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# A REVIEW ON AIR POLLUTANTS MEASUREMENT TECHNIQUES AND ITS FUTURE ADVANCEMENT

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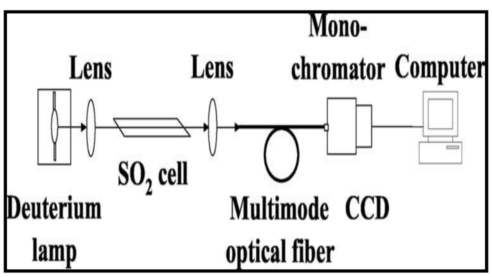
**Graphical abstract**




**Abstract**

Recently, the issues of air pollutants have become a major topic that is currently being debated among researchers and authority as it give negative impacts to the environment. This paper will discuss thoroughly on techniques that are currently being applied in monitoring air pollution. Techniques that are quite familiar in monitoring air pollution are such as the absorption spectroscopy technique, ozone monitoring instrument (OMI) and solid state gas sensor. Throughout this paper, the equipment used and the outcome from a number of methods will be reviewed. For future improvements, a new sensor for air monitoring will be proposed which is envisaged capable to detect ultrafine particles (UFPs) (i.e. with a diameter less than 100 nm).

*Keywords*: air pollutants, absorption spectroscopy, ozone monitoring instrument (OMI), solid state gas sensor, ultrafine particles (UFPs), air quality index (AQI)



## 1.0 INTRODUCTION

Rapid growth in industrial, automotive and mining sector especially in the developing countries such as Malaysia, Indonesia, Thailand, India and etc. will impose costs in terms of air pollution. For example, in Malaysia, reviews of air pollution is based on the reports of air quality monitoring at several main cities in Malaysia, which cover air pollutants such as carbon monoxide (CO), sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), ozone ($O_2$) and suspended particulate matter ($PM_x$). The results of the monitoring indicate that suspended particulate matter and nitrogen dioxide are the predominant pollutants. Other pollutants such sulphur dioxide and lead (Pb) are also observed in several big cities in Malaysia [1].

Air pollution also has become a major problem in Guangzhou which is located in South China. The main air pollutants in Guangzhou are sulphur dioxide, nitrogen dioxide and total suspended particulates (TSP). Nitrogen dioxide has become a principal pollutant due to rapid increase in vehicles after 1995 and an inadequate road system leading to frequent traffic jams. Extensive infrastructure and building projects which are the main sources of particulates have significantly raised TSP concentration [10]. United States that is classified as developed country also faced major air pollution problem. In United States, pollution removal such as ozone, particular matter that have a diameter less than 10 µm, sulphur dioxide, nitrogen dioxide and carbon dioxide varied among cities with total annual pollution removal are estimated at 711,000 metric tons and cost of USD3.8 billion in value [16]. It shows that, the higher the development of the country the higher the quantity of air pollutant released. Air pollutant is a worldwide problem and everybody needs to play their own role to reduce the air pollutant and make the world as a better place to live.

Air pollutants are ubiquitous and a certain level of exposure is inevitable, whether a person is indoors or outdoors [21]. Exposed to the air pollutant can cause oxidation stress and inflammation. Oxidative stress can trigger redox-sensitive pathways that lead to different biological processes such as inflammation and cell death [14]. Furthermore, exposed to air pollutant can cause chronic obstructive pulmonary disease (COPD) such as cardiovascular diseases, lung cancer, pneumonia and bronchitis symptoms. Different pollutants and sources may play different roles in the development and exacerbation of health effects [20].

This paper will explain in detail about air quality index, type of gases released and their particle that produced air pollutant and how it will affect citizen health. Three type of measurement air pollutant scale such as small, medium and big also will be discussed in this paper. Air pollutant measurement techniques such as the absorption spectroscopy, Ozone Monitoring Instrument (OMI), solid state gas sensor, Sensor Map, Mobile GPRS-Sensors Array and Gas-Mobile system using a smartphone will be deliberated in this paper. The equipment required in conducting the technique and the advantage of the technique will also be explained. To overcome the deficiency from the previous methods, future improvements will be proposed.

