THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF ELECTRICAL ENGINEERING AND TELECOMMUNICATIONS

"Calibration of a wireless sensor board for measuring air pollution"

Judy Liu

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Supervisor: Dr Vijay Sivaraman
Assessor: Dr Wei Zhang

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Thesis Title: Calibration of a Wireless Sensor for Measuring Air Pollution
Topic Number: VR24 **Student Name:** Judy Yuan Liu **Student ID:** z3253755

A. Problem Statement:

Air pollution is a major affect on society as it impacts not only our health but also our environment and economy. Action must be taken immediately to monitor and control this situation before a critical point is reached. In NSW the government is spending up to $8.4 billion per annum to cover costs associated with the affect of air pollution. Therefore it is necessary to design a device that can monitor air pollution in real time and provide its data to users on the go.

B. Objective

To assess the current state of air pollution from major pollutants to common sources and to review the background literature on research within this field. This will help in understanding the need for a more accessible, mobile and user-friendly tools in monitoring air pollution.

C. My Solution

Designing and calibrating a wireless sensor board to monitor pollutants such as carbon monoxide and nitrogen dioxide as they are the two main pollutants affecting society today. Also improving the wireless sensor board device through a better selection of gas sensors and improve the readings that are being monitored.

D. Contributions

Constructed an experimentation method of the calibration of both CO and NO2 sensors.
Performed data reduction on the collected data by comparisons to a commercial device (MicroAlertGas5).
Selected an alternative sensor to improve the accuracy and stability of the recorded measurements.
Review of the background literature in determining the affects of air pollution as well as the need for new technology and research underway within this area.

E. Suggestions for Future Work

Assembly of the printed circuit board and trials of on-road testing.
Improvement with the software that transfers data from the device so that it is capable of handling multiple.
Creation of a user-friendly application for mobile devices using the foundations of the interface that was already previously designed.

While I may have benefited from discussion with other people, I certify that this thesis is entirely my own work, except where appropriately documented acknowledgements are included.

Signature:  Date: 30/05/2012

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17-19	[16] [17] E2V technologies (2010)
12-13	[12] SOUTH EASTERN SYDNEY PUBLIC HEALTH UNIT & NSW DEPARTMENT OF HEALTH (2003)
10	[8] Department of Environment and Conservation (NSW) (2005)
7	[2] U.S. Census Bureau (2012)
9	[4] Department of the Environment and Heritage (2005)

Abstract

Clean Air is a basic necessity for all human being living on earth yet 80% of the world's population breathes air that has pollutants, which exceeds the World Health Organization's recommended levels [1]. From US to Asia the threat of air pollution has become a factor that must be addressed immediately.

This report will look at the issue of air pollution and it's major impacts on society, as well as assesses and analyzes the different types of pollutants within the air we breathe. It will look at the current methods and devices we currently have in place to measure and monitor air pollution and lead into the new trends that are been developed which sets up the scope for my Thesis project.

Acknowledgements

I would like to acknowledge and thank my thesis supervisor Dr Vijay Sivaraman for all the guidance and support that was provided throughout the entire duration of my thesis project. His advice and continuous feedback was helpful and very much appreciated. I would also like to thank fellow project member Matthew Kelly whose support and assistance during this period has been invaluable. With regards to my procurement of nitric acid I need to thank Dr Toby Jackson from the School of Chemistry at UNSW. Without his help and cooperation NO2 dioxide calibrations would have been extremely difficult to accomplish.

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1 Introduction

According to the United States Census Bureau (USCB) the population of the world exceeded 7 billion on approximately March 12th 2012 [2]. It is quite evident that as a global society we continue to develop and strive through the innovation of new technology as well as rapid growth in a range of industries. However with progress and development comes consequences and as a result one key issue that must be addressed is air pollution.

The environmental and health impacts with regards to air pollution have become a growing concern. Currently within Sydney air pollution is monitored by only 14 fixed air monitoring sites that are spread across a radius of approximately 40km, as a result the distance between each site is too greater for accurate and real time measurements.

This report will address the relevant background surrounding the causes and effects of air pollution as well as bring to light recent research and initiatives employed by cities both local and global. Comparisons will be made between the previous prototype and the changes that have been implemented in achieving the new design. A breakdown of the sensor board as well as the experimental process undertaken for calibration will be addressed. There will be a detailed description of the method and procedures undertaken for calibration of the carbon monoxide (CO) and nitrogen dioxide (NO2) sensors. Extensive testing was also performed with comparison to the commercial meter and the result was analyzed.

Lastly the PCB design and mounting of the actual device is briefly described as recommendations are made for further testing (using PCB) with specific emphasizes in certain aspects so that improvements and progress on this project continue.

2 Background Information

2.1 Air Pollution

Air pollution is a mixture of substances [refer to figure 2.1] within the air called pollutants, these pollutants are most commonly separated into toxic gases and particulate matter. The most commonly found toxic gases as seen in the chart include carbon monoxide, carbon dioxide, oxides of nitrate, ozone and etc.

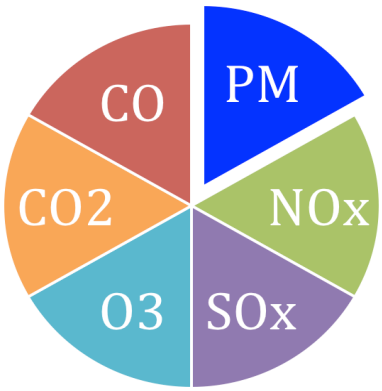


Figure 2.1 Air Pollutants

2.1.1 Major Pollutants

There are many forms of air pollutants within the atmosphere however as the pollution from on-road vehicles start to rise there comes a greater need to monitor pollution specifically carbon monoxide and nitrogen dioxide.

2.1.1.1 Carbon Monoxide:

Carbon monoxide is called the 'silent killer' [3], as it is colorless, odorless and tasteless. On many occasions individuals do not know that they've inhaled a substantial amount until the symptoms and affects begin to appear.

From the table in Appendix 15.4, the symptoms associated with the varying levels of concentration of Carbon Monoxide can be seen to be mild to life threatening. As we want to produce a commercial device for monitoring air pollution in a wider market, that is why we have chosen to measure concentration levels to reach a maximum of 0-100ppm focusing specifically on accurate and stable reading below 50ppm. Any concentration reading higher that this range would be unnecessary to monitor and government agencies would need to be contacted if surrounding areas recorded values this high.

2.1.1.2 Nitrogen Dioxide:

Nitrogen Dioxide is a strong and pungent smelling natural gas that is produced naturally from lightning and from some plants, soil and water. However only around 1% of NO2 is formed this way as 80% of this gas is a direct result from motor vehicle exhaust as well as burning of fossil fuels and electricity generation from coal-fired power plants [4].

The affects of Nitrogen Dioxide are more severe than Carbon Monoxide even when exposure is only for a short amount of time and in low concentrations, therefore the range in which we monitor this gas can range between 0-20ppm. The US (EPA National Ambient Air Quality Standards) state that NO2 in ambient (outdoor) conditions should not exceed 0.053ppm over 24 hr period however no standards have been set for NO2 in indoor conditions and nitrogen oxides are usually measured to be higher in indoor air [4].

2.1.2 Effects of Air Pollution

The effects of air pollution are separately predominately into 3 main categories impacts on health, economy and the environment.

2.1.2.1 Impacts on Health

The impact of air pollution on health is one of the most significant concerns of the World Health Organization. It is estimated by the WHO that around 2 million people per year [5] die globally from a direct result of poor air quality. Indicators show that this is not only affecting developing countries but health issues such as respiratory infections, heart diseases, asthma and lung cancer are all on the rise in developed countries such as the USA and the UK. We must recognize and acknowledge that the issue of air pollution as a growing health burden within society and finds more efficient and effective ways to monitor this issue so we are able to find a sustainable solution.

Especially in recent decades more research has gone into the study of the looking more closely at specific cities around the world and how pollutant levels in the air affect the people living there. An article in the BBC News [6] stated that the negative health consequences of air pollution couldshorten a person's lifespan and breathing in unclean air was likened to inhaling second-hand smoke from a smoker continuously.

Other Associated Health Issues:

- Respiratory Infections
- Heart Disease
- Asthma
- Chronic Bronchitis
- Lung Cancer

Within Australia national policies and programs are focused on reducing emissions and improving air quality within three main areas: Transport, Residential and Industry. As most air pollution is a result of the increase of on-road vehicles governments are trying hard to encourage less on-road traffic.

2.1.2.2 Impacts on the Economy

With the rising cost in Health Care, the burden on the economy is another major impact that air pollution has on society. Billions of dollars are spent globally to address the health concerns, and in one article it was seen that in California alone the 'dirty air' caused $193 million in hospital based health care within a 2-year period. The elevated pollution levels meant that "exposure to excessive levels of toxic gases and particulate pollution caused nearly 30,000 emergency room visits and hospital admissions"[7]. This impact may not be as concerning as the health concerns however it proves that air pollution does have a significant impact on the state's economy.

Within Australia a study was conducted on the health costs of air pollution with regards to the Greater Sydney Metropolitan Area [8]. Total health costs were estimated to be between $1 billion and $8.4billion per annum. Indicators that were assessed included 'Cost of Illness' and 'Willingness To Pay' which was direct costs generated by illness (i.e. hospital emission, medicine costs etc.) in parallel comparison with willingness to pay to avoid illness.

2.1.2.3 Impacts on the Environment

Global Warming is an undeniable issue with the earth average temperature "increasing by about 0.8°C over the past 100 years, with about 0.6°C of this warming occurring over just the past three decades"[9]. This shows that the jump in human activity with regards to production and manufacturing has lead to excess amounts of waste and pollution being released, contributing to the greenhouse effect and in turn accelerating the global warming process.

2.1.3 Trends past, present and future

Statistics have showed that the world population of motor vehicles has topped 1 billion, this is a staggering figure especially when you take into account that the human population has just hit 7 billion, therefore the ratio of cars to humans is 1:7. Although the production of cars within the world has slowed in recent years, figures show that the miles driven in automotive vehicles has more that quadrupled since the 1950's. In the UK 1 in 7 children are affected by varying degrees of asthma and between the period 1980 and 2000 asthma sufferers doubled. If

we look closely at the Figure 2.2 we can see that within the same period motor vehicle use increased from around 150 billion miles/year to almost 300 billion miles/year. This shows a correlation between an increase in asthma and motor vehicle activity.

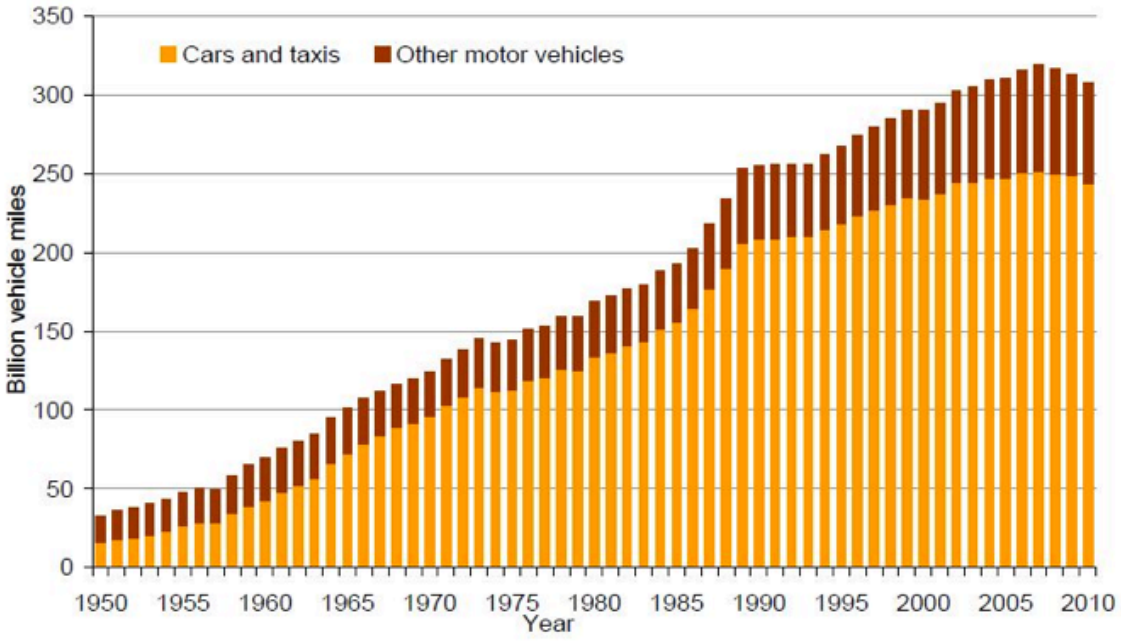


Figure 2.2 Increases in Motor Vehicle

Sydney car ownership:

Another interesting trend is the increase in the number of car ownership within Sydney [figure2.3], from the Australian Bureau of Statistics, the data from the Census of Population and Housing between 2001 and 2006 showed 4,487 jump in households owning at least one vehicle and 1,587 jump in households owning at least two vehicles while only +118 households have a had the luxury to own three vehicles.

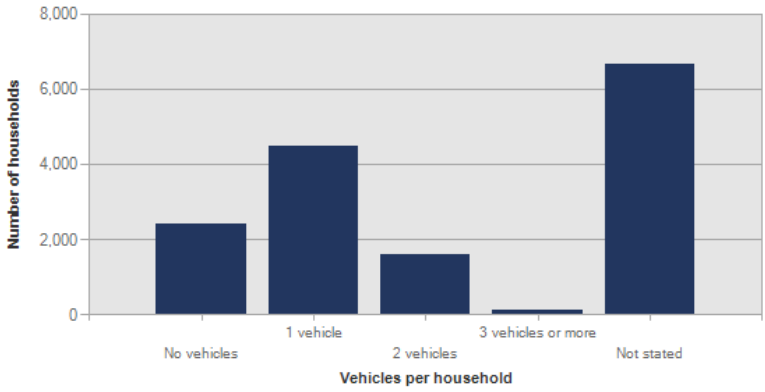


Figure 2.3 Sydney Household Car Ownership [10]

2.2 Monitoring Air Pollution

Within Australia there are currently only 14 active air-monitoring sites within Sydney [Figure 2.4] and an additional 9 decommissioned sites [11]. However the distance between each site does not give a sufficient overview of spikes in certain toxic gases may affect residents and that should be monitored. One example is that air quality has become a serious concern in the suburb of Turrella near the M5 tunnel.

Figure 2.4 Air Monitoring Sites

2.2.1 Case Study: M5 Tunnel (Sydney)

Air Quality Monitoring and Investigation into Potential Health Impacts:

2.2.1.1 Background

The issue of air pollution does not appear to be a critical issue within Australia, especially when viewed on a global scale. Indicators demonstrate that countries such as India, China, Mexico and US have more devastating statistics associated with the air quality index as well as related health concerns affecting the general population and more importantly children living within these countries. However the M5 tunnel in Sydney, more specifically the M5 East Freeway that links Kingsgrove and Arncliffe is a 4km tunnel that has a lot of controversy regarding the air toxicity within the tunnel every since it's construction.

Objectives:

- Levels of air pollution-general overview
- Specific pollutants: Carbon Monoxide and Nitrogen Dioxide
- Correlation between the pollution and health issues/concerns
- Residents near the M5 motorway stack near Turrella

2.2.1.2 Study Method

The South Eastern Sydney Public Health Unit in conjunction with NSW Department of Health did a study on monitoring the Air Quality levels [12] within the M5 tunnel. The study was conducted between October 2002 and January 2003 and the physical report was released in July 2003, however the tunnel had only been operating for less than a year (opened in December 2001), therefore recent reporting and focus on the air quality within the tunnel have

be under more intense scrutiny. The tunnel currently has been opened for more than 10 years and the congestion, number of incidents and traffic levels that have surpassed the initially projected numbers have caused severe concern with the quality of air within the tunnel.

