the raw analog signal data is acquired and is calibrated. This calibrated data is what provided for people to understand the useful benefit of mobile CHCD device.

## II. CHEMICAL GAS SENSORS

Currently, there are many different types of harmful chemicals and gases ($NO_2$, $N_2$, CO, $CO_2$, LPG, $CH_4$, CNG, $C_2H_5OH$, $NH_3$, and others) that can harm innocent people and could give serious negative environmental impact on the planet we live on. To prevent the loss of innocent human lives, effective detection and handheld monitoring systems need to be developed. The mobile CHCD is a state-of-the art device to detect many kinds of harmful chemical gases in the air and on the ground through the use of various chemical gas sensors. This detection device provides an advance warning system and alerts the general public through their smart devices. This could reduce human casualties, environmental destruction, and property loss.

How do the various chemical gas sensors work? Many gas sensors use a heater to detect certain gases. In general, many of these gas sensors have similar schematic diagram [3] as follows:

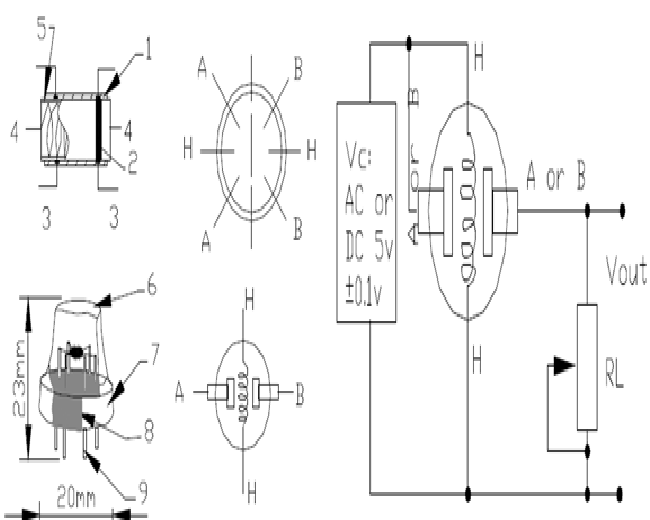


Figure 1. General Gas Schematic.

According to the chemical gas sensor schematic diagram shown in Figure 1, there are 6 pins coming out of the gas sensor itself. However, some chemical gas sensors have only 3 or 4 pins. 5 volts can supply to pins (A H A); whereas, both pins B can be used as an analog output signal. The other pin H, in between both pins B, can be used as a ground (GND) pin. This is illustrated in Figure 2 as follows:

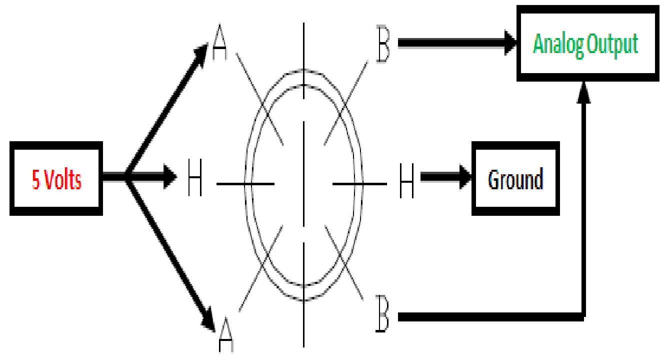


Figure 2. Gas Sensor.

Then the data from an analog output signal is incorporated into specially designed software codes capable of detecting a wide range of harmful and lethal chemical gases by using different types of gas sensors. The sensor testing and calibration of analog signal data acquisition will be fully discussed in later Section IV.

In term of the working principle for the gas sensor for $CO_2$, as an example, it takes on the solid electrolyte cell principle and is composed by the following solid cells: Air Au|NASICON|| carbonate|Au, air, $CO_2$ [4].