## 2.0 AIR POLLUTION INDEX

Air quality index (AQI) is an index for reporting daily air quality. It will tell the public on much the air is currently polluted and its effect to the human. Air quality index is also known as Air Pollutant index (API) or Pollutant Standards Index (PSI) [3].

Air quality index is varying from 0 to 500 as shown in Figure 1. The higher the AQI value will indicate higher air pollutant level [15]. This index is based on concentration of five pollutants such as particular matter, ozone, nitrogen dioxide, sulphur dioxide and carbon dioxide. The air quality index can be categorized, as a good, moderate, unhealthy, very unhealthy and hazardous.

The value of air quality indexes ranging from 0-50 shows that the air quality is in good condition, while the air quality index value within range 51 to 100 shows that the quality of air is in standard condition. Values within the range of 201 to 300 are considered very unhealthy and dangerous for human. The value of air quality index ranging from 300 to 500 is known as hazardous. The air pollutants' concentration can be measured in various specific unit such as parts per million (ppm) and micrograms per cubic meter (μg/$m^3$). Table 1 shows the standard AQI levels and their corresponding level of health concern.

The air quality index can be measured using the following formula:

$$AQI_{pollutant} = \frac{Pollutant\ concentration}{pollutant\ standard\ concentration} \times 100$$

In general, data readings are translated on to a linear scale based on relevant air quality standards to derive the AQI values for the hourly AQI and daily AQI. The maximum of individual pollutant indexes at a monitoring station is then taken as the overall index for that station.

**Table 1** AQI values and the level of health concerns [15]

| Sr. no. | AQI values (when the AQI value is in this range) | Levels of health concern (air quality conditions) |
|---|---|---|
| 1. | 0 to 50 | Good |
| 2. | 51 to 100 | Moderate |
| 3. | 101 to 150 | Unhealthy for sensitive groups |
| 4. | 151 to 200 | Unhealthy |
| 5. | 201 to 300 | Very unhealthy |
| 6. | 301 to 500 | Hazardous |

It is important for the citizens to be up to date about the reading of air quality index as it could affect their daily activities. For example, in good air quality index, citizens are encouraged to practice healthy lifestyle such as exercising regularly e.g. three times a week. However, in unhealthy and hazardous air quality index, citizens are advised to reduce vigorous outdoor activities and should stay indoors. For those who have health problems, they are advised to receive consultation from the doctors. The citizen should also follow the advice and order from National Security Council through mass media.

## 3.0 SIX KEY AIR POLLUTANTS AIR POLLUTION INDEX

Air pollution is a worldwide problem and is reported to cause the greatest damage to the health of living thing especially in the Asian countries. Developing country such as Malaysia is now facing an environment problem caused by the rapid urban growth in industrial sector.

The main source of air pollutant in Malaysia are mobile source particularly motor vehicles, stationary and trans-boundary emission [1]. Stationary source includes power plants, industrial waste incinerators, the emission of dust from urban construction works and quarries and open burning. Transboundary pollution is defined as the transported air pollution from forest fires from neighbouring countries.

The six key pollutants that released in the atmosphere are particulate matter, ozone, nitrogen dioxide, sulphur dioxide, lead and carbon monoxide.

Particular matter categorized by aerodynamic diameter such as particle less than10 $\mu$m is known as thoracic particle ($PM_{10}$), all particle less than 2.5 $\mu$m is defined as fine particle, all particle less than 0.1 $\mu$m is defined as ultrafine particles (UFP) and the particle between 2.5 $\mu$m and 10 $\mu$m which is known as coarse particle ($PM_{2.5}$-$PM_{10}$ ). The concentrations of particular matter are basically measured in their mass per volume per air (mg/m³) [4]. The micro size of particle matter can make it easily enter the respiratory tract and can cause asthma. The main source of this pollutant comes from combustion such as combustion of wood and biomass fuel.

Ozone is made up of three oxygen atom. Ozone is formed in the atmosphere by photochemical reaction in the present of sunlight and pollutant such as oxides of nitrogen and volatile organic compound. It is destroyed by reactions with nitrogen dioxide and it is deposited to the ground [24]. Source of ozone pollution are coming from chemical solvent and combustion product of fuel. Exposure to ozone for a few hours will lead to chest pain, reduces lung function, coughing and asthmatics.