2.2.1.3 Previous Findings

The study method within the 2003 report took reading of the air within the cabin of a car as it travelled through the M5 tunnel. There were 3 main variations of the results presented:

1. The windows of the car up with the air condition off
2. The windows of the car up with the air condition on
3. The 3 windows of the car down

A number of different gases and pollutants were measured from CO, CO2, NO2, and particulate matter…etc. the two main pollutants of interest are the CO and NO2 gas.

2.2.1.4 Current Reports

Recently there has been a lack of testing done within the tunnel, the only measurement that have been taken are near the exits of the M5. The road minister states that concentration levels are within acceptable limits however there have been fresh complaints within the media that the pollution levels surrounding the M5 tunnel have caused concern to residents in the community of Turrella and surrounding areas. These worries have been on going since the construction of the M5 motorway and the stack.

2.3 Relevant Designs

2.3.1 MAML

The Mobile Air Monitoring Laboratory (MAML) [13] seen in Figure 2.5 is an initiative developed by the government in British Colombia, Canada that is an efficient and cost-effective way of monitoring air pollution in areas that do not have fixed air-monitoring stations. The Laboratory is built on a Ford F550 chassis and is a self-contained mobile unit that can measure a wide range of toxic gases as well as particle matter (PM). The resulting data is then transferred in real time via a cellular Ethernet modem to the Ministry's of Environment's Database. This information is then posted

Figure 2.5 MAML

on the Mobile Air Quality Monitoring website for public access.

2.3.2 MAQUMON

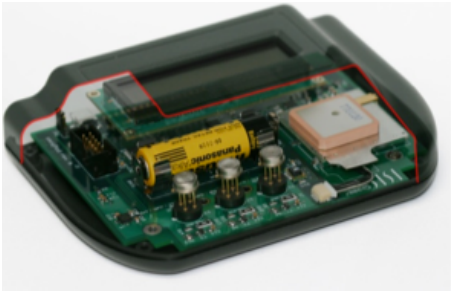


Figure 2.6 MAQUMON

The Mobile Air Quality Monitoring Network (MAQUMON) [14] on the left in Figure 2.6 is a system that is very close to what we hope to achieve. It is basically a device that contains sensor nodes that measure different pollutants in the air and data points are labeled with regards to location and time through the use of a GPS component. The measurements are then uploaded via a server and published on the 'SensorMap' portal.

2.3.3 Previous Prototype

The previous prototype [figure 2.7] developed by James Carrapetta used metal oxide sensors to monitor three main pollutants: carbon monoxide, nitrogen dioxide and ozone [15]. The aim was to be able to develop a simple to use wireless sensor board to accurately measure and monitor the level of air pollution within our environment. In addition a smart phone application was to be synced with the device so that readingscould be easily checked and accessed. Similarly to the MAQUMON the full range of data collected would be uploaded to a server site therefore users without the device could still check data readings via the main server.

Figure 2.7 Wireless sensor board

3 Project Objectives

With regards to this project the main objective is clear: To design a device that is able to measure the pollutant levels with more accuracy.

The hardware objectives are to:

- Select a better performance gas sensor component,
- Select compatible and datasheet specified components for the analogue circuitry that surrounds sensor.
- Ensure that the bias between the reference and sensing electrode is correct.
- Ensure that the gain within the current-voltage circuit is appropriate.
- Ensure that the analogue output of the analogue circuit is acceptable.

With the software, the objectives are:

- Using the same PIC software to code and install a program on the microcontroller.
- Ensuring that the microcontroller (which is essentially the A/D converter) reads the analogue input and gives an appropriate digital output.
- Selecting a Bluetooth that is compatible with the microcontroller as well as the connecting android phone and other indicators (LEDs).

Within Thesis A the focus was more on researching and understanding the background literature of the project and any technical concepts that were unfamiliar. It was also critical that an appropriate sensor (electrochemical) was chosen the sensors and an initial design of the analogue circuitry was determined.
Within Thesis B the focus was put directly into testing and calibrating the sensors. Firstly the experimental process needed to be set so that testing on each sensor remained consistent and repeatable. Then the method of analysis needed to be determined as to how to evaluate the data collected and whether it met our objectives.
It is critical that enough time and effort is spent building and testing the circuitry so that as the software (of the microcontroller) is later added there are no unresolved analogue issues. By implementing new hardware combined with new software we wish to produce a device that has better performance than the previous one.

4 Design Overview

4.1 System Design

With regards to this project the main objective is clear: To design a device that is able to measure the pollutant levels with more accuracy.

The hardware objectives are to:

- Select a better performance gas sensor component,
- Select compatible and datasheet specified components for the analogue circuitry that surrounds sensor.
- Ensure that the bias between the reference and sensing electrode is correct.
- Ensure that the gain within the current-voltage circuit is appropriate.
- Ensure that the analogue output of the analogue circuit is acceptable.

4.2 Sensors

There are many different types of gas sensors available commercially from metal oxide semiconductor to pellistor. The first prototype of the device used the metal oxide sensors, and the underlying initial objective for my thesis was to research on the different effects of a wide range of sensors and allowing for higher cost select a suitable sensor with higher accuracy.

The wide range of available sensors included:

1. Infrared Gas Sensor
2. Pellistor-Catalytic Gas Sensor
3. Electromagnetic Gas Sensor
4. Thermal Conductive Gas sensors

The Infrared sensor detection method is based upon the absorption of infrared radiation at specific wavelengths as it passes through a volume of gas. This method is based on the ability for certain gases to be able to absorb the IR radiation, which limits the range of gases it detects. It's advantages included ability fail-safe operations, ability to operate in absence of oxygen and immunity to contamination however the complexity of its calibrations for each particular gas and the added high costs made it suitable for our device.

The Pellistor-Catalytic sensor is based on the principle that combustible gases oxides and produces heat, within the sensor are platinum heating coils, which change in resistance when the temperature varies. This change in resistance is linearly proportional to the gas it detects. However the disadvantages for this method included easily susceptible to contamination, prologue use may affect performance and complexity of calibration.

The Electromagnetic Sensor detects via a chemical reaction within the sensor. Its advantages include its linearity, repeatability and it's long life span. It could detect a wide range of gases and had proven results theoretically, due to this and other distinguishable feature the electrochemical sensor was selected. The next section will provide a more detailed analysis of its characteristics and why it was selected.

4.3 Electrochemical Sensors

Electrochemical Sensor seen in Figure 4.1 has many distinguishing characteristics, from its use of low power to its ability to detect toxic gases in low concentrations. However it was the sensor's linearity, sensitivity and interference qualities that contributed to its better accuracy.

Figure 4.1 Electrochemical Sensors CO/NO2

The sensors linearity can be seen as it output current that is directly proportional to the concentration of gas it detects when it is operating under the acceptable range of the sensor. The CO sensor has a range 0-500ppm [16] and the NO2 0-20ppm [16]. The sensors has been selected especially we can detect the gases in lower concentrations.

The sensitivity of the sensor is sometimes seen as a negative characteristic, as it creates limitations on the selection of certain components however it is due to the sensitivity of the sensors that allows for more accurate readings. The sensitivity of the sensor is also affected my temperature and humidity, the temp must be kept at around 25C although the sensor is also able to internally compensate for slight changes. The humidity must also be operating between 15-90% RH [16] as we must ensure that the small amounts of chemicals with the sensors do not dry out.

The electrochemical sensor has a high interference ratio; this means that there is less risk of a specific sensor detecting an interfering gas, this is due to an in built membraic filter within the sensors. A choice was made early on during thesis B that the likelihood of being able to detect NO and SO2 were either in extremely low amounts and so calibrating for these gases would be extremely difficult. Therefore more focus and concentration were aimed at the CO and NO2 sensors. Below is a list of manufacturers that was assessed before a selection was made to choose e2V as our supplier.

Electrochemical Gas sensors									
Gas measured	Model	Company	Price	Range	Sensitivity	Humidity	Temperature range	Reponse Time	Physical Dimensions
Carbon Monoxide	EC4-500-CO	e2V	$46.36	0 - 500 ppm	55 - 85 nA/ppm CO	15 - 90% RH	-20 to +50 °C	<30 s	20(W) 16.6(D)
	EC4-2000-CO	e2V	$46.36	0 - 2000 ppm	18 - 38 nA/ppm CO	15 - 90% RH	-20 to +50 °C	<35 s	20(W) 16.6(D)
	ME2-CO	Zhengzhou Winsen Electronics Technology Co., Ltd	$7.90	0-2000ppm	15±5nA/ppm	15%-90% RH	-20 to +50 °C	<50secs	20(W) 16(D)
	ME3-CO	Zhengzhou Winsen Electronics Technology Co., Ltd	$28.00	0-500ppm	0 . 0 8 ±0 . 0 2	<=95% RH	-20 to +50 °C	<30 s	
Nitrogen Dioxide	EC4-20-NO2	e2V	$96.50	0-20ppm	450 - 750 nA/ppm NO2	15 - 90% RH	-20 to +50 °C	<35 s	20(W) 16.6(D)
	ME3-NO2	Zhengzhou Winsen Electronics Technology Co., Ltd	$62	0-20ppm	600±150nA/ppm	<=95% RH	-20 to +50 °C	<25 s	20(W) 16(D)

Table 4.1 Various Electrochemical Gas Sensors

4.4 Analogue Circuitry

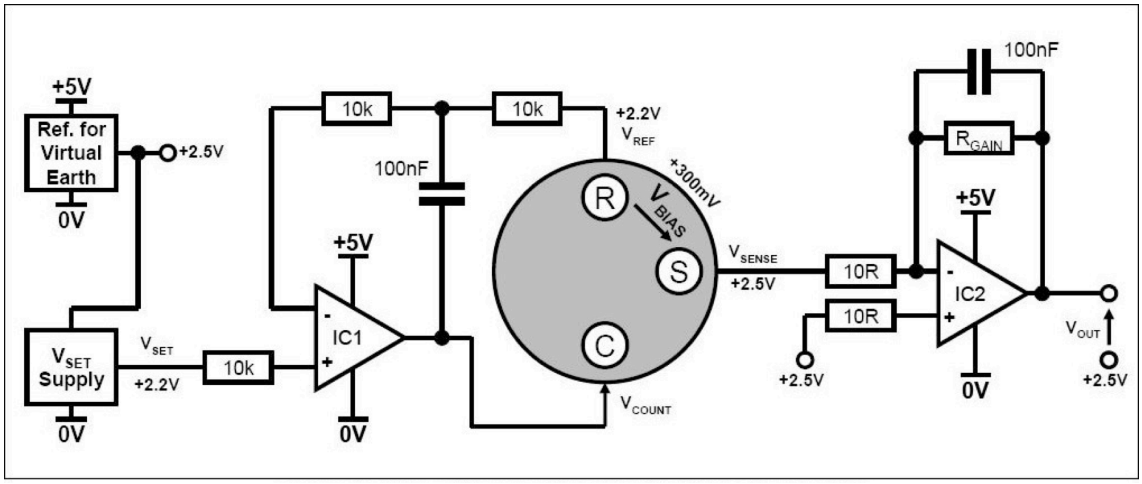


Figure 4.2 Analogue Circuitry [17]

The design of the circuitry [Figure 4.2] surrounding the sensors is the most crucial aspects, selecting the most appropriate components as well as the layout of the circuit must be done before any testing is attempted. With regards to the analogue section of the circuit it was important to understand that the sensors were very specific about the amount of current and voltage that could be applied as well as the bias between the reference pin and sensing pin must be maintained at 300mV. The company e2V provided an application note [17] with regards to corresponding circuitry surrounding the sensor and it was decided that the circuitry

provided within the application notes would be used as a model to achieve the most accurate measurements and readings.

The analogue circuit design consists of 2 main circuits: the potentiostat circuit and the transimpedance amplifier circuit.

The purpose of the potentiostat circuit is to control the bias between the reference electrode and the sensing electrode. This was critical because if the bias was incorrect it could damage sensor, this was due to the sensitivity of the electrochemical sensor. The capacitor is used to vary the voltage at the counter electrode, depending on the concentration of gas being detected the voltage at Vcount would adjust accordingly so that the Vbias would remain acceptable.

The purpose of the transimpedance amplifier is to convert small currents into voltage by a factor of Rgain. The sensor works by outputting a current proportional to the concentration of gas it is detecting. The voltage level can vary depending on the factor of Rgain that is selected; the capacitor is also used to result in a smoother voltage output.

The two voltage regulators that were selected were the LP2951ACN-3.3 and the LP2951ACN-5, these two components were essential in maintaining a stable voltage of 5V for the analogue circuitry and 3.3V to drive the Bluetooth. Testing before the implementation of the 3.3V voltage was intermittent as it was difficult maintaining a 3.3V therefore the laptop had difficulty detecting whether the Bluetooth was operational or not.

4.5 Digital Circuitry

Although not as heavily involved with the software aspects of the project, it was essential that I understood the selection of the microcontroller and Bluetooth components and how to monitor and use them so that I would be able to continue the second stage of testing and compare the circuit readings with the commercial meter (MicroAlertGas5).

The microcontroller used was a PIC16f690 [18] that is a 20-pin microcontroller, it has 12 available channels with a resolution of up to 10 bits for testing purposes the Matlab code used only 8 bit however it is to my understanding that all 10 bits of the A/D can be used to improve resolution. More focus will need to be emphasized on the coding with regards to the

microcontroller as multiple units are added during testing instead of just using the one device setup.

The Bluetooth module used within our circuit was the same as the one within the previous prototype. As the previous units were currently not being actively used for testing it was cost effective and productive to incorporate this model into our digital design. The most important factor to note is the allowed voltage of the Bluetooth must be within 2.85V and 3.6V, any lower than 2.85V and the Bluetooth will fail to connect to the laptop however any higher than 3.6V and the Bluetooth component will burn. Therefore 3.3V is the recommended nominal supply voltage as specified within its datasheet [19].

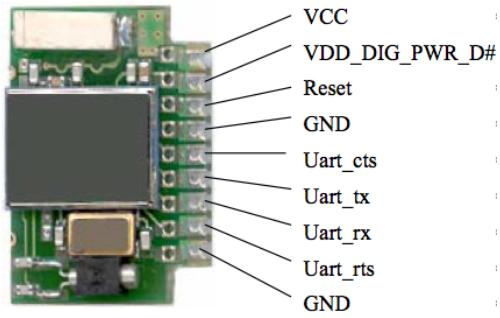


Figure 4.3 Bluetooth Module

The reasons for selecting Bluetooth connectivity:

1. Largely due to the fact that the device is wireless, Bluetooth allows the ease and accessibility of a portable device while still able to deliver reliable data.
2. The standard for Bluetooth will allow compatible or synced devices to share data which is appropriate as we wish to extend this in addition to a mobile phone application.
3. The connectively of Bluetooth is automatic which implies that the user is able to just have devices within a range of 20 feet of each other and they will automatically communicate. However a passcode is an alternative setup option that offers users security.
4. Bluetooth devices generally have low interference and low power.
5. Update ability with respect to Bluetooth standards. If new versions of Bluetooth are in progress it is crucial that the standard for Bluetooth is compatible with older ones.

5 Experimental Setup

5.1 Carbon Monoxide (CO)

As previously mentioned carbon monoxide is a toxic odourless gas that should be handled with care. However to be able to calibrate and test the accuracy of the sensors an experimental processes was to setup using the exhaust of a car. Immediately after turning on the engine of the car carbon monoxide levels are at they're highest, therefore the output concentration measured exceed 500ppm at a rapid rate. After research and planning a realistic range of 0ppm to round 150ppm was selected in monitoring CO, as this device was not intended for monitoring industrial sites this range was sufficient for the objective and purpose of the device.