When the $CO_2$ sensor exposes to the $CO_2$ environment, it will have electrochemical reaction with the following equations [5]: Cathodic reaction equation:

$2Li + + CO_2 + 1/2O_2 + 2e - = Li_2CO_3$. Anodic reaction equation: $2Na+ + 1/2O_2 + 2e- = Na_2O$. The overall chemical reaction equation:

$Li_2CO_3 + 2Na + = Na_2O + 2Li + + CO_2$. As a result of electrochemical reaction, according to Neste equation (Nernst), the process will produce the following electromotive force (EMF): EMF = Ec - (R x T) / (2F) ln ($P(CO_2)$), where $PCO_2$ is the partial pressure of $CO_2$; Ec is a constant; R is the gas constant; T is temperature in Kelvin; F is the Faraday constant.

From Figure 1, the sensor heating voltage supplied from other circuit. When its surface temperature is high enough, the sensor equals to a cell, its two sides would output voltage signal, and its result accord with Nernst's equation [5]. In sensor testing, the impedance of amplifier should be within 100-1000GΩ, Its testing current should be control below 1pA.

## III. MOBILE CHCD DEVICE

In this section, we will discuss and provide more details on how we design the prototype of Mobile Custom-made Chemical Detection (CHCD) Device.

### A. *Hardware Schematic of Mobile CHCD Device*

The set up pins of a gas sensor in Figure 2 provide some ideas of how to hook up the hardware schematic diagram of mobile CHCD device. Using Fritzing [6] software program, the design of the overall hardware schematic for the device is shown in Figure 3.

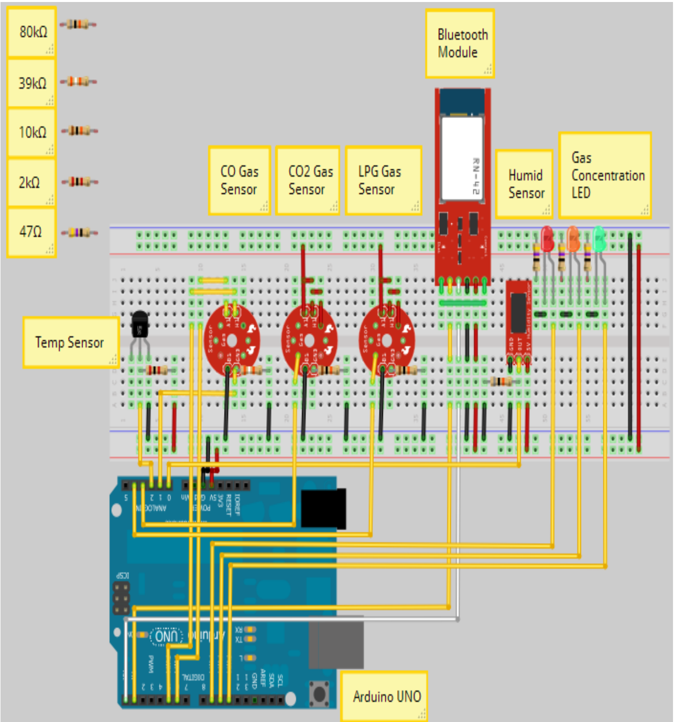


Figure 3. Schematic of CHCD Device.

From the schematic of Figure 3, the yellow, red, and black wires are used as data signal communication, voltage, and ground, respectively. The signal lines for the three sensors (CO gas, $CO_2$ gas and LPG gas) are connected to the Arduino microcontroller analog pins A1, A3 and A4. In addition to the three gas sensors in Figure 3, temperature and humidity sensors are added to the CHCD device for monitoring the effect of data acquisition in correlation to the three gas sensors. Whereas, the red and black lines across the breadboard in Figure 3 are connected to Arduino 5V and ground pins, respectively. The yellow and white wires from the Bluetooth module are used as the transceivers and are connected to Arduino pins TX (transmitter – yellow wire) and RX (receiver – white wire). The use of a Bluetooth module provides the wireless communication lines between CHCD device and smartphone (or tablet or laptop). Also, for instance, the three color LEDs indicate the CO gas concentration levels. Green, orange, and red color LEDs are indicated the least, medium, and highest PPM, respectively. PPM is for part per millions, and it is used to measure the concentrations of chemical gas. Hence, this makes CHCD device as a unique embedded mobile handheld device in monitoring the surrounding areas of one's present.