Nitrogen dioxide is very reactive gasses known as nitrogen oxides. It will be produced when fossil fuels such as coal, natural gas are burned. Nitrogen dioxide also emitted by motor vehicle and stationary source such as electric utilities and industrial boilers. Exposure to nitrogen dioxide for will lead to influenza and reduces lung function.

Sulphur dioxide is poisonous gas. It can dissolve with water to form sulphuric acid. The sulphuric acid is the main component of acid rain. Sulphur dioxide is commonly released from the industry section such as a factory that burn high sulphur coal, petroleum refineries and solid waste that contains hazardous and medical waste. Study shows that exposure to acid rain will cause skin cancer, asthma and bronchitis.

Lead is an abundant heavy metal in the earth, about 14 parts per million by weight or one part per million by moles. Lead is grey colour, soft and ductile metal. It rarely occurs in pure form in nature. Lead is usually found in ores, mostly with copper, zinc and silver. The most common lead mineral is galena, which is lead sulphide (PbS) and other minerals include lead carbonate and lead sulphate [26]. Lead has become widely distributed in the environment since it was discovered and used by humans for a long time [17]. Lead is an important metal and be used in many industrial especially in the electric battery industry. Lead emissions come from motor vehicle, fossil fuel and manufacturing and mining will cause to premature birth and neurological impairments such as seizures, mental retardation and behavioural disorders.

Carbon dioxide is made up from one carbon and two oxygen atoms. Carbon dioxide is released on combustion to the atmosphere [9]. Source of carbon dioxide pollution are mainly come from burning of fossil fuels and production of cement. Exposure to carbon dioxide will effects the range from physiologic (e.g. ventilatory stimulation), to toxic (e.g. cardiac arrhythmias and seizures), anesthetic (significantly depressed CNS activity), and lethal (severe acidosis and anoxia) [19]. However, the effect of carbon dioxide on the individuals is depending on age, health, occupation, physical activities and lifestyle.

## 4.0 AIR POLLUTANTS MEASUREMENT TYPES

In general, there are three type of measurement scale to monitoring air pollutant such as big, medium and small. The size of the measurement scale is one of the characteristic needs to be considered when choosing a suitable method to detect the air pollutant.

Basically, the big type of measurement scale performs excellent in detect or monitor the air pollutant as it is high in resolution, but this type is difficult to handle and high in cost. There are some techniques that used a big measurement scale such as absorption spectroscopy technique, differential optical absorption spectroscopy (DOAS), Infrared spectroscopy and Ozone monitoring instrument (OMI).

The medium type of measurement scale is portable to detect the air pollutant, easy to handle and low in cost. The solid electrolyte gas sensor, semiconductor and capacitor gas sensor are some of the examples for medium measurement scale. The small type of measurement scale is unusual to be used to detect air pollutant because it is low in accuracy.

### 4.1 Air Pollutant Gases Measurement Techniques

#### a. Absorption Spectroscopy

Sulphur dioxide is the main gas that causes pollutant in the environment and has a higher transition in the ultraviolet (UV) spectral region. The absorption spectroscopy technique is a suitable method to monitoring sulphur dioxide in air. There are several methods to detect sulphur dioxide in the air such as differential optical absorption spectroscopy (DOAS) [6] and correlation spectroscopy (COSPEC) [7].

The Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) is the enhanced technique or the improvement from (DOAS) technique. (MAX-DOAS) is technique to monitor trace gas such as sulphur dioxide in the in the lower troposphere from ground based scattered sunlight observations. MAX-DOAS instruments observe scattered solar radiation in the UV and visible region at a spectral resolution of typically 0.5 nm in horizontal and vertical dimension [22].

The absorption spectroscopy technique is one of the famous methods to detect gases in the atmosphere that cause pollutant. This technique is mainly used in mid-infrared spectral region (2-15 $\mu$m), where numerous species of interest have fundamental vibrational absorption bands, and in the near-infrared region (0.6-2 $\mu$m), where weaker overtone and combination bands occur [25]. Many atom and molecule have strong electronic transitions in the ultraviolet (UV) spectral region (200-400 nm).