For measurements the car engine was switched on, by waiting 2-3 minutes it allowed the high concentrations of CO to dissipate into the air, the gas was then collected so that it would not exceed 200pm and did not overload the commercial meter or sensors. However if the car is left on for more than 30mins the commercial meter and sensor would infrequently have difficulty reading the CO value. A reliable method for transferring the gas into the chamber was done by securing a gasbag over the opening of the chamber using a metal nut, after the gas was transferred the opening was sealed tight to minimize any gas leak.

5.2 Nitrogen Dioxide (NO2)

Nitrogen Dioxide was a more difficult gas to obtain, as there is only a small quantity present in car exhaust. Testing showed that even the commercial meter could not determine a minimal concentration. One method of creating NO2 gas was a mixture of nitric acid (HNO3) and copper, unable to find small quantities from external sources (cleaning agents, chemist, gardening supplies etc.) the next avenue was approaching the School of Chemistry at the University.

Figure 5.1Nitric Acid

The first sample of HNO3 that was obtained was around 300mL of diluted 2 molar HNO3, testing proved that this sample was too diluted for a chemical reaction to occur and no measurable amount of gas that was released. Concentrated HNO3 is around 70% which equates to 15 molar, after obtaining a second sample of HNO3 [Figure 5.1] around 200mL at 15 molar, testing proved

to be successful as NO2 was a immediately result of a combination of nitric acid and small quantities of copper pieces.

5.3 Commercial Meter (MicroAlertGas5)

Using a commercial handheld gas detector device (MicroAlertGas5 – Figure 5.2) allowed experiments to be monitored so that experimental readings could be compared against a set of readings from an accurate and reliable source. The device contained a removable SD card where data reading were measured and stored every second. These reading were contained within a .csvlogfile and the data could be easily accessed so that I could import it into the excel workbook containing my experimental data readings and then plot both sets of data on the same timescale to compare the results. Three issue that I came across during testing and calibration with the commercial meter was:

Figure 5.2
MicroAlertGas5 Meter

1. Low Battery

   This was not a big issue as the device had a removable battery pack and came with a battery charger, the lifetime of the battery was also very lengthy as I only needed to charge it 3 times during the 4 months of testing and calibrating.

2. Out of Calibration

   This was an extremely difficult issue to deal with, as we could not do recalibrate the commercial device ourselves. The process was to send the device to a representative of the company and let them recalibrate the device before returning it to us. This was a lengthy process and would result in the fact that we would not have access to the device for up to 3 weeks. Therefore measurements taken within the last 2 weeks of the experimental periods were compared with a commercial meter that was slightly out of calibration.

3. Memory of SD card

   The SD card was a simple and very effective way of physically recording the data measurement taken by the device at one-second intervals. I was able to extract the data I needed from the .csvlogfile however towards the end of my testing the file became corrupted and this may have been due to the fact that there was no enough memory on

the card. However I was able to resolve this issue by removing the original log file and allow readings to start recording within a new .csv file.

Overall this device was a crucial factor in my experimental setup as it was necessary to be able to accurately determine the concentration level of the gas within the container as a base comparison for any further readings I was taking experimentally.

5.4 Multimeter

The multimeter was selected so that I could monitor the voltage between the output of the sensor and the voltage reference pin (set at 2.5V). Ideally the starting point would be 0V at 0ppm and the voltage would rise in correspondence with the amount of gas being pumped into the tank. Discrepancies must be noted, as the output voltage would fluctuate by about +/- 0.05V, which corresponds to an extra 2-3ppm offset error. However the longer the allowed stabilization time that more accurate the output voltage compared to the reference voltage.

5.5 Fan

The original fan within the setup was a 12V DC Ball Bearing Fan, the use of an internal fan setup within the system was essential so that as the toxic gas that was pumped into the container had an even distribution with regards to the level of concentration of the gas being measured. However the original fan used a lot of power and battery life was extremely poor.

Therefore at the beginning of this semester I was able to modify the fan setup [seen in Figure 5.3] by taking a commercially available handheld fan and attaching it to a solid base platform so that it could stand upright within the container and not tip over. The base platform was a solid wooden block and the handheld fan was attached to a narrow metal stand that held it upright. Behind the fan was 2 pieces of metal and they were attached so that there was enough weight holding the device upright. This setup allowed me to reduce the amount of batteries I used from 6xAA to 3xAAA. It also had a long battery life meaning as even greater reduction in the number of batteries being consumed.

Figure 5.3 Electric Fan

6 Analogue Experimental Method & Process

Figure 6.1 Analogue Experimental Setup

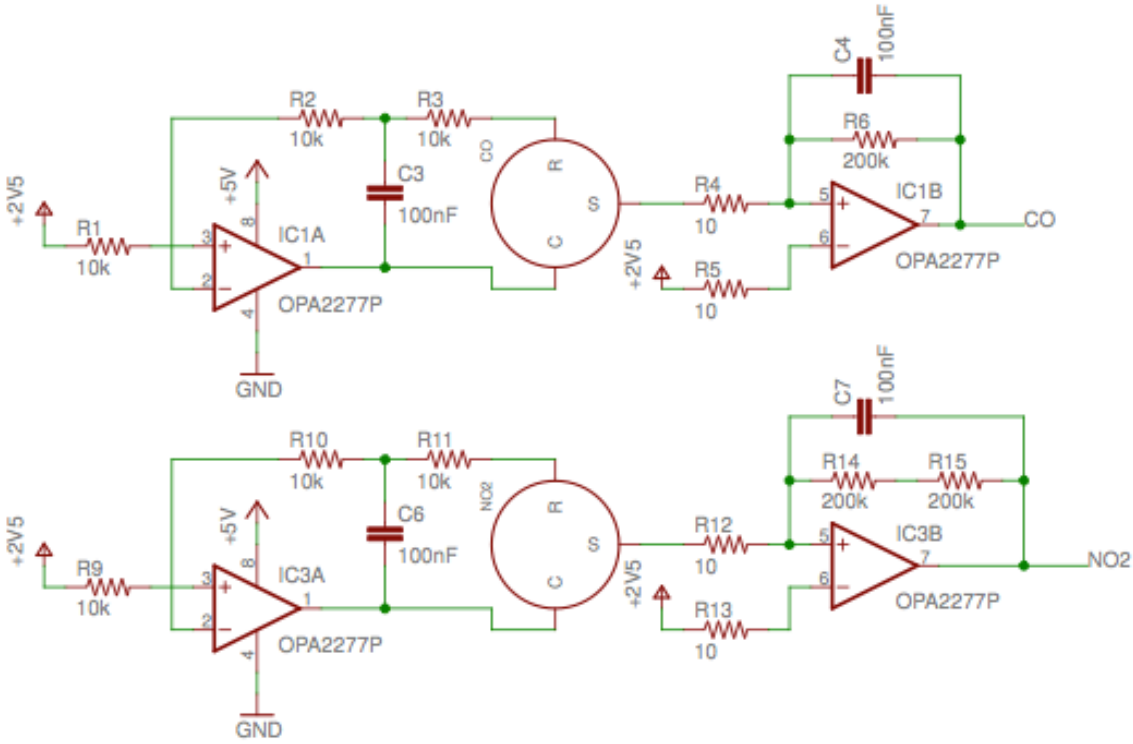


Figure 6.2 Analogue Schematic

6.1 Calibration of Carbon Monoxide (CO)

Description:

To be able to identify that the analogue circuitry for the Carbon Monoxide sensor works accurately and the sensitivity is close to the specifications provided within the datasheets, an experimentation was setup with the aim of comparing the accuracy of the e2V sensors with its theoretical specifications (i.e. it's linearity characteristics). Any adjustments or modifications with regards to the circuit provided by the e2V Electrochemical Sensors Application Note 2 [17] were made based on an adjusted range this included choosing an appropriate Rgain and multiple capacitors to reduce noise and stabilize the output from the sensors.

Procedure:

1. Equipment:
    - Sensor circuitry
    - Perspex container (air tight)
    - Multimeter – allows consistent monitoring of the voltage changes
    - Commercial gas sensor – Gas Alert
    - Fan Setup – allows a more even distribution of gases when being measured
    - CO gas:
        - Candle (optional 1)
        - Car Exhaust (optional 2)

2. Variable measured

The voltage between the output voltage and the reference voltage displayed when the concentration level of CO gas fluctuates between a high (150ppm) and low (20ppm) point

3. Process
    a. Connect the CO circuit as shown in Figure 6.2
    b. Starting from multimeter voltage reading, wait for circuit to stabilize (voltage will drop to approximately around 10mV that equates to 1-2ppm discrepancy, takes anywhere between 5-15mins)
    c. Allow the circuit to read values at zero gas concentration, as the circuit has a reference voltage of 2.5V this needs to be converted into the corresponding ppm and subtracted from within Matlab.

d. CO gas is transferred into the Perspex tank through the use of a plastic gasbag and to ensure that gas does not escape the septum cap is screw in place.
e. As the tank is largely airtight the gas concentration will stabilize within 5mins, to achieve a drop in ppm gas will need to be let out at periodically to be able to record a collection of value for calibration.
f. As the concentration moderately drops by around a controlled value of 10ppm we note down the corresponding voltage. A collection of more than 15-20 data values is sufficient for analysis
g. As the concentration of gas reaches close to zero confirm that voltage readings from the multimeter have fallen below 20mV.
h. Repeat step a-f to achieve multiple sets of data for calibration (all tests must be repeatable so that any discrepancies are noted)

6.2 Calibration of Nitrogen Dioxide (NO2)

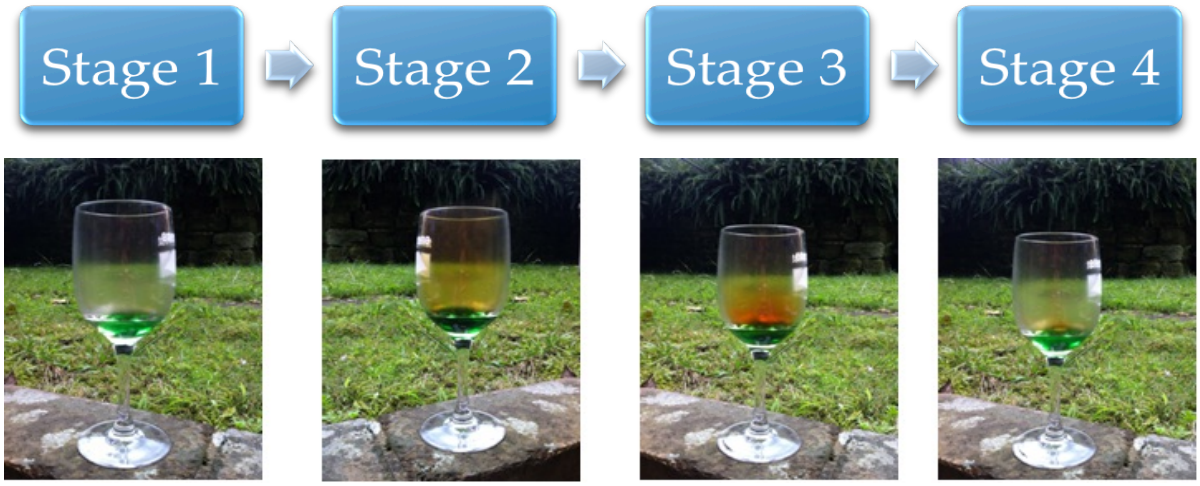


Figure 6.3 Production of Nitrogen Dioxide

Description:

To be able to identify that the analogue circuitry for the Nitrogen Dioxide sensor works accurately and the sensitivity is close to the specifications provided within the datasheets, an experimentation was setup with the aim of comparing the accuracy of the e2V sensors with its theoretical specifications (i.e. it's linearity characteristics). Any adjustments or modifications with regards to the circuit provided by the e2V Electrochemical Sensors Application Note 2 [17] were made based on an adjusted range this included choosing an appropriate Rgain and multiple capacitors to reduce noise and stabilize the output from the sensors. Due to the fact

that NO2 gas is hard to find in everyday applications it was necessary to find ways to produce the gas on our own, this meant that all safety guidelines needed to be followed.

Procedure:

1. Equipment

- NO2 gas sensor circuit
- Perspex container (air tight)
- Multimeter – allows consistent monitoring of the voltage changes
- Commercial gas sensor – Gas Alert
- Fan Setup – allows a more even distribution of gases when being measured
- 15 molar Nitric Acid
- Small Copper Strips/Wires

2. Variable measured

The voltage between the output voltage and the reference voltage displayed when the concentration level of NO2 gas fluctuates between a high (20ppm) and low (0.5ppm) point.

Producing NO2:

AIM: Using 15 molar nitric acid combined with a small amount of copper produces a chemical reaction that results in nitrogen dioxide that we are using for calibration testing of our circuit setup.

- The nitric acid turns greenish blue instantaneously after the reaction seen in Figure 6.3
- The copper dissolves within a couple of seconds as soon as it is placed in the acid.
- The nitrogen dioxide gas produced is a pungent brownish gas that can be stored in a glass flask if necessary.

3. Process
    a. Connect the NO2 circuit as shown in Figure 6.2
    b. From multimeter voltage reading, wait for circuit to stabilize (voltage will drop to approximately >5mV that equates to **ppm discrepancy, takes approximately 5-20mins)

c. Allow the circuit to read values at zero gas concentration, as the circuit has a reference voltage of 2.5V this needs to be converted into the corresponding ppm and subtracted from within matlab.
d. NO2 gas is transferred into the Perspex tank through the use of a plastic gasbag and to ensure that gas does not escape the septum cap is screw in place.
e. As the tank is largely airtight the gas concentration will stabilize within 5mins, to achieve a drop in ppm gas will need to be let out at periodically to be able to record a collection of value for calibration.
f. As the concentration moderately drops by around a controlled value of 0.5ppm we note down the corresponding voltage. A collection of more than 15-20 data values is sufficient for analysis
g. As the concentration of gas reaches close to zero confirm that voltage readings from the multimeter have risen to close to -5 to 5mV.
h. Repeat step a-f to achieve multiple sets of data for calibration (all tests must be repeatable so that any discrepancies are noted)

An important factor to note for the NO2 circuit is that the NO2 gas undergoes a reduction in the cell, which means electrons, flow into the sensing electrode and it results in a negative voltage from the circuit. Therefore the voltage reading decrease as concentration increases, so within the software to be able to achieve a baseline of 0V (approx. 0ppm) you would need to subtract the reference voltage of 2.5V from the output voltage and times the result by -1. This is to compensate for the fact that NO2 has a resulting negative voltage.