*B. Prototyping of Mobile CHCD Device*

Based on the hardware schematic of CHCD device in Figure 2, the custom-made physical prototype of this device is created. The following Figure 3 shows the final prototype design of the CHCD device.

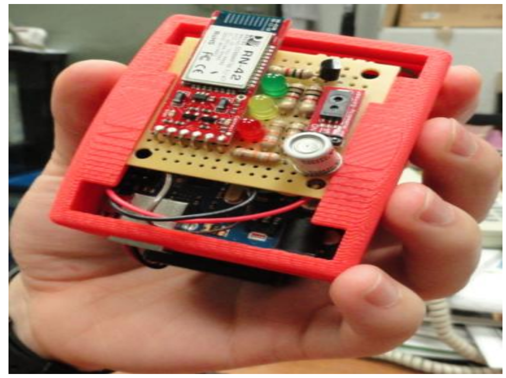

Figure 4. Prototyping of CHCD Device.

Currently, as seen in Figure 4 above, the custom-made prototype of chemical detection device has been used for testing the CO (Carbon Monoxide) concentration levels along with the temperature and humidity. This device will be expanded to include the testing of $CO_2$ (Carbon Dioxide), LPG (Liquefied Petroleum Gas), and among other known chemical gases.

Figure 5 shows the progress stages in designing the CHCD device leading to the final prototype.

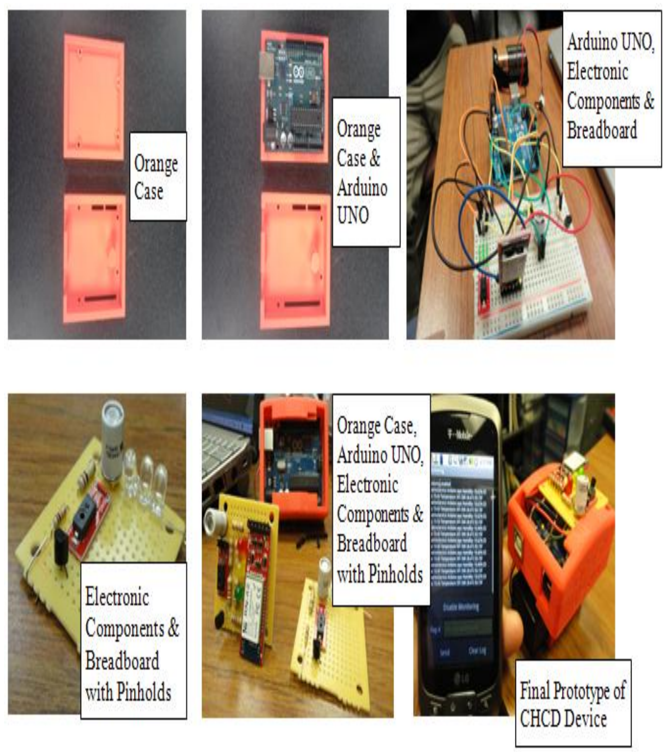


Figure 5. Design Stages of CHCD Device.

The CHCD device cover (orange case) is for holding the Arduino UNO microcontroller and electronic components (sensors, resistors, LEDs, and Bluetooth) with breadboard. To accomphish this, a computer model of the CHCD device is created using Autodesk Invnentor [7] software. Figure 6 shows a computer model of the CHCD device assembly. Figure 7 is a computer rendering of the device. Then a phyical prototype was made using 3D rapid prototyping machine as shown in Figure 8. The electronic components are soldered on the back side of the breadboard. Upon completing all the electronic components soldering on the breadboard, we are able to slide the completed breadboard onto the orange case. This completes the design stages of the CHCD prototype as seen in Figure 4.