The absorption spectroscopy technique is a method that based from Beer-Lambert's law. This method is conducted in the real time measurement which is real-time sulphur dioxide pollution is monitoring using the method of broadband absorption spectroscopy in the UV region.

The equipment used to setup the real-time monitoring of sulphur dioxide are such as deuterium lamp, lens, sulphur dioxide cell, multimode optical fiber, monochromator charge coupled device (CCD) array and computer as shown in Figure 1.

The equipment used to set up the real time monitoring of sulphur dioxide is a broadband 30 W deuterium lamp that function as UV light source, a quartz lenses of 75 mm focal length to collimate the light. The light beam passing through a 35 cm long sulphur dioxide gas cell equipped with quartz windows at Brewster angle. The transmitted light is focused by a quartz lens of 145 mm focal length into a multimode optical fiber. The signals from charge coupled device (CCD) array detector are transmitted to the personal computer. The spectrometer control and real time data collection are performed using software called visual basic language.

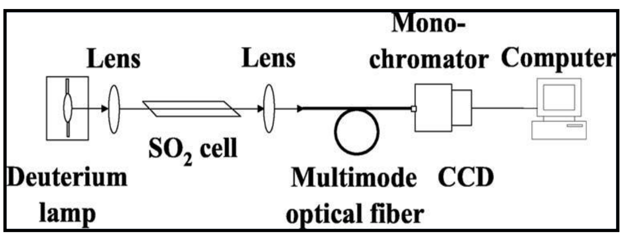



**Figure 1** Experimental setup for real-time monitoring of sulphur dioxide [25]

This method is tested in Harbin, China for measurement of sulphur acid emitted from a coal-fire boiler. The concentration recorded was in range 100-200 ppm [25]. The higher value concentration recorded show the higher sulphur contains in bituminous coal in China. This show, the spectrometer can detect the sulphur emitted as expected.

From this experiment, it can be concluded that only temperature can influence the absorption spectrum due to Doppler Effect. This method will neglect influence from gas absorption inferences and scattering effect from other gas and dust. This method is recommended because of easy data evaluation, low in cost and higher dynamic range in CDD array.

### b. Ozone Monitoring Instrument (OMI)

In July 2004, the ozone monitoring instrument (OMI) is introduced to the world by NASA's Earth Observing System AURA satellite. OMI is an ultraviolet or visible (UV/VIS) nadir solar backscatter spectrometer which provides nearly global coverage in one day with a spatial resolution of 13 km × 24 km. This method can detect gases such as ozone, sulphur dioxide and nitrogen oxide. Furthermore, OMI can also measure aerosol characteristics, cloud top heights, cloud coverage and UV irradiance at the surface [12].

The OMI technique is a modern technique as it uses 2-D CCD Detector. OMI consists of three elements such as an optical assembly including the optical bench and the detector modules, the electronics unit, and the interface adaptor module as shown in Figure 2. UV/VIS spectrometer detects the solar irradiance scattered and absorbed by the constituents of the earth atmosphere. OMI consist of three channels such as UV1, UV2 and VIS channel. For UV1 channel, OMI can measure the reflected solar radiation in the ultraviolet and visible part in the spectra range between 270 nm to 314 nm with a spectral resolution about 0.42 nm. For UV2 channel, OMI can measure the reflected solar radiation in the ultraviolet and visible part in the spectra range between 306 nm to 365 nm with a spectral resolution about 0.45 nm. For the last channel which is VIS, OMI can measure the reflected solar radiation in the ultraviolet and visible part in the spectra range between 350 nm to 500 nm with a spectral resolution about 0.63 nm.

The OMI technique is a generic technique because it can measure the trace gases such as ozone, nitrogen dioxide, sulphur dioxide, formaldehyde, chlorine dioxide and hypobromite. Daily global coverage provided from this method will help the authority to understand more about stratospheric and tropospheric chemistry and climate changes. OMI technique is high in spectral resolution so the air pollutant can be detected on urban scale resolution. Unfortunately, this method is expensive to be conducted because it requires modern equipment and the latest technology.