7 Digital Experimental Method & Process

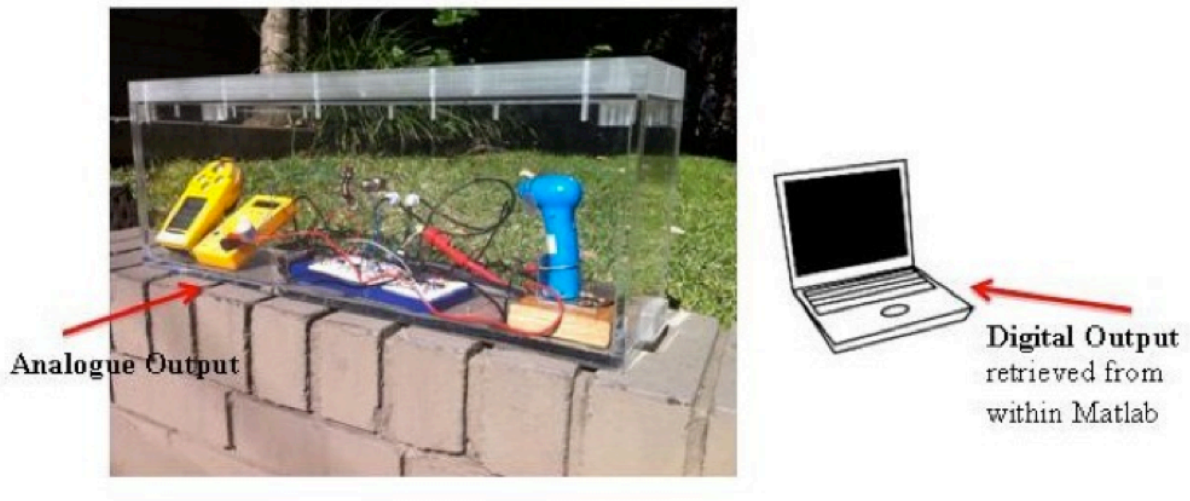


Figure 7.1 Digital Experimental Setup

To compare the calibrated sensor the digital circuit was connected with a laptop so that values from the commercial meter and the experimental circuitry could be read simultaneously and recorded automatically within Matlab.

The following setup demonstrates the method used in connecting the wireless circuit through the Bluetooth module.

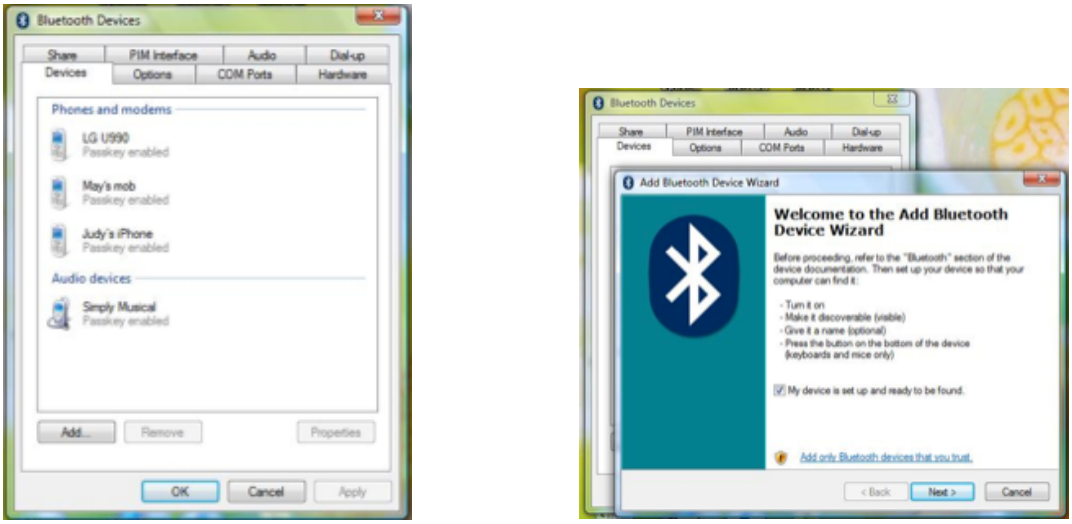


Figure 7.2 Screenshot of Bluetooth Setup 1

Step 1: Open the Bluetooth Devices on the control panel menu of your PC [refer to Figure 7.1]. Click “Add” once you have connected the digital circuit to a supply its voltage of 3.3V, as you enter the Bluetooth Device Wizard [Figure 7.2] check the ‘My device is set up and ready to be found’.

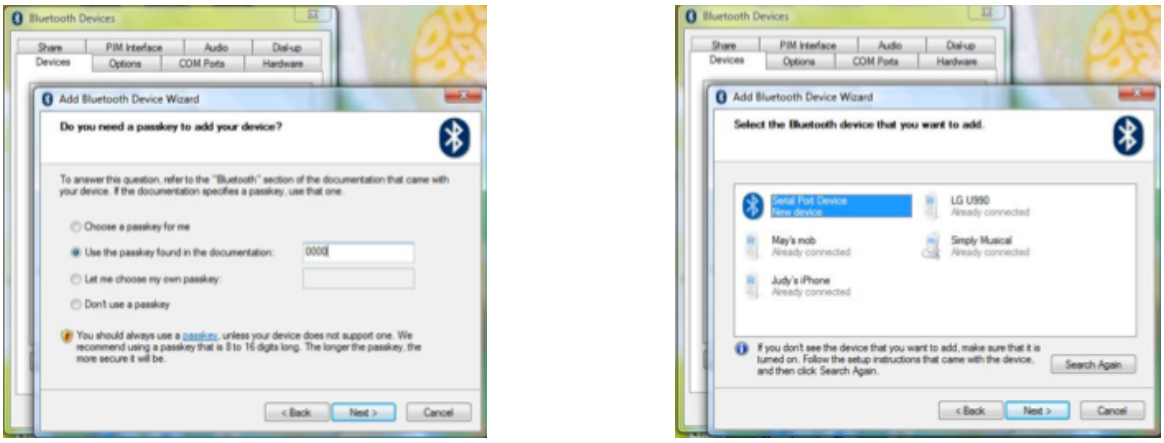


Figure 7.3 Screenshot of Bluetooth Setup 2

Step 2: If the device is undetectable, check that the power rails is supplying 3.3V any lower than 2.85V and the Bluetooth will not operate and any higher than 3.6V would be unsafe as the Bluetooth is likely to burn at voltages higher than datasheet specification. Once the device is found [Figure 7.3] it will be “Serial Port Device” click next and proceed to the enter the passkey found in the documentation (0000) [Figure 7.4]

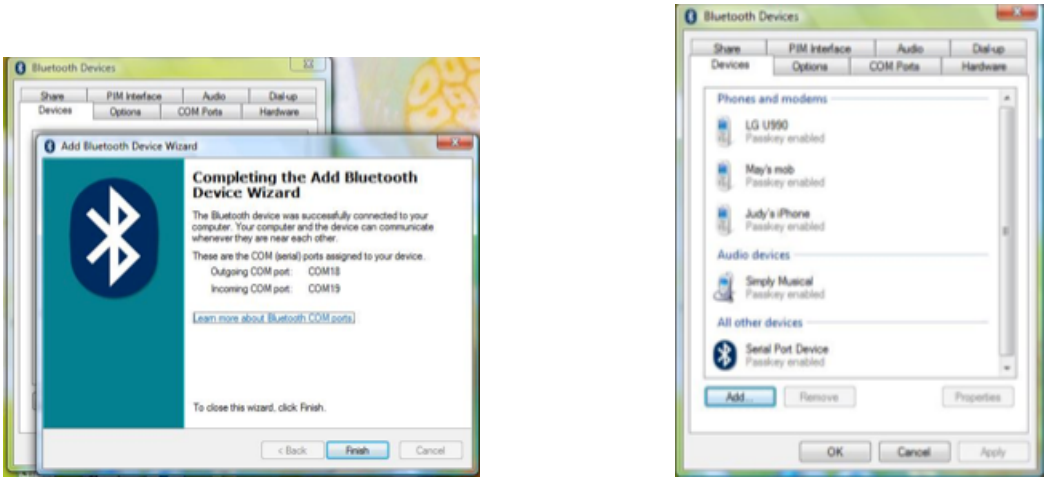


Figure 7.4 Screenshot of Bluetooth Setup 3

Step 3: If the installation of the device is successful a screen [Figure 7.5] will display the outgoing and incoming COM ports ensure that the Matlab code reflects the used ports listed here. Once it has been setup click finish and the screen [Figure 7.6] will show the Serial Port Device added to the Bluetooth Devices menu with the message Passkey enabled.

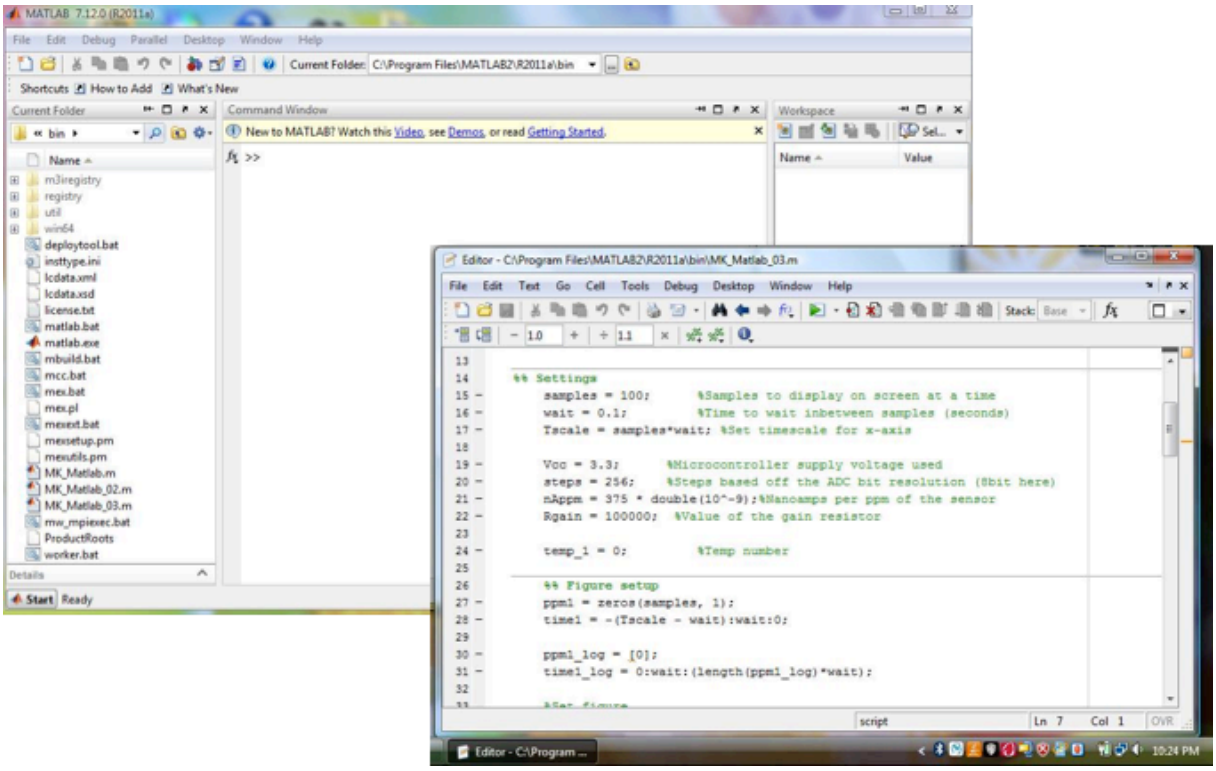


Figure 7.5 Screenshot of Bluetooth Setup 4

Step 4: Lastly Matlab is opened and the code [refer to Appendix] used for testing purposes is run from the editor display. Careful consideration must be given to the settings section within the code as the voltage used for the microcontroller was 3.3V this value can be adjusted to 5V to improve resolution and the sensitivity value is the calibrated value and that is adjusted depending on the sensor being tested. The resistor value Rgain has been selected to be 100Kohms to suit the range that we are measuring as it is unlikely for us to see CO to exceed 100ppm in the average atmosphere in surrounding Sydney suburbs.

Note: It was important to note the outgoing and incoming COM ports of the device, as it would vary between trials and testing.

8 Results

8.1 Raw Matlab Data

Figure 8.1 on the right shows a screenshot of the raw Matlab data from a CO sensor. We can see that the 0pmm concentration is in fact at around 360ppm there as the concentration rises to 480ppm we are only actually monitoring around 120ppm.

Figure 8.1 Raw Matlab Data CO

The following Figure 8.1 shows a screenshot of the raw Matlab data from a NO2 sensor. We can see that there were intermittent instances where the voltage would drop down to 0V or 8.9375mV in less than a second and then rise back up to the stable and accurate data range. This issue however needed to be further addressed within the Matlab, as slight modifications would be needed as a result of a negative voltage flowing from the NO2 sensor.

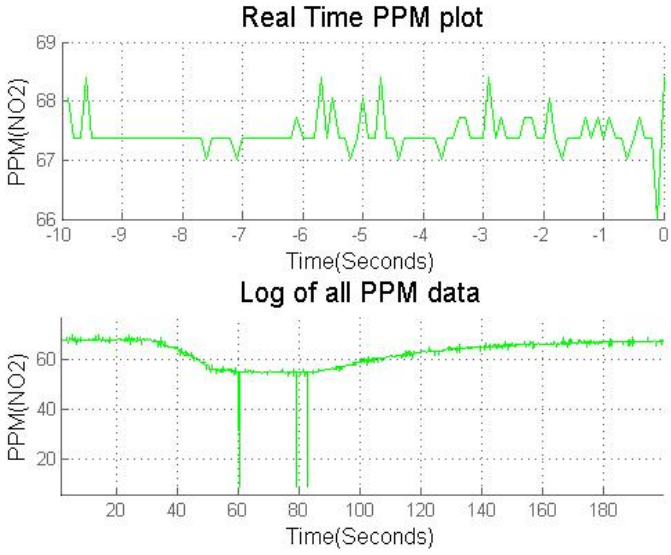


Figure 8.2 Raw Matlab Data NO2

8.2 Calibration Results CO & NO2

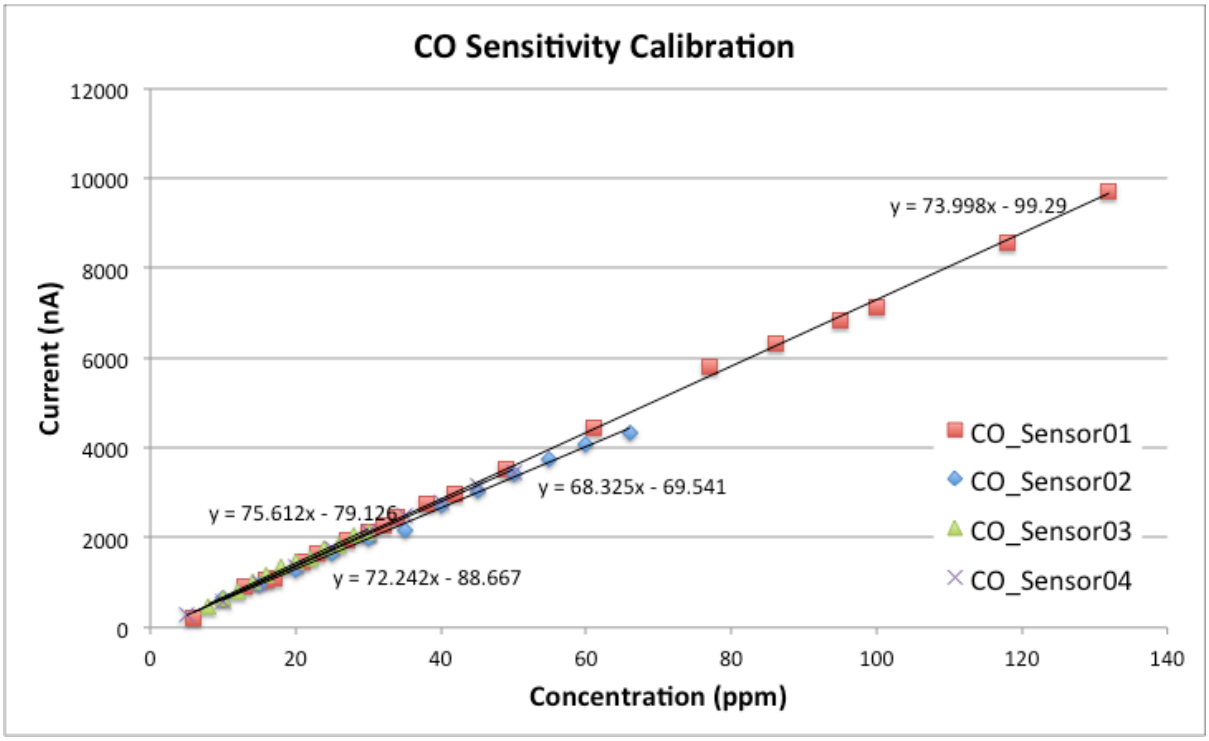


Figure 8.3 Calibration of CO Sensitivity

The sensitivity calibration was measured for each individual CO sensor [Figure 8.3] to monitor the slight variation with regards to the sensitivity factor. Multiple measurements were taken to ensure the overall linearity performance of the electrochemical sensors. Three trials were performed for each individual sensor (refer to Appendix 15.5 for detailed trial results) as there were minimal differences and a small offset error of 1-2ppm, therefore sensitivity with the lest amount of offset error was selected and tested as the final calibration value. Initially an average of the sensitivities was selected however that resulted in a greater offset.