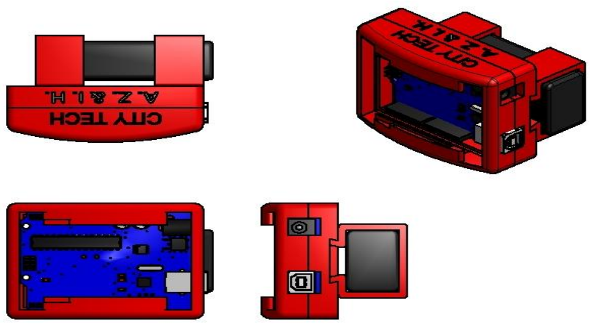

Figure 6. Assembly View of the CHCD Device.


Figure 7. Computer Rendering of CHCD Device.

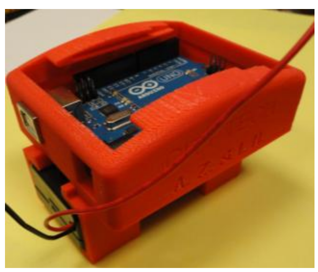

Figure 8. Physical Prototype of CHCD Device.

## C. *Wireless Communication*

Figure 9 is a block diagram of Bluetooth wireless communication for the mobile CHCD device.

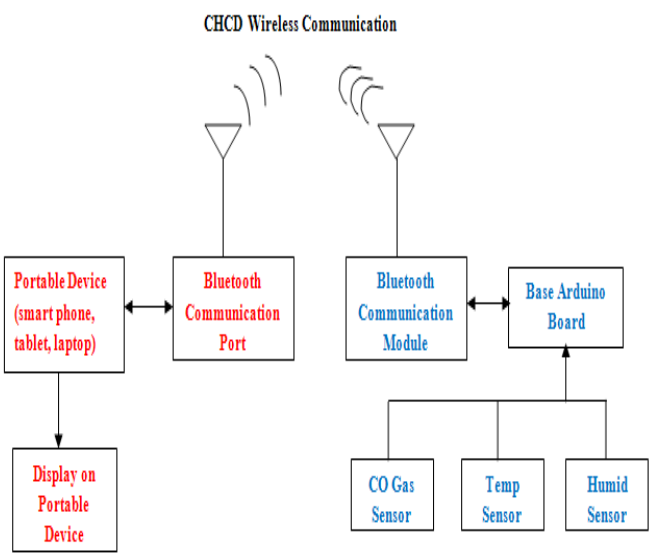


Figure 9. CHCD Wireless Communication.

Namely, the mobile CHCD device is capable of communicating to portable devices such as smartphone or tablet or laptop through the use of Bluetooth technology. Bluetooth wireless technology is based on the IEEE 802.15 standard. Bluetooth was developed to replace the cables that were connect to desktop and portable computers, mobile phones, handheld devices, computer accessories and peripheral electronic devices [8]. Thus, the use of Bluetooth wireless communication enables the users to retreat the data from the chemical gas sensor and, at the same time, display gas concentration levels on the portable devices.

To make the CHCD device to communicate and interface wirelessly with portable device (smartphone, tablet and laptop), as illustrated in Figure 9, the programming source codes must be introduced to provide access of communication and interface between devices. First, the source codes are written in Arduino sketch [9] to communicate and interface with the electronic components such as CO gas sensor, temperature sensor, humidity sensor, and LEDs, as shown in Figure 5. Upon the success of interfacing with the sensors and LEDs in Arduino sketch, the Android library MeetAndroid is import to the Arduino library folder, so that the data acquired from the Arduino Serial Monitor is sent to the Amarino Application (App) progam. The Android library MeetAndroid is part of Amarino driver device that is required to be imported in the library folder of Arduino sketch. The Amarino progam [10] is a freeware program that incorporates a plug-in mechanism which allows programmers and developers to integrate their events into Amarino. Then, this provides a gateway to communicate with smartphones and tablets based on the Android open source operating system. Figure 10 illustrates the details of communication between Arduino Sketch , Amarino App, and Android operating system.