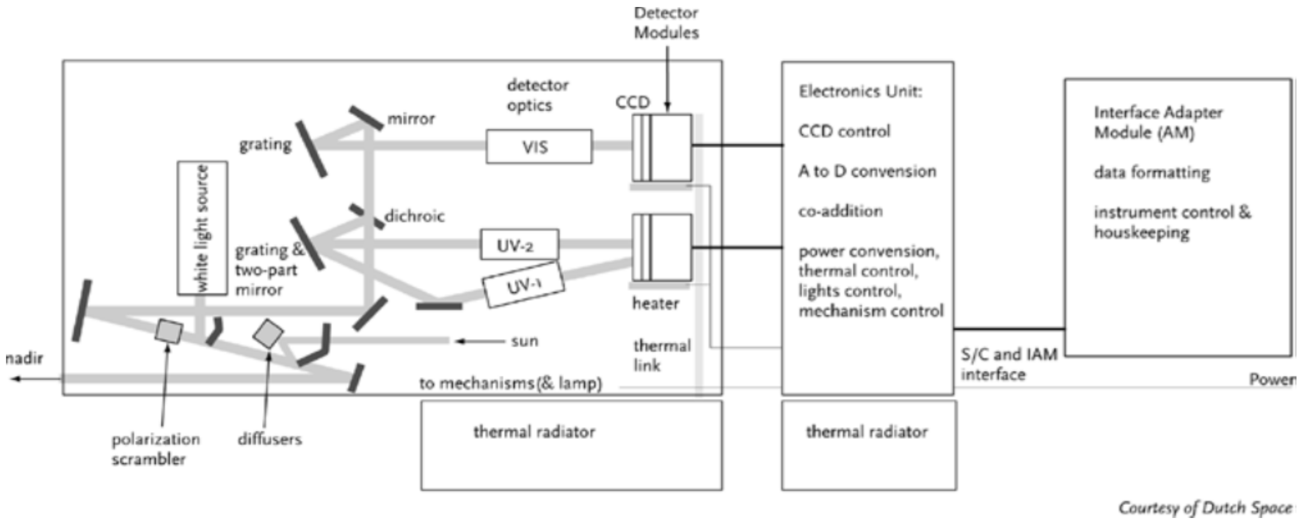



**Figure 2** Conceptual design of OMI with the large field of view out of the plane of the paper. The OMI instrument is composed of the following three elements: 1) Optical Assembly, consisting of the Optical Bench (OPB), two Detector Modules, and Thermal Hardware; 2) the Electronics Unit , performing CCD readout control and analog-to-digital conversion; 3) Interface Adaptor Module, performing Command Buffering as well as the data formatting and satellite bus interface functions [13]

The previous researchers measure the air pollutant with analytic instrument. These instruments can give a precise analysis and can seldom be used in real-time in the field but they are time-consuming and expensive [11]. To overcome this problem, gas sensor is introduced because it is compact, robust, versatile and low in cost.

### c. Solid State Gas Sensor

There are many type of solid state gas sensor but only solid electrolyte, non dispersive infrared absorption and semiconductor type are widely used.

Solid electrolyte sensor can be used to detect or monitor nitrogen dioxide and sulfur dioxide. Three types have been classified by Weppner which can stand on whether the ionic species derived from the gas questionable coincides with the mobile ion (Type I), the immobile ion (Type II), or neither of them (Type III) of the solid electrolyte used. Type III sensor demanded auxiliary phase attached to the surface of the solid electrolyte. This auxiliary phase uses compounds that enclose ionic species obtained from the gas.

This auxiliary phase performs as a poor ion-conducting solid electrolyte which mix up together from half cell of Type I or Type II. After that, the electrochemical cell is produced. Type III sensor can be divided by a few subgroup depending on the type of half cell combined. Type III sensor used to detect oxygenic gases such as carbon dioxide, nitrogen dioxide and sulfur dioxide.

### d. Infrared Absorption

Non dispersive infrared absorption is a simple method and focus on particular gas detection. Gas molecules absorb energy that resemble to their quantized energy which is mostly located in infrared region. The gas absorbing degree is proportional to the gas concentration to be detected.