The CO sensors displayed consistently stable and accurate results, within the specification outline in the datasheet. Stabilization time for sensors was usually less than 20minutes, however with the analogue aspect of the circuit on 100% of the time would negate any lag time.

Initially testing was performed without an even distribution of gas/air within the tank, as a result the recorded measurements would be inconsistent and prone to error. However after replacing the original fan setup and polishing the method of calibration (so that it was repeatable and consistent) by allowing a controlled amount of gas to be released from the tank until it was empty, multiple measurements could be noted and then plotted to achieve a sensitivity calibration.

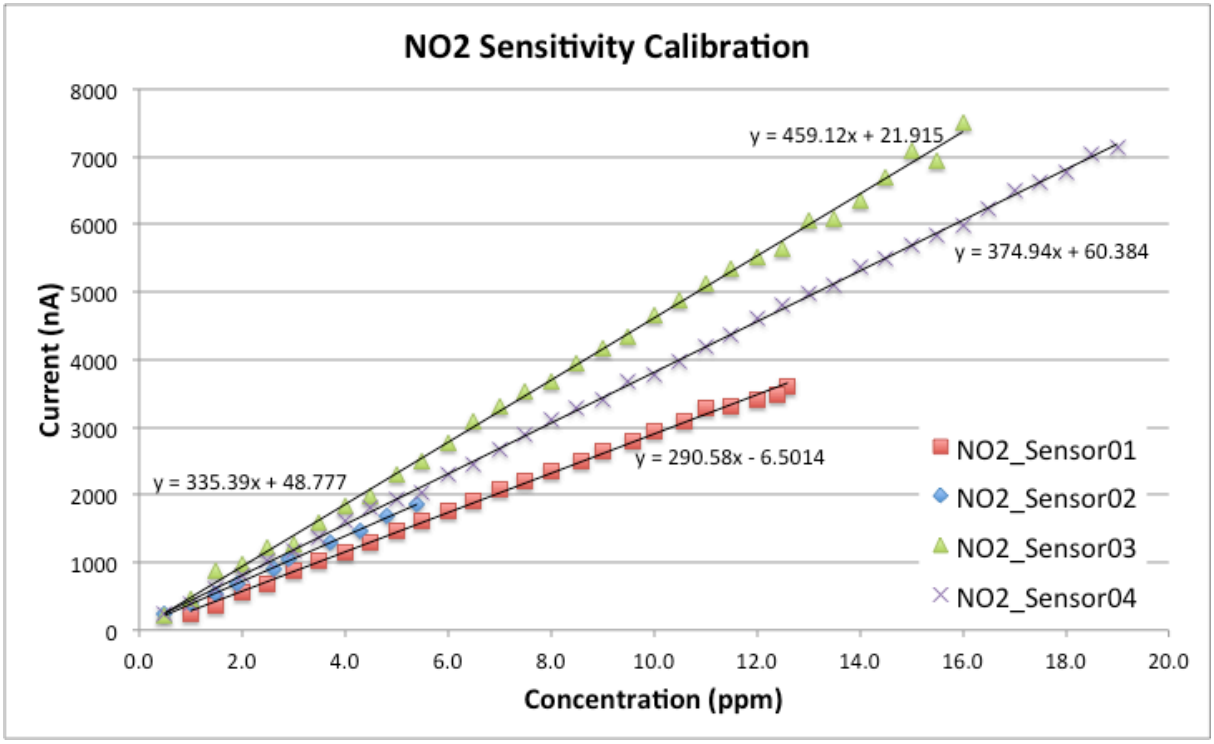


Figure 8.4 Calibration of NO2 Sensitivity

The sensitivity for NO sensors [Figure 8.4] was much lower than the specifications addressed within the datasheet. Testing showed that the response of each individual sensor was largely linear with minor offset errors of around 0.2ppm. Three trials were performed for each individual sensor (refer to Appendix 15.5 for detailed trial results) as there were minimal differences and a small offset error, therefore sensitivity with the lest amount of offset error was selected and tested as the final calibration value.

From the Figure 8.4 it can be seen that the NO2 sensitivity calibrations varies a bit more than the CO sensors (trend lines are a bit more spread out) this is due to the fact that NO2 is monitoring in much lower concentrations so each sensor is a lot more sensitivity when detecting the NO2 gas as commercial meter readings as well as our circuit will hope to display one-tenth of a ppm.

The NO2 sensors displayed slightly more erratic data readings, especially the sensors that had been brought 6-9 months earlier. However stabilization time for NO2 sensors was usually much faster than CO sensors as the voltage output was able to drop extremely close the reference voltage of 2.5V with only +/-3mV difference.

8.3 Calibration Equations

$$CO(ppm) = \frac{1}{Sco}\left(\frac{Vout-Vref}{Rgain} - A\right) \quad \text{Equations 8-1}$$

$$NO2(ppm) = \frac{1}{Sno2}\left(\frac{Vout-Vref}{Rgain} - B\right) \quad \text{Equation 8-2}$$

*Vref = 2.5V

*Rgain = 100Kohms

	Sensitivity (Sco)	Offset (A)		Sensitivity (Sno2)	Offset (B)
CO Sensor1	73.99	-99.29	NO2 Sensor1	290.58	-6.5014
CO Sensor2	68.33	-69.541	NO2 Sensor2	335.39	48.77
CO Sensor3	75.61	-79.126	NO2 Sensor3	459.12	21.915
CO Sensor4	72.24	-88.667	NO2 Sensor4	374.94	60.384

9 Analysis

To be able to determine the accuracy of calibration, analysis must be undertaken with regards to the Commercial Meter. The following graphs show the individual comparisons between CO sensors 1-4 and NO2 sensors 1-4. Each sensitivity value used below corresponds to the value stated in the Results section of the report. There is a large volume of data readings from the Matlab output so for the ease of analysis I grouped 60 data reading into one point which equates to a reading every 6 seconds however 60 is a large number set for one point so I decided to take three readings, a maximum, minimum and average to give a wide scope on the analysis. Since the commercial meter takes readings every second I would take every sixth reading to coincide with the experimental data readings. The graphs below plot 4 trend lines, the commercial meter (MicroAlertGas5), the maximum, minimum and average of the experimental circuit. As we will see the ideal goal is to have the average circuit trend match to the commercial meter however this is not always the case and therefore consideration must then be given as to whether maximum or minimum values best represent a more accurate reading from the circuit.

For CO Sensor 1 seen within Figure 9.1 you can see that our overall experimental trends follows extremely closely with the trend for the commercial device. However it lies between the CO_Sensor1_MAX and CO_Sensor1_AVG trend line, as long as the error does not exceed 5ppm a slight error of 2-3 ppm is acceptable at this point. The overall sensor was measured over period of 4 minutes.

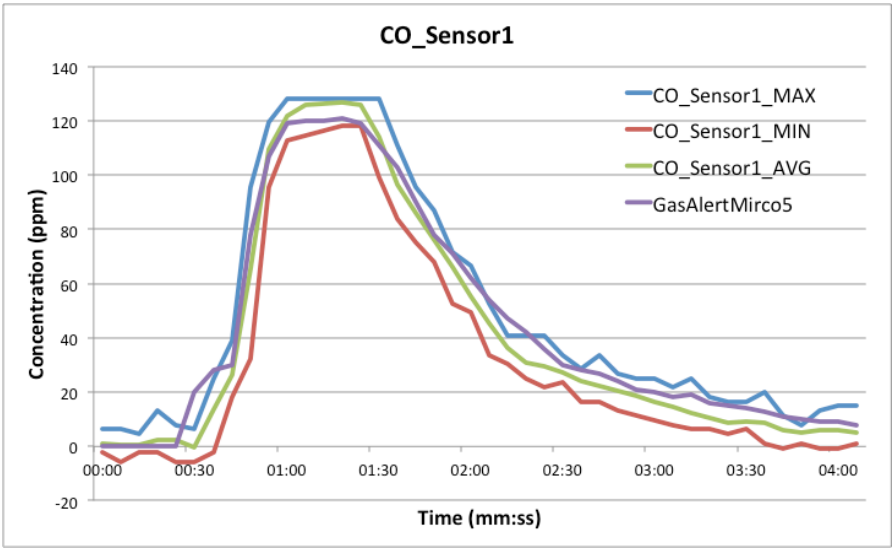


Figure 9.1 CO Sensor 1 (Sensitivity Factor: 73.99nA/ppm)

For CO Sensor 2 seen within Figure 9.2 you can see the CO_Sensor2_MAX trend line matches the commercial meter until around 21ppm when it shift to the CO_Sensor2_AVG trend line, a condition within the code could be stated that when the concentration reaches low values average experimental values can be taken instead of maximum values. However if CO_Sensor2_AVG readings are accepted there is a max. of 5ppm error which could be on the boarder line of inaccuracy.

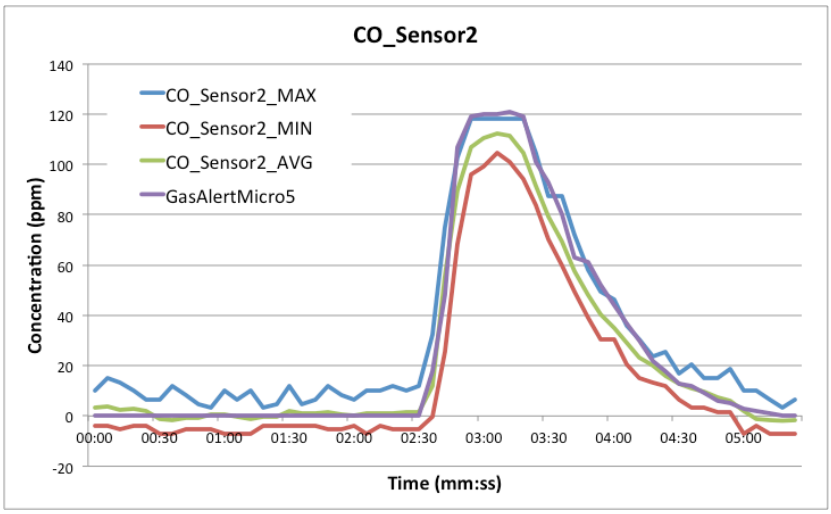


Figure 9.2 CO Sensor 2 (Sensitivity Factor: 68.33nA/ppm)

For CO Sensor 3 seen within Figure 9.3 it can be seen that as the concentration increases the experimental circuit has a slightly slower response rate, as the CO_Sensor3_AVG trend is slightly shifted towards the right. As the concentration of the gas is slowly released at a consistent rate it can be seen that the decreasing response of the CO_Sensor3_AVG matches the commercial meter.

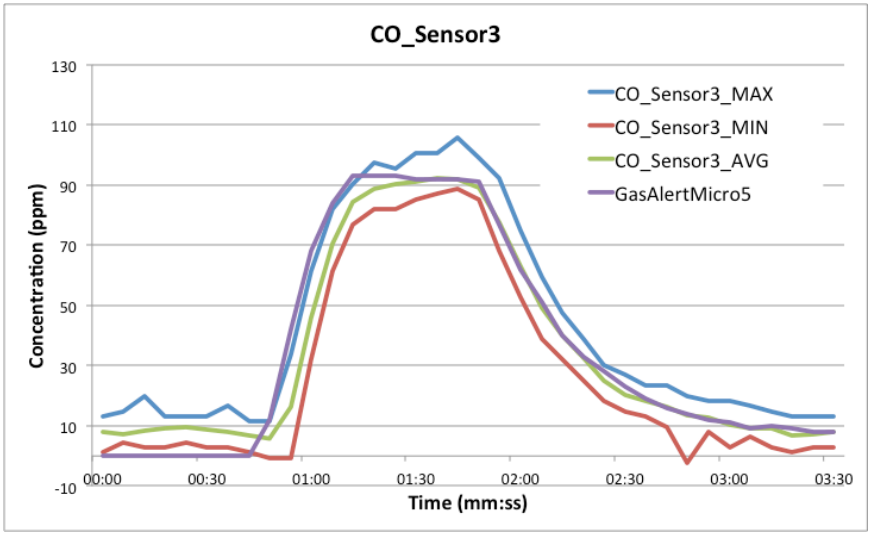


Figure 9.3 CO Sensor 3 (Sensitivity Factor: 75.61nA/ppm)

For CO Sensor 4 seen within Figure 9.4 it follows a similar pattern to that of CO Sensor2, the CO_Sensor4_MAX trend line matches the commercial meter until around 21ppm when it shift to the CO_Sensor4_AVG trend line. Similar a condition within the code could be stated like previously mentioned. However if CO_Sensor4_AVG readings are accepted then there is again likelihood of a max. of 5ppm error.

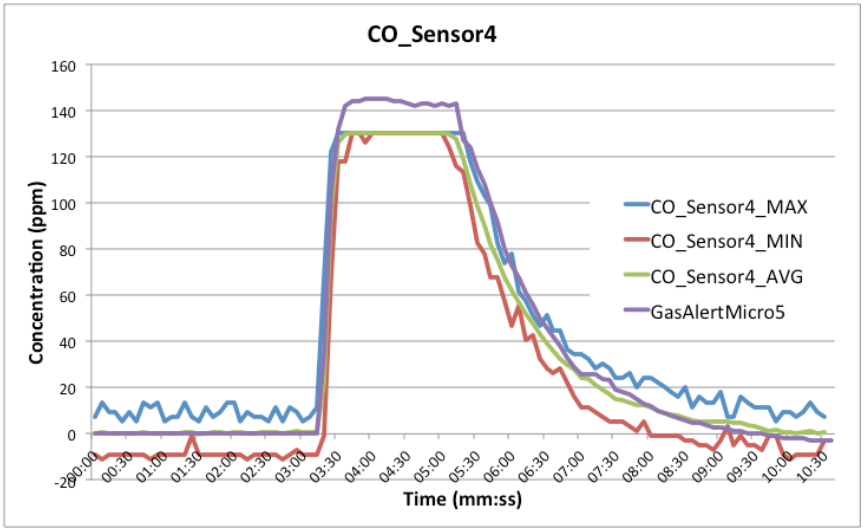


Figure 9.4 CO Sensor 4 (Sensitivity Factor: 72.24nA/ppm)

For NO2 Sensor 1 seen within Figure 9.5 you can see that our overall experimental trends still follows closely with the trend for the commercial device. However there is a slow response when a sudden decrease in initial nitrogen dioxide gas is being released. It is not until 16ppm does the NO2_Sensor1_AVG matches the commercial meter data points. The overall sensor was measured over period of 4 minutes.