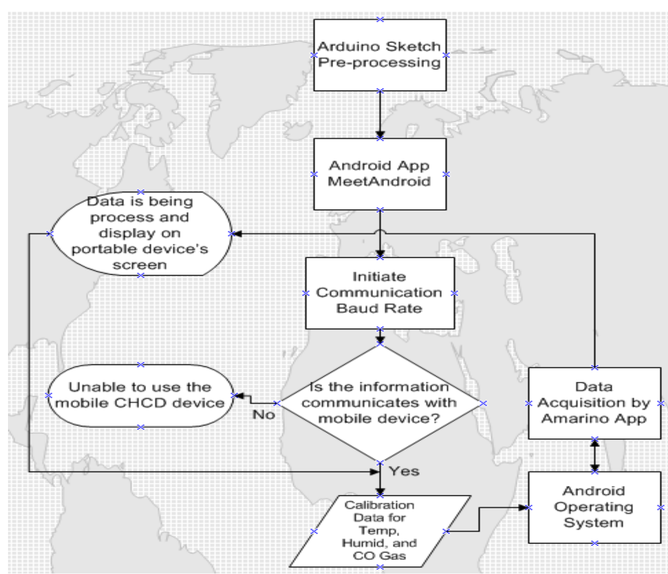


Figure 10. Flowchart of Wireless Interface and Communication.

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## IV. CO GAS SENSOR CALIBRATION

In this section, the calibration of data acquisition from CO gas sensor is discussed in details. Using the CHCD device in Figure 4, the raw analog signal data is acquired from the CO gas sensor. Then the raw data must be calibrated with respect to that analog data. For instance, taking all factors such as the type of sensor and the conditions of the application into consideration, the proposed calibration procedure is based on the following block diagram:

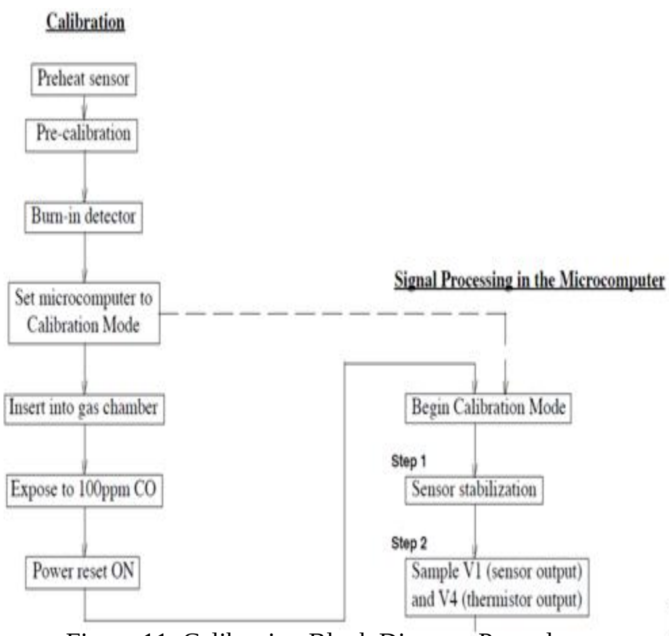


Figure 11. Calibration Block Diagram Procedures.

Based on the flowchart in Figure 11 above, 100 PPM is exposed and is used for calibration standard. Applications of how safe and unsafe of PPM for CO gas can be seen in Figure 12 below. For instance, 200 PPM would have a symptom of mild headache, fatigue, nausea and dizziness in two to three hours [11].

| PPM CO | Time | Symptoms |
|---|---|---|
| 35 | 8 hours | Maximum exposure allowed by OSHA in the workplace over an eight hour period. |
| 200 | 2-3 hours | Mild headache, fatigue, nausea and dizziness. |
| 400 | 1-2 hours | Serious headache-other symptoms intensify. Life threatening after 3 hours. |
| 800 | 45 minutes | Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2-3 hours. |
| 1600 | 20 minutes | Headache, dizziness and nausea. Death within 1 hour. |
| 3200 | 5-10 minutes | Headache, dizziness and nausea. Death within 1 hour. |
| 6400 | 1-2 minutes | Headache, dizziness and nausea. Death within 25-30 minutes. |
| 12,800 | 1-3 minutes | Death |

Figure 12. Gas Concentration in PPM and Symptoms.