In the Nondispersive infrared sensor (NDIR) gas detecting method, filter is used to retrieve a monochromatic beam from an infrared light source with a wide range 4 to 5 $\mu$m. Indium antimonide (InSb), Lead selenide (PbSe) and mercury cadmium telluride (HgCdTe) are usually used as sensing material for an infrared detector within in low temperature range in 77 K to 196 K. With a wide range 3 to 5 $\mu$m, PbSe and Lead(II) sulfide (PbS) are usually used as sensing material for an infrared detector for measuring hydrocarbon (HC) gases. IR sensor is used to detect gas such as carbon dioxide, carbon monoxide and HC together with chromatic sensor used in the NDIR method. The output voltage in IR sensor is directly proportional to the gas concentration because the absorptivity of the incident beam, when the gas passes through the cell, is proportional to the path length and the gas concentration, according to the Beer-Lambert law.

### e. Semiconductor Gas Sensors

Semiconductor gas sensors are famous for detecting inflammable gases and certain toxic gases in atmospheric. The absorption of the gas on the surface semiconductor material gives change in the density of the conducting electrons in the polycrystalline sensor element.

The chemical reaction are divided by four step such as pre-adsorption of oxygen on semi-conducting material surface, adsorption of specific gas, reaction between oxygen and adsorbed gas and finally, desorption of reacted gas on the surface [11].

Semiconductor sensor such as MQ7, MQ3 and MQ2 can be used detects the air pollutants. MQ7 semiconductor sensor is used to detect carbon monoxide and sensitive material for MQ7 gas sensor is $SnO_2$, which is lower conductivity in clean and fresh air [18].

### 4.2 Mobile and Network Measurement Techniques

#### a. Mobile Air Quality Monitoring Network (MAQUMON)

Next, the Mobile Air Quality Monitoring Network (MAQUMON) is introduced to make up sensor nodes mounted on cars or any vehicles as shown in Figure 3.

**Figure 3** Sensor node prototype [23]

A sensor node made up from a microcontroller, an on-board GPS unit and set of gas sensors measuring ozone, carbon monoxide and nitrogen dioxide concentrations as shown in Figure 4. The node is included with Bluetooth and it make it easily connected to the laptop to upload the measurements or data.

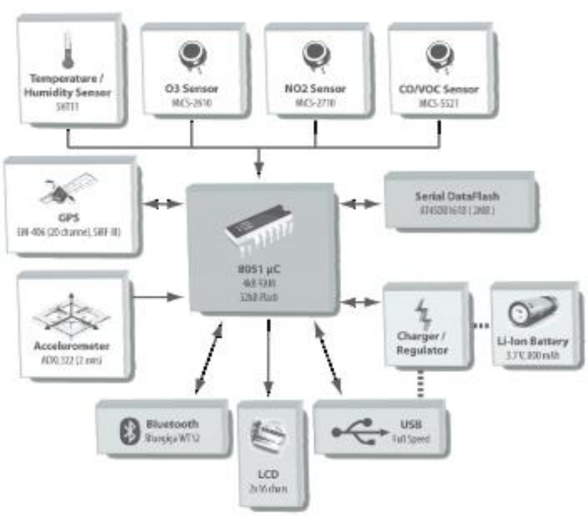



**Figure 4** Architecture of the sensor node [23]

If the car is moving, the device samples the pollutants every minute and store the results tagged with a location and time stamp. If the car is stop, the samples are only taken a few times an hour. If a car is in the area that Wi-Fi can be accessed, all data are uploaded to the server to be processed and published on the SensorMap port.

The advantages of this system are this system is available in the USB cable, can supply power to the board both for on-line operation and for charging the integrated Li-ion battery, a 2-axis microelectromechanical systems (MEMS) accelerometer is function to detect if the system is moving or not. If the system is at rest, all the power hungry components such as GPS, Bluetooth and gas sensor will be turned off.