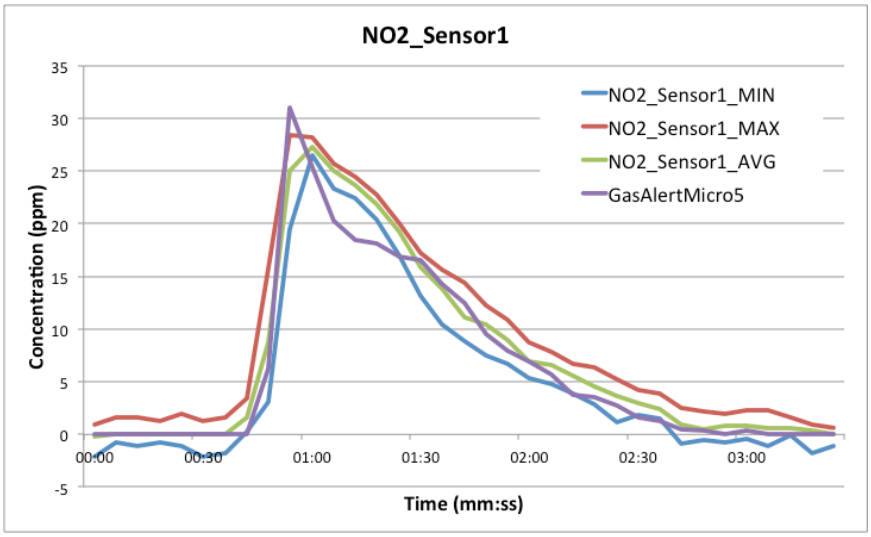


Figure 9.5 NO2 Sensor 1 (Sensitivity Factor: 290.58nA/ppm)

For NO2 Sensor 2 seen within Figure 9.6 there is a slight fluctuation between data readings you can see that our overall experimental trends hovers between NO2_Sensor2_AVG and NO2_Sensor2_MAX, one reason for the discrepancies could be due to the testing done on this sensor was within the latter part of the semester and the commercial meter is now slightly out of calibration. Although the error seems small at just 0.5-1.5ppm since NO2 is measure to 1 decimal point is crucial that these values continue to be monitored.

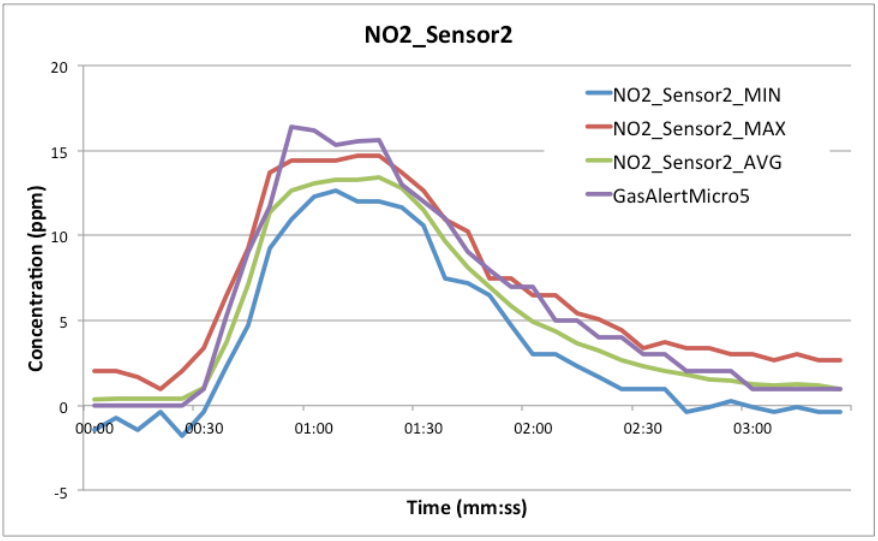


Figure 9.6 NO2 Sensor 2 (Sensitivity Factor: 335.39nA/ppm)

For NO2 Sensor 3 seen within Figure 9.7 there is a significant peak that is not recorded by our experimental readings however since the values measured by the sensor are only suppose to range between 0-20ppm we can concentrate on the reading <20ppm that were measured. The calibration seems to fit extremely well for NO Sensor 3 and the NO2_Sensor3_AVG trend can be taken quite comfortably.

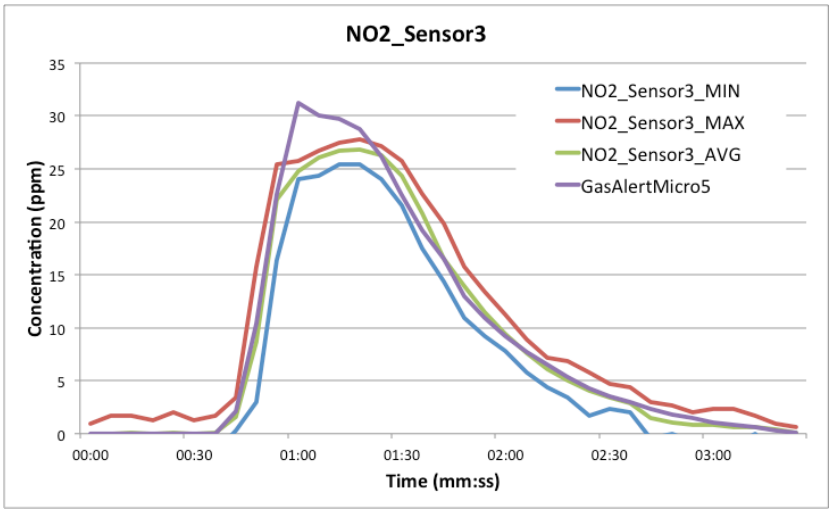


Figure 9.7 NO2 Sensor 3 (Sensitivity Factor: 459.12nA/ppm)

For NO2 Sensor 4 seen within Figure 9.8 there is a significant discrepancy at the high concentration of over 15ppm, another factor that must be taken into account is the pressure of airflow within the device. For NO2 Sensor 4 the day of testing was extremely windy and this may have affected the data readings, as the tank was open to release a certain amount of gas. Overall the experimental trend seems to correlate well with the commercial device that was available.

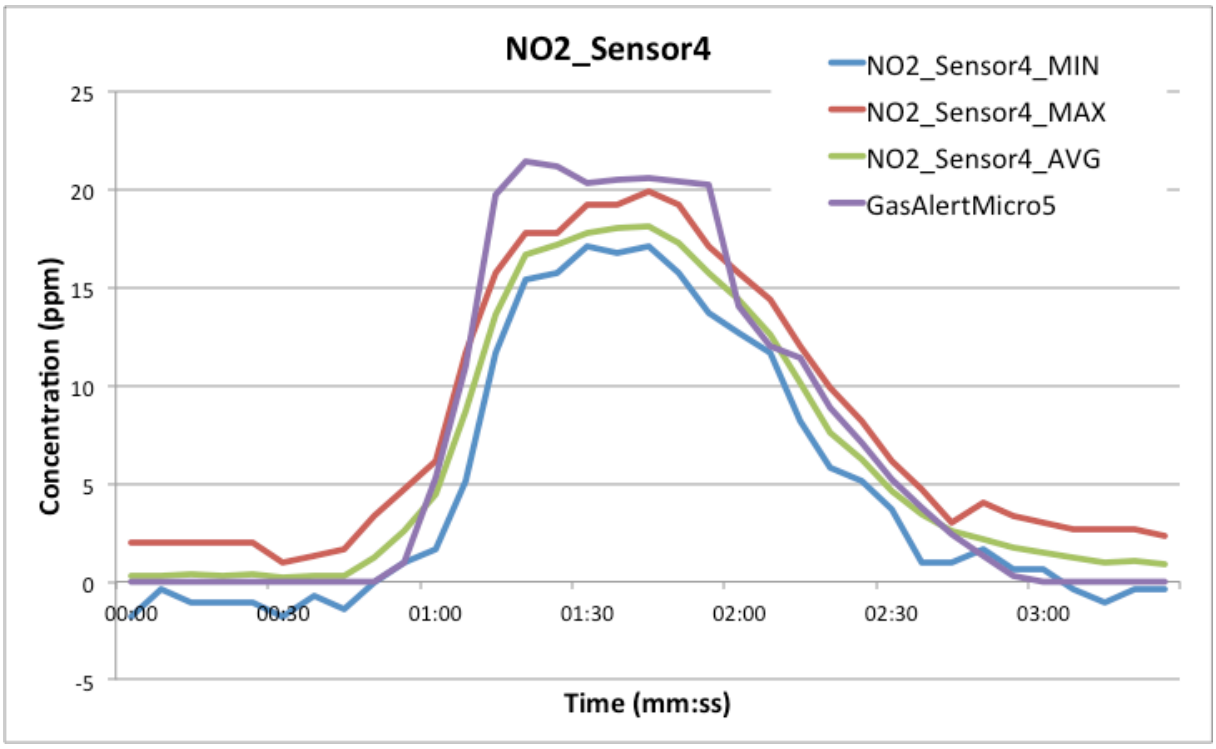


Figure 9.8 NO2 Sensor 4 (Sensitivity Factor: 374.94nA/ppm)

As seen in the analysis above the calibrations that have been used to compare the digital output perform quite closely with the commercial meter. However fluctuations within the monitored NO2 readings are due to the fact that the output voltage from the NO2 sensor is negative, therefore after extensive testing slight adjustments to the Matlab code still need to be made to improve the accuracy of readings. There were intermittent instances where the voltage would drop down to 0V or 8.9375mV in less than a second and then rise back up to the stable and accurate data range. These outliner points were excluded during the analysis and data reduction process however it is important to note that due to the negative output of voltage for the NO2 sensor modifications of the Matlab code needs to be addressed.

10 Printed Circuit Board (PCB)

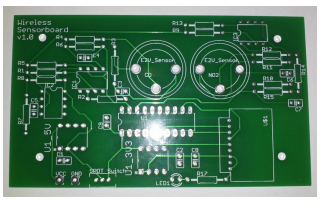
10.1 Bill of Materials

The bill of materials for each sensor board can be seen in the table below [Table 10.1]. The most expensive components within the device are the electrochemical sensors, as well as the Bluetooth module. Another key aspect of the device that must be carefully considered is the battery that will be utilized. The advantage of using an AA battery is that you can purchase slightly more expensive rechargeable batteries so you do not need to keep purchasing batteries in the long term. As the total cost of the device equates to $255.92, if more units were manufactured the prices for components would drop. The prices of the sensors may also reduce in the future as electrochemical sensors become more accessible and widely distributed.

Bill of Materials					
Component	**Model**	**Supplier**	**Price/Component**	**Amount Required**	**Price/Device**
Bluetooth	ADEUNIS - ARF7044A	Element14	$51.46	1	$51.46
CO Sensor	EC4-500-CO	e2V	$46.36	1	$46.36
NO2 Sensor	EC4-20-NO2	e2V	$96.50	1	$96.50
Socket terminal (sensor)	450-336-01-03-00	Wearnes Cambion	$0.75	6	$4.50
Microcontroller	PIC16f690	Microchip Technology Inc.	$3.00	1	$3.00
Voltage Regulator (3.3V)	LP2951ACN-3.3	NATIONAL SEMICONDUCTOR	$1.43	1	$1.43
Voltage Regulator (5V)	LP2951ACN	NATIONAL SEMICONDUCTOR	$1.88	1	$1.88
Capacitors	N/A	Element14	$0.03	9	$0.27
Resistors	N/A	Element14	$0.08	16	$1.28
JFET	J177	Element14	$0.35	1	$0.35
Operational Amplifiers	OPA4277	Texas Instruments	$3.60	1	$3.60
Operational Amplifiers	OPA277	Texas Instruments	$11.14	1	$11.14
LED	N/A	Element14	$0.25	1	$0.25
Rechargeable Batteries (AA)	N/A	Element14	$5.83	4	$23.30
Battery holder	N/A	Jaycar	$1.65	1	$1.65
Casing	N/A	Jaycar	$3.95	1	$3.95
Soft Outer Case (for mounting)	N/A		$5.00	1	$5.00
				Total	$255.92

Table 10.1 Bill of Material (Price correct May ‘11)

10.2 PCB



Having only taken one design course that required PCB design I was not confident in my ability to undertake this aspect of the project. Matthew Kelly designed the entire PCB using the simulation too Eagle CAD. It was decided that as much of the analysis that could be done would be done within the software aspect so to save space on the actual PCB. Comparisons with the previous prototype board we can see that the schematic used is far more complex and there are far more components. This then resulted in a slightly large overall device.

10.3 Power Requirement

As the circuit is separated into two sections, the analogue and digital consideration needs to be given to the different components that make up the overall sensor board. The main difference is the voltage required for the Bluetooth module is 3.3V (still able to operate from between 2.85V – 3.6V).

Component	Quantity	Supply Voltage	Supply Current	Total Supply Current
CO Sensor	1	5V	low (n/a)	low (n/a)
NO2 Sensor	1	5V	low (n/a)	low (n/a)
Operational Amp	5	5V	10mA	50mA
Microcontroller	1	5V	0.6mA	0.6mA
Bluetooth	1	3.3V	40mA	40mA
LED	1	3.3V	16mA	16mA

Table 10.2 Power Requirement

10.4 Casing and Mounting

The follow Figure 10.1 shows a basic prototype for the mounting of the device, a plastic black casing is purchased from Jaycar and a faux leather outer casing is used. Holes will be drilled onto the side of the plastic and leather casing to allow for air circulation and flow. This is a initial starting point for mounting as a more secure method need to be developed if passengers wish to roll down the windows. Suggestions have be made with regards to a metal clip to secure the leather holder in place.

Figure 10.1 Mounting of the wireless device

11 Recommendations

The first stages that include the initial layout of the board with regards to components as well as the new calibrating the sensors are now done. However there are still a couple of aspects that need further development so that progress reaching the final product can be achieved and actual on-road testing can begin. It is important to remember that as this device is still in prototyping stages testing and constant monitoring needs to be undertaken at every phase of the project.

Recommendations for essential tasks that need to be improved on or adjusted includes:

- Assembly of the PCB to ease testing in the next phase of the project
- Further developments in mounting the device
- Improving the software used to sync the circuit with Matlab
- Developing the software so that it can connect with multiple units
- Building on the foundation of previous project members in creating a smart phone application interface

The majority of the following tasks will be software based, as progress on the device continues we need to be able to have the supporting software to drive the wireless device. A key factor to note is the reference voltage of the electrochemical sensor is set at 2.5V, testing was done between the reference voltage and the output voltage so all measurement began at approximately 0V (+/- 10mV). Carefully consideration needs to be place within the software to compensate for the high baseline at which gas concentrations are measured.

As the version of the Matlab code is updated, the accuracy with regards to the number of bit used for improved resolution must be appropriately tested with the device. Currently 8bit of the 10bit microcontroller was used however the updated version of the code has already incorporated the full 10bits to improve overall resolution.

The sensors that were selected were the most appropriate and reliable, e2V is a well-known gas sensor manufacturer and it is important all restriction and guidelines are followed. However since the company that sells the sensors is based in North America, there is strong recommendation in finding a local supplier if multiple units are to be deployed. The likelihood of continuing to purchase these sensors from the current suppliers are unrealistic

since it’s recently come to light that the supplier are only suppose to sell this sensor within North America.

Lastly calibrations are extremely important, even though extensive testing has been undertaken within this thesis to ensure stability and accuracy the sensors are not foolproof, especially since the MircoAlertGas5 requires recalibration every 6-9months. Calibration should be checked with regards to the commercial device in 3-6 months if the sensitivity is still linear as we expect only slight adjustment are necessary. This is to ensure that the reading do not have a drastic increase in error.

12 Further Developments

Many countries are already taking initiative to wirelessly monitor air pollution, countries such as the USA and UK have already developed prototype device that can be attached to cars and bike to be driven around the city to monitor and measure various pollutant levels at different locations. This will be the next phase in monitoring air quality.