In addition to the block diagram in Figure 11, the gas concentration chart [12] in Figure 13 is used as part of the calibration for the CO concentration in PPM.

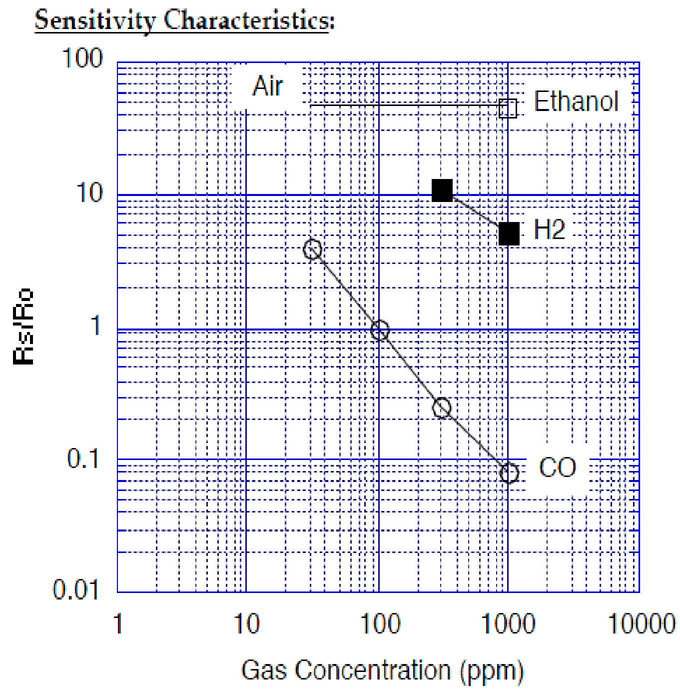


Figure 13. Gas Concentration in PPM.

Figure 13 represents typical sensitivity characteristics of CO concentration levels. The Y-axis is indicated as sensor resistance ratio (Rs/Ro) [12] which is defined as follows:
Rs = Sensor resistance of displayed gases at various concentrations and Ro = Sensor resistance in 100 PPM CO
In other way of looking at Ro is the level of expose gas to the sensor in clean air. For instance, if we pour 100 PPM gas in the container with confined space, what would Rs sensor read? It may read 98 PPM or 102 PPM.
The formula [13] for defining the sensor resistance Rs is as follows:

$$Rs = \frac{Vc \times R_L}{V_{out}} - R_L \qquad (1)$$

From equation (1), Vc is the voltage input, and it is 5 Volts from Arduino microcontroller embedded in CHCD device. $R_L$ is the load resistance (in this case, we use 39kΩ) that is connected to CO gas sensor. Vout is a voltage signal from the CO gas sensor, and it varies depending on the amount of CO concentration within PPM (parts per million). Then the value of Rs in equation (1) changes according the amount of CO gas present, and as seen in Figure 13 above, the typical range for CO gas concentration is from 30 to 1000 PPM. If Rs resistance value is the same as Ro resistance value, it means 100/100 = 1, which correlates to 100 PPM in Figure 13. In theory, Ro represents the X axis in Figure 13 if conditions are perfect.

## V. PRELIMINARY TESTING AND RESULTS

We have done several tests of mobile CHCD device with smartphone, laptop and tablet. The indoor tests were performed at the College as seen in Figure 14 and Figure 15.