In this system, location and time information is provided by an on-board 20 channel SiRF-III-based GPS module at 1 Hz sampling rate [23]. Pollutant gas that can be measured using this method is ozone, volatile organic compounds, carbon monoxide and nitrogen dioxide. The data, temperature, and relative humidity data and GPS data is located in serial flash device 2MB. A 2x16 character LCD panel is used to display feedback about the status of the system such as connected interfaces, GPS lock, time, motion detection and sensor readings. The Intel 8051-based microcontroller is function to controls all activities in this system including battery charging, analog to digital conversions and the USB protocol.

#### b. GPRS-Sensors Array

GPRS-Sensors Array is another method to detect air pollutant. This method is advance method from the sensor node method. This system used a hardware known as Mobile Data-Acquisition Unit (Mobile-DAQ) and a fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server). Mobile Data-Acquisition Unit (Mobile-DAQ) consists of single-chip microcontroller, General Packet Radio Service Modem (GPRS-Modem), and a Global Positioning System Module (GPS-Module) and air pollution sensors array such as carbon monoxide, nitrogen dioxide and sulphur dioxide as shown in Figure 5.

Air pollutant sensors are included with a GPS physical such as location, time and date. A fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server) consists of a laptop with an internet access as shown in Figure 6. This sensor is located on the top of the vehicle, when the vehicle is moving the microcontroller will produced a flame that show the air pollutant level from the sensor array and it tagged with physical location as attached by GPS module. Then, the pollutant frame is uploaded to the (GPRS-Modem) and transmitted to the Pollution-Server by the public mobile network. The Pollution-Server is connected to Google maps to display real-time pollutants levels [2].