Other Uses Include:

- Commercial use in large production factory.
- Government incentives so that factories keep their pollutant levels in control.
- Domestic uses for sufferers of bad health such as respiratory infections.

We are now in the technology era where everyone has at least one mobile. To be able to incorporate this device and the simplicity of a mobile phone allows accessibility of data straightaway. In the next couple of years when we think of monitoring air pollution people will say “there’s an app for that”.

13 Conclusion

From a general review of the vast amount of background literature with regards to air pollution it is quite clear that the existing 14 stationary monitoring sites are insufficient to observe the fluctuations of varying concentrations of carbon monoxide and nitrogen dioxide. The high risks it poses on society not only within health but by placing a financial burden on our economy is just one of the reason why research and development of this project is so crucial.

For us to be able to sustainably monitor and measure air pollution, the key is in controlling and minimizing the amount we produce. The project I have undertaken looks at the benefits of developing a more mobile and accessible devices to monitor air quality. The fundamental objectives surrounding this project remains the same from designing a complementary circuit for the selected sensors as well as selecting appropriate and economical components so testing and development can continue.

From this report we can now better understand electrochemical sensors and the process in measuring its performance and accuracy through developing a calibration method. After extensive testing and monitoring it is clear that gas sensors selected have a good linear sensitivity. Although some adjustments have been made the overall performance of the sensors has improved accuracy and stability compared with the previous metal oxide sensors.

14 Bibliography

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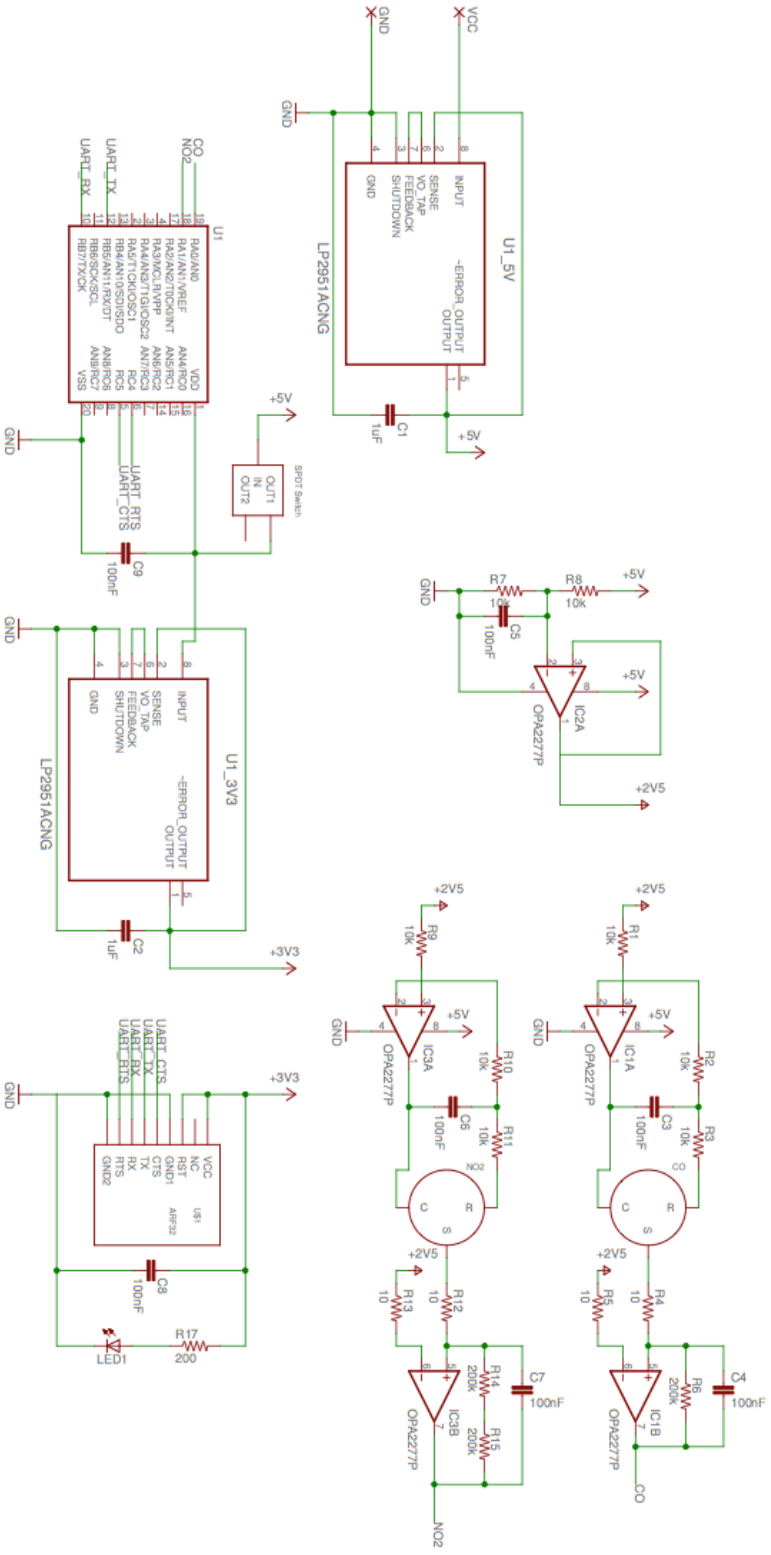
15 Appendices

15.1 Schematic



15.2 Affects of Carbon Monoxide

Affects of produced by carbon monoxide in relation to ambient concentration in parts per million:

Concentration	Symptoms
35ppm (0.0035%)	Headache and dizziness within six to eight hours of constant exposure
100ppm (0.01%)	Slight headache in two to three hours
200ppm (0.02%)	Slight headache within two to three hours; loss of judgment
400ppm (0.04%)	Frontal headache within one to two hours
800ppm (0.08%)	Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours
1600ppm (0.16%)	Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours
3200ppm (0.32%)	Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes
6400ppm (0.64%)	Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes.
12800ppm (1.28%)	Unconsciousness after 2-3 breathes. Death in less than three minutes.

Sources of Carbon Monoxide:

Concentration	Source
0.1ppm	Natural atmosphere level
0.5ppm-5ppm	Average level in homes
5ppm-15ppm	Near properly adjusted gas stoves in homes
100ppm-200ppm	Exhaust from automobiles in the Mexico City central area
5000ppm	Exhaust from a home wood fire
7000ppm	Undiluted warm car exhaust without a catalytic converter

15.3 Calibration of Individual sensors

Sensor 1 was tested first, the exposure range was a lot higher as the CO from car exhaust was initially difficult to control. The number of points recorded was also less than the other 3 sensors however a range of readings was consistently recorded to produce an appropriate sensitivity value. The offset error for Trial 1, 2& 3 was around 2-6ppm.

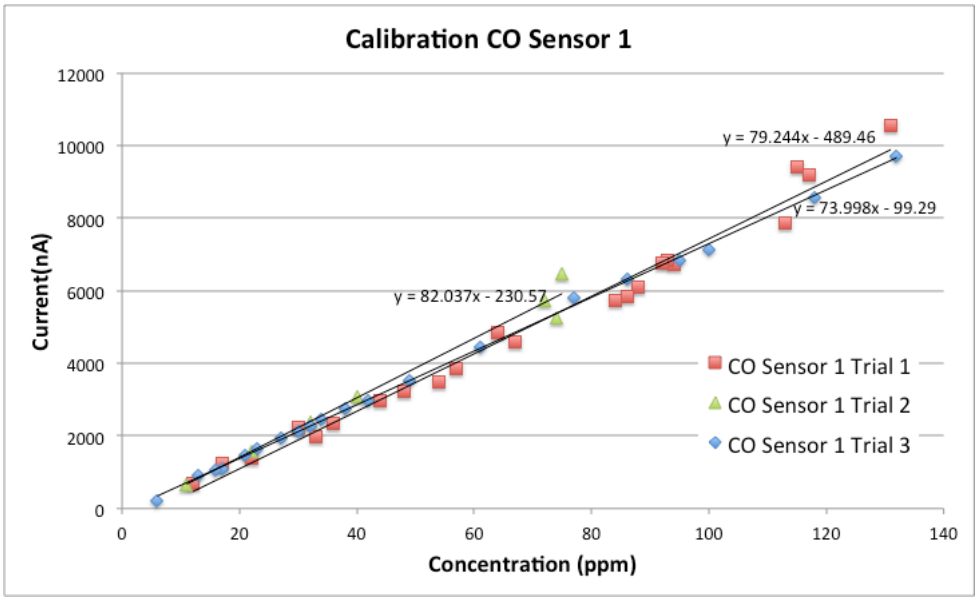


Figure 15.1 Calibration CO Sensor 1

Sensor 2 displayed a more consistent set of data readings, the concentration range measured had also been adjusted (under 200ppm) as the testing methods became more consistent the values recorded showed less discrepancies. Offset error (<2ppm).

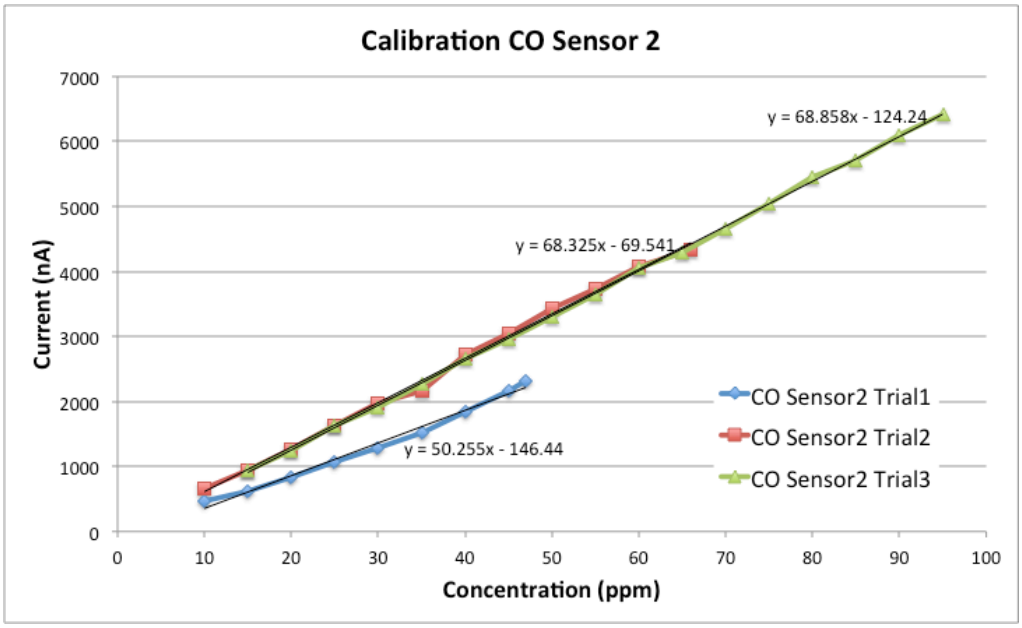


Figure 15.2 Calibration CO Sensor 2

Sensor 3 was measured specifically to test the sensitivity calibration for 3 specific ranges (>30ppm, >80ppm >190ppm). The offset error appeared to be larger as the concentration was measured over a larger this was due to a discrepancy between sensitivity values when there was a lower concentration of gas within the tank compared to a much higher concentration.

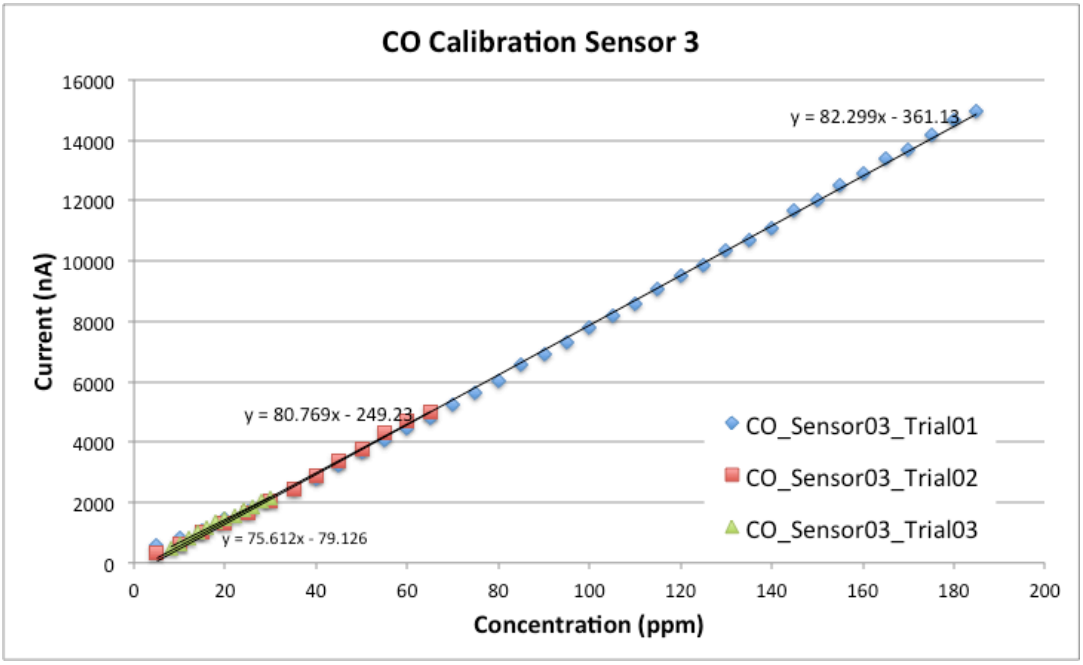


Figure 15.3 Calibration CO Sensor 3

Sensor 4 showed a fairly similar response to the other 3 sensors. One trial does show a higher offset error however this was due to values a rapid dispersion of gas, it was necessary during calibration to maintain a steady rate as gas was released from tank.

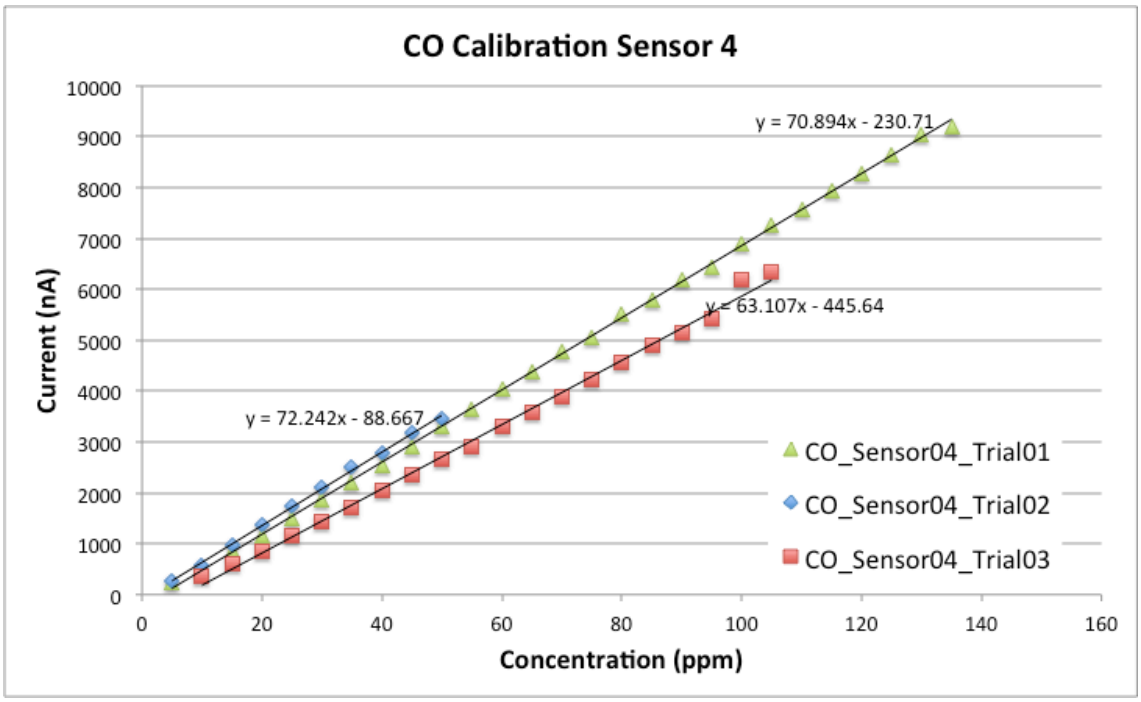


Figure 15.4 Calibration CO Sensor 4

Sensor 1 showed a strong linear realtionship with minimal offset error, however the overall sensitivity was the lowest of the four NO2 sensors. Testing against the commeical meter response seemed normal, although this experiment was completed quite early on almost immediately after I managed to obtain some nitric acid.