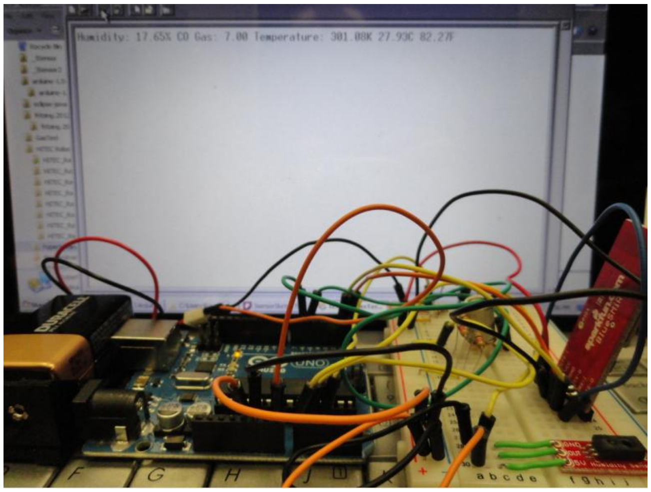

Figure 14. Indoor Testing Using Laptop.


Figure 15. Indoor Testing Using Smartphone.

And the preliminary data from the indoor tests can be seen in Figure 16. The data is then tabular in Excel spreadsheet.

| Base on 100 ppm Calibration | | |
|---|---|---|
| Where Rs = Ro: | | |
| PPM | Rs/Ro | |
| 15 | 11 | |
| 35 | 3 | |
| 100 | 1 | |
| 310 | 0.2 | |
| 1100 | 0.09 | |

Figure 16. Data from Preliminary Indoor Tests.

Then the data in Figure 16 is plotted in Excel chart. The chart can be seen in Figure 17. And it is used to tell the sensitivity characteristics of CO concentration levels.

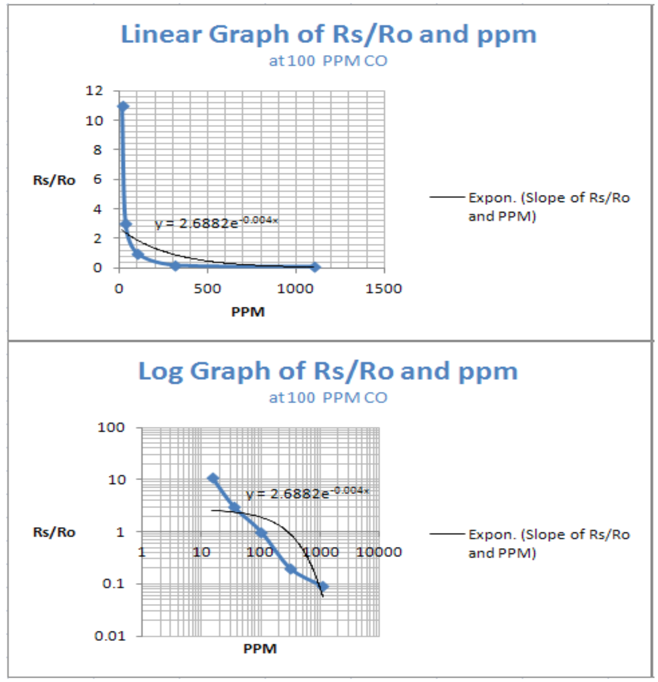


Figure 17. Sensor Resistance Chart for Indoor Tests.

Similarly, the outdoor tests of CHCD device (without the orange case) were performed with the tablet and smartphone. The test was done by placing the CHCD device behind the car's exhaust pipe, while the car engine is on, as seen in Figure 18 and Figure 19 below.

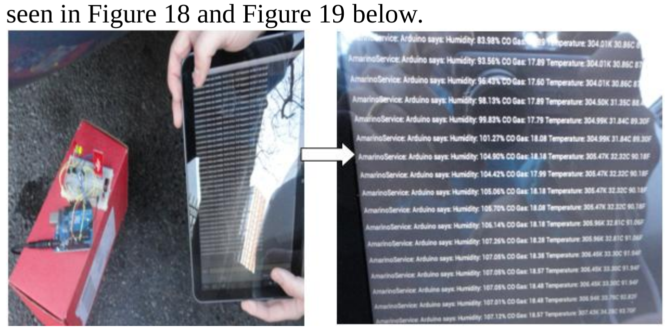

Figure 18. Outdoor Testing Using Tablet.


Figure 19. Outdoor Testing Using Smartphone.