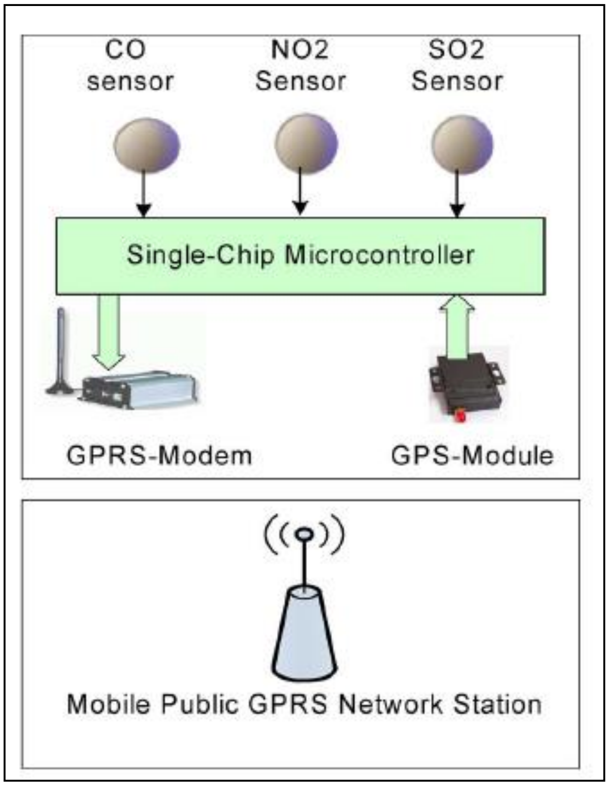



**Figure 5** The Mobile Data-Acquisition Unit [2]

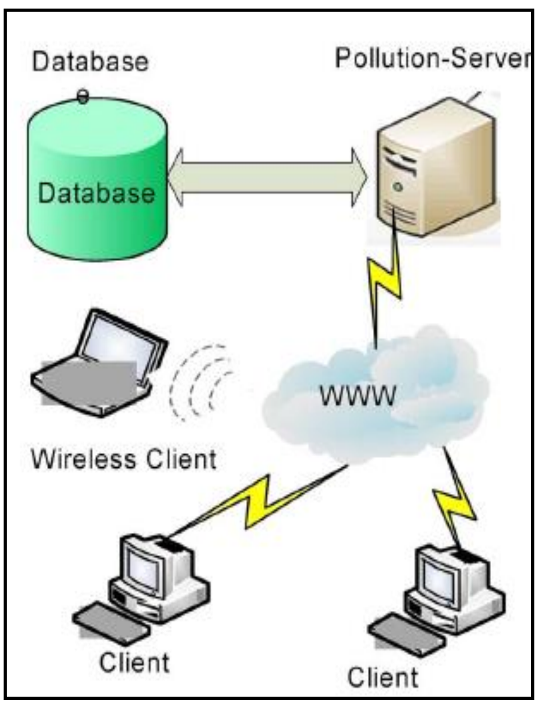



**Figure 6** The fixed Internet-Enabled Pollution Monitoring Server (Pollution-Server) [2]

## c. GasMobile

The latest technique to detect air pollutant is using a GasMobile. GasMobile is a low cost mobile system that can be used to detect the air pollutant. This system uses hardware such as USB and power supply in host mode and power consumption as shown in Figure 7. USB in host mode is function to allow the interaction with the various USB devices such as memory sticks, external hard drives, keyboards and gas sensor. For power consumption, battery pack is used to energize the total current draw of the ozone sensor and the USB-RS232 translator.


**Figure 7** Hardware architecture [8].

The software used in this system is android-serial-api for the serial communication between ozone sensor and the smartphone. The application is started with main menu that consist of settings, take measurements, upload measurements, calibrate the sensor and quit as shown in Figure 8(a). Using the settings screen, user can change an assorted parameter as shown in Figure 8(b) and for the calibration and measurement process occur are shown in Figure 8(c) and 8(d).

The GasMobile only uses 41.5 kB from the 166 MB of internal storage on the HTC Hero and CPU usage is increased by 5% while polling the sensors and calculating the ozone concentration [8]. This can be concluded, this method is very low in resource requirements.

The GasMobile prototype system is small, low in cost and do not used hardware to monitor the ozone pollution. GasMobile can produce high data accuracy by exploiting sensor readings near static measurement stations to frequently maintain sensor calibration up to date.

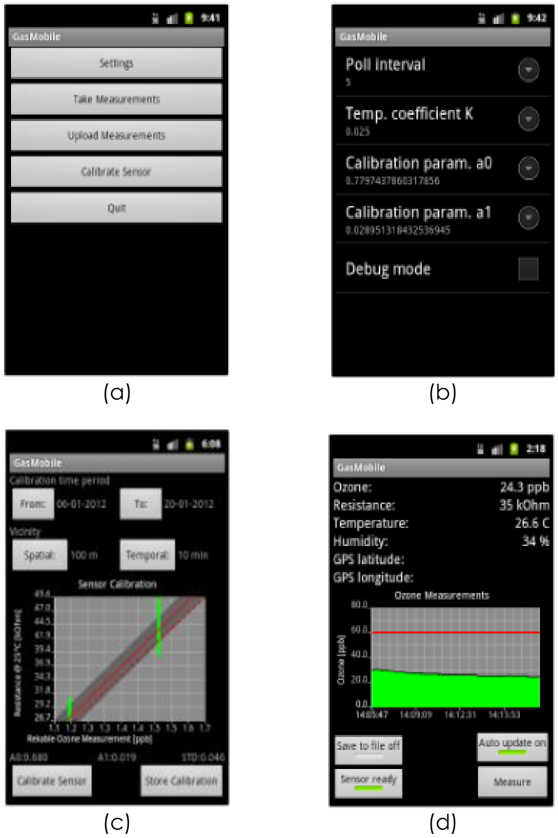



**Figure 8** GasMobile system menu; (a) main menu, (b) setting, (c) calibration, and (d) measurement [8]

## 5.0 CONCLUSION AND SUGGESTION FOR FUTURE ADVANCEMENT

This paper is point out different techniques that could be considered in monitoring several types of gases such as carbon monoxide, nitrogen dioxide, ozone, sulphur dioxide and suspended particulate matter. It is suggested that the GasMobile technique is one of the latest technique used for monitoring air pollutant and perform well rather than previous techniques for monitoring and detecting air pollutant as it provides high data accuracy and low in cost. For future improvements, more technique should be introduced to detect air pollutant to help in monitoring the quality of air. The new technique introduce should be able to detect air pollutant in a size of ultrafine particles (UFPs) with a diameter less than 100 nm such as diesel exhaust particles (DEPs) and be able to sense the particle consisted in the air pollutant.

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