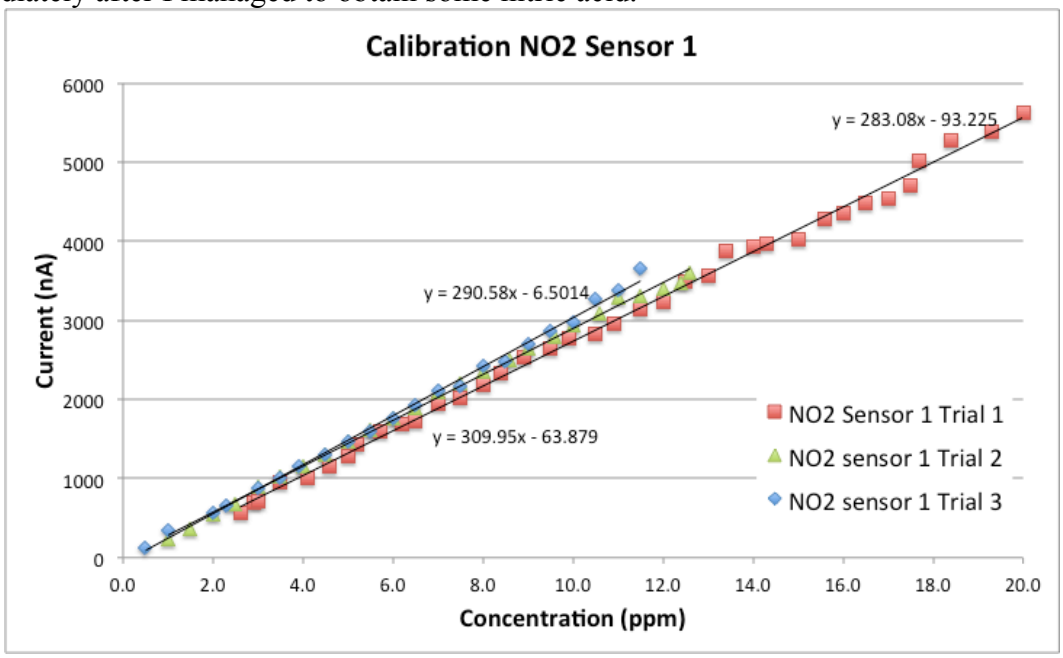


Figure 15.5 Calibration NO2 Sensor 1

The only issue with sensor 2 was the large offests with respect to trial 2 and trial 3, the calculated concentration offset would be around or less than 1ppm but if the NO2 sensors are to display data reading of up to one-tenth of a concentration this is something that should be noted.

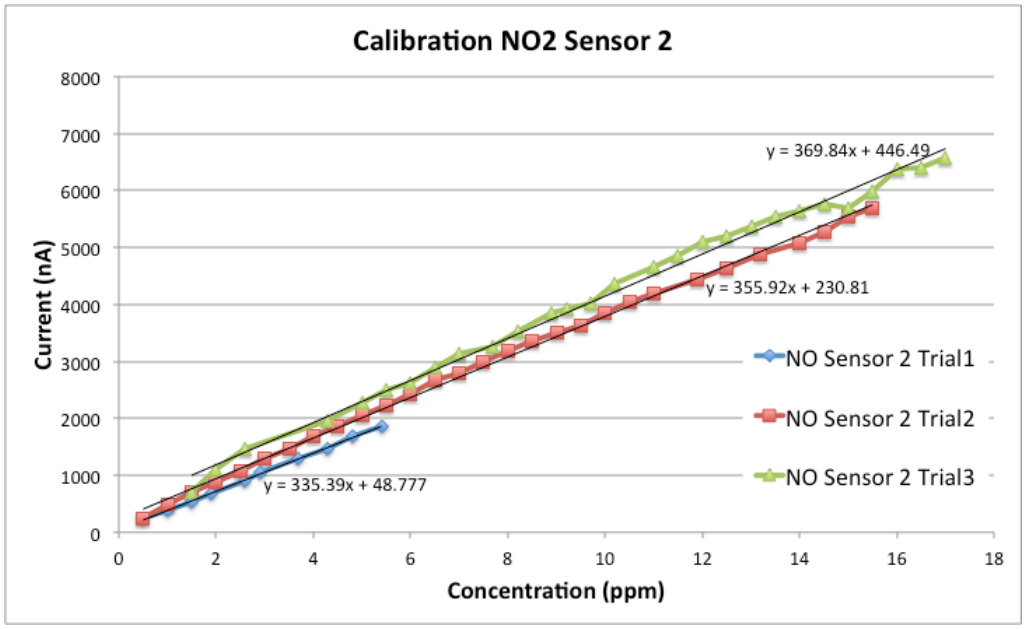


Figure 15.6 Calibration NO2 Sensor 2

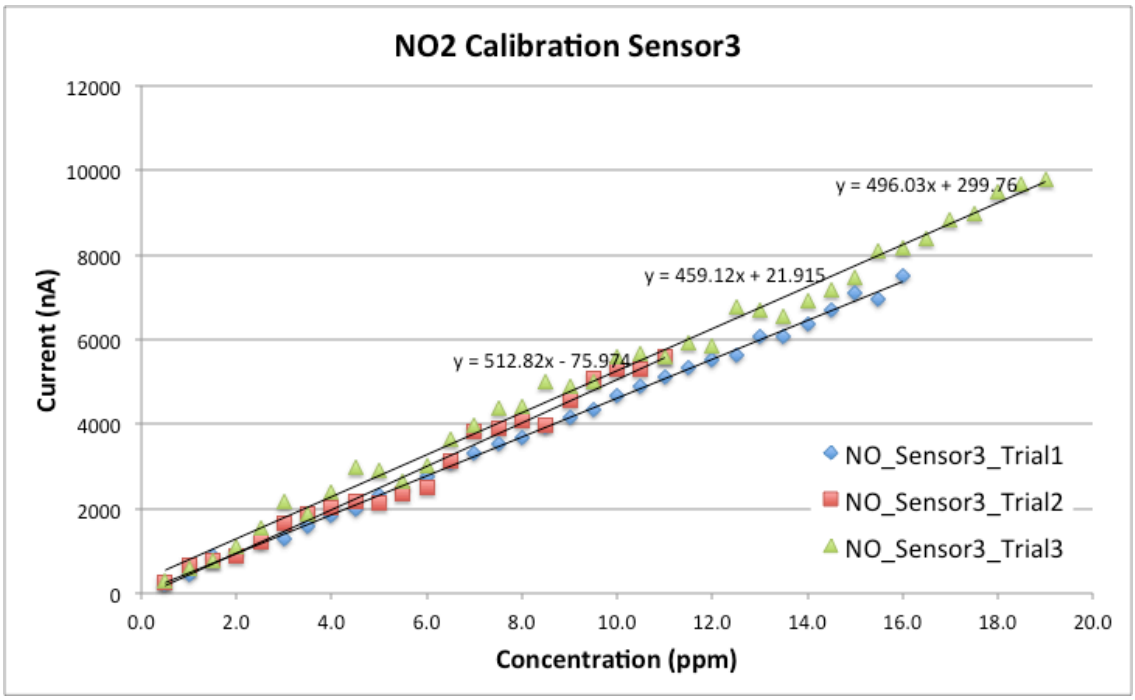


Figure 15.7 Calibration NO2 Sensor 3

Sensor 3 had fluctuating data readings due to a slightly irregular change in the weather (winds were a lot stronger on testing day) since weather and strong wind will always be a factor regarding the device I decided to incorporate into the data shown above.

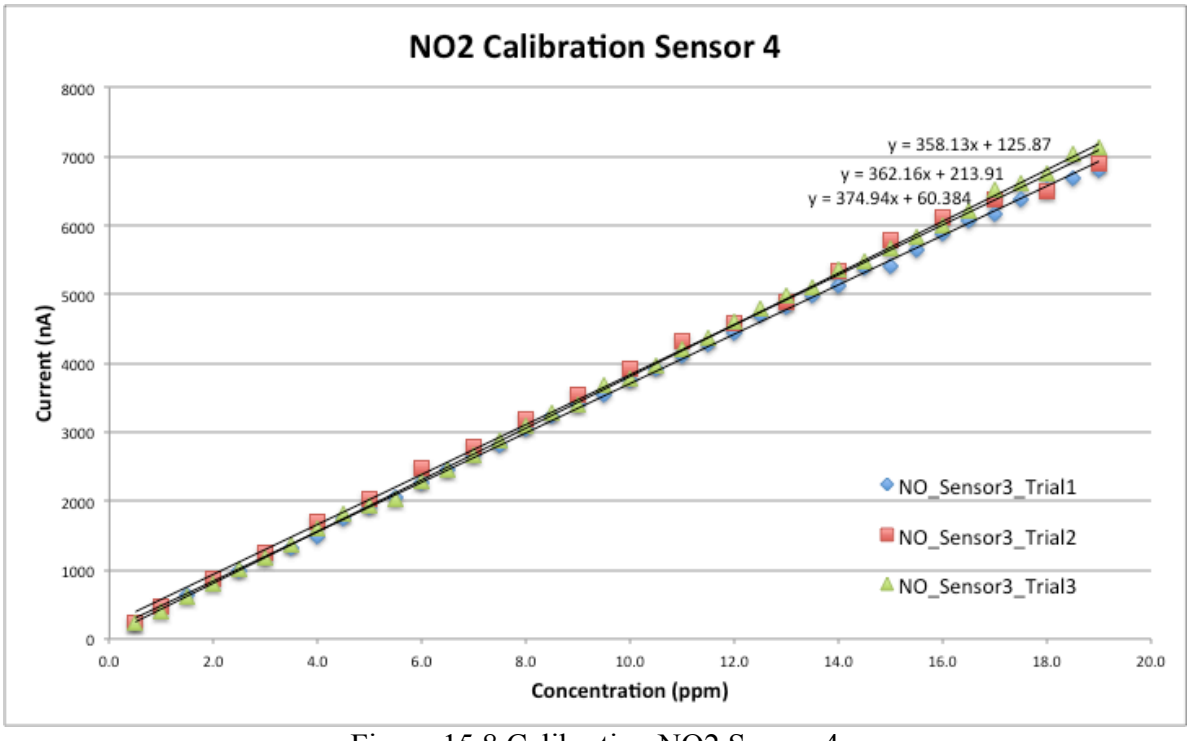


Figure 15.8 Calibration NO2 Sensor 4

Sensor 4 showed an extremely consistent set of data readings, even the error offset varies only slight from 0.2ppm to 0.3ppm.

15.4 Matlab Code

Acknowledgments made to team member Matthew Kelly for the following Matlab code using in testing:

```
%Data plot for Wireless BT Pollution sensorboard
%Displays Wireless and Cumilative plot
%4th year Thesis project
%Matthew Kelly UNSW z3251873
%Last updated 19/03/2012

%% Bluetooth serial initialisation
s = serial('COM18','BaudRate',9600);%Set to relevant COM port
fopen(s);
s.ReadAsyncMode = 'manual';     %MUST as BT output is async

%% Settings
    samples = 100;       %Samples to display on screen at a time
    wait = 0.1;          %Time to wait inbetween samples (seconds)
    Tscale = samples*wait; %Set timescale for x-axis

    Vcc = 3.3;       %Microcontroller supply voltage used
    steps = 256;     %Steps based off the ADC bit resolution (8bit here)
    nAppm = 375 * double(10^-9);%Nanoamps per ppm of the sensor
    Rgain = 100000;  %Value of the gain resistor

    temp_1 = 0;          %Temp number

    %% Figure setup
    ppm1 = zeros(samples, 1);
    time1 = -(Tscale - wait):wait:0;

    ppm1_log = [0];
    time1_log = 0:wait:(length(ppm1_log)*wait);

    %Set figure
    fig1 = figure('NumberTitle','off',...
        'Name','Sensorboard measurements');

    % Set axes
    axes1 = subplot(2,1,1);
    set(axes1, 'Parent',fig1,...
        'YGrid','on',...
        'YColor',[0.4 0.4 0.4],...
        'XGrid','on',...
        'XColor',[0.4 0.4 0.4]);
    title(axes1, 'Real Time PPM plot','FontSize',15);
    xlabel(axes1, 'Time(Seconds)','FontSize',12,'Color',[0 0 0]);
    ylabel(axes1, 'PPM(NO2)', 'FontSize',12,'Color',[0 0 0]);
    hold on;

    axes1_log = subplot(2,1,2);
        set(axes1_log, 'Parent',fig1,...
        'YGrid','on',...
        'YColor',[0.4 0.4 0.4],...
        'XGrid','on',...
        'XColor',[0.4 0.4 0.4]);
    title(axes1_log, 'Log of all PPM data','FontSize',15);
    xlabel(axes1_log, 'Time(Seconds)','FontSize',12,'Color',[0 0 0]);
```

```
    ylabel(axes1_log, 'PPM(NO2)', 'FontSize',12,'Color',[0 0 0]);
    hold on;

    %Setup Plot
    plot1 = plot(axes1,time1,ppm1,...
        'Marker','none',...
        'Color','green');

    plot1_log = plot(axes1_log,time1_log,ppm1_log,...
        'Marker','none',...
        'Color','green');

%% Main loop - Collecting & Displaying Data
count = 1;
while(1) %to break out press ctrl+c, or close figure window

   % x1 = rand(1)*200; %Generate random value for testing purposes (from 0
to 200)
   % ppm1(100, 1) = x1;
   % ppm1_log(count) = x1;

    %read in unicode data from BT module
    c1 = fscanf(s, '%c', 1);

    %Convert the BT data to a number
    if(isempty(c1) == 1) %Must check for null else unicode2native explodes
        temp_1 = 0;
    else
        temp_1 = unicode2native(c1); %Read value from BT module
    end

    %Scale data from binary level to PPM
    if(temp_1 ~= 0)
        temp_1 = (double(temp_1) * double((Vcc / steps)));
        %convert from level to voltage
        temp_1 = (temp_1 / (nAppm * Rgain));
        %convert from voltage to ppm
    end

    %Put data into the arrays
    ppm1(samples, 1) = temp_1;
    ppm1_log(count) = temp_1;

    %Plot realtime data
    set(plot1,'YData',ppm1);

    %Plot continuous data
    time1_log = 0:wait:((length(ppm1_log)-1)*wait);
    set(plot1_log, 'XData', time1_log);
    set(plot1_log, 'YData', ppm1_log);

    ppm1 = circshift(ppm1, [-1 0]);
    pause(wait);
    count = count + 1;
end

%% Finish and close ports
fclose(s);
delete(s)
```

```
clear;
clc;
```