The preliminary data from the outdoor testing scenario can be seen in the following Figure 20:

| Base on 200 ppm Calibration | |
|---|---|
| Where Rs = Ro: | |
| PPM | Rs/Ro |
| 55 | 12 |
| 110 | 3.1 |
| 200 | 1 |
| 900 | 0.15 |
| 1600 | 0.08 |

Figure 20. Data from Preliminary Outdoor Tests.

Then the data in Figure 20 is plotted in Excel chart and can be seen in the following Figure 21:

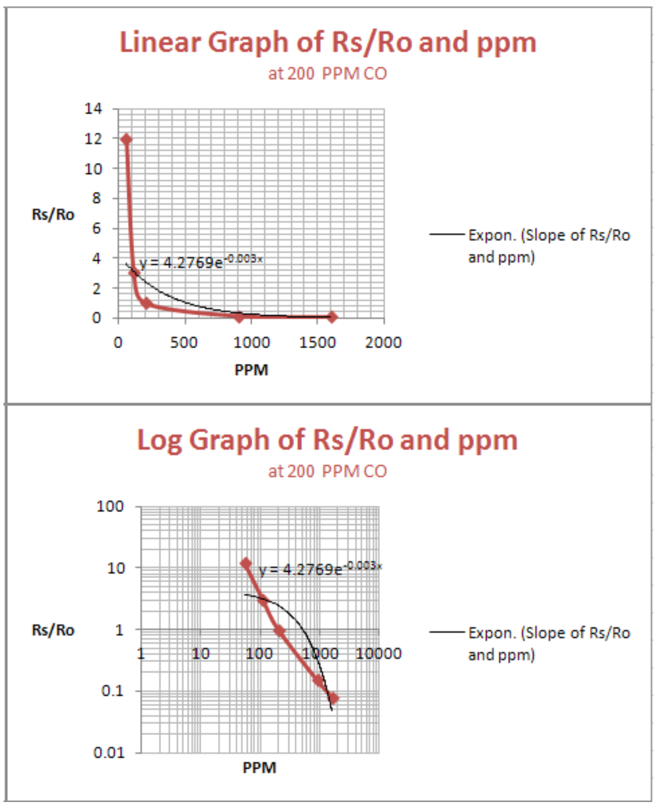


Figure 21. Sensor Resistance Chart for Outdoor Tests.

Two scenarios had been conducted on the mobile CHCD device using smartphone, tablet and laptop. Of the two scenarios, the worst case was found when the CHCD device was placed behind the car's exhaust pipe while the car engine was running. These results are encouraging and show that the mobile CHCD device provides a reliable data to determine the chemical concentration PPM levels. Note that when performing outdoor tests of CHCD device, it is taken into considerations of wind, temperature, and humidity. Clearly, this is a small preliminary sample test for the mobile prototype CHCD device. More testing of this device will be performed in the near future.

## VI. SUMMARY AND CONCLUSION

"Detecting explosives is not an easy thing," said David Danley, a retired Army colonel and head of defense programs at Combimatrix Corp., a small biotechnology company near Seattle [14].

David Danley is right, and the goal for this research project is to develop a mobile and portable chemical detection device that will assist and provide significant impact to society in term of reducing the potential loss of human life through detection and prevention. The mobile CHCD device provides early warning system if there is a possible expose of harmful and lethal chemical concentration levels within distance. This early detection and prevention could save many human lives from harmful chemical gases. Thus, the mobile CHCD device becomes an analytics engine capable of picking out emergent patterns in human environments and biology.

The mobile CHCD device is a low-cost miniature detection device that could provide crucial instant information of chemical detection and preventing the loss of human life. This crucial information of sensing and detecting the quality of the air become possible with the aid of modern technologies (smartphone, tablet, and laptop). Hence, the mobile CHCD device, along with modern technologies, provides an alternative affordable resource for the people to have access and use it to identify the invisible harmful chemicals at early warning stage and could possibly lead to save many human lives.

The current cost for producing the prototype of this mobile CHCD device is approximately $60 to $80.

## ACKNOWLEDGMENT

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