Ollscoil Chathair
Bhaile Átha Cliath
Dublin City University

School of Electronic Engineering

Personalised Air Quality Monitor using Wearable Sensors

Literature Survey

Patrick Byrne
ID Number: 22267483

January 2023

MEng in Electronic and Computer Engineering

Supervised by Shirley Coyle

Declaration

I hereby declare that, except where otherwise indicated, this document is entirely my own work and has not been submitted in whole or in part to any other university.

Signed: .... Date: ....

Personalised Air Quality Monitor using Wearable Sensors

Patrick Byrne

***Abstract*— This literature review has been written to discuss the currently available articles and journal publications that are relevant to this project: "Personalised Air Quality Monitor using Wearable Sensors". This is done by reviewing the available literature that discusses and defines the pollutants relevant when defining air quality. Investigating the best methods to measure these pollutants and the best suited way of describing the measured pollutants to a citizen that will make sense to them. Finally, this will review some similar implementations to that being constructed for this project.**

I. INTRODUCTION

Previously published materials available in relation to this topic: "Personalised Air Quality Monitor using Wearable Sensors" will be reviewed in this paper. Air quality has always been important since the advent of the Industrial Revolution, where there was intense smog descended upon cities due to the combustion engines in manufacturing plants. The emissions from combustion engines are a clear contributor of outdoor air pollution but there are other elements that define the pollution levels of an area, whether indoor or outdoor.

Since governments have begun regulating the emissions of gases and particles contributing to air quality, the issue has become less apparent to the public. This is partially due to the inability to see the everyday effects that it is having on us. Despite air pollution not being as visible in many areas of the world, it can still have a deadly effect on our health. The health effects differing pollutants may have is briefly outlined later in this paper (Figure 1).

It has been decided that the focus of this project is the system design and implementation of a "Personalised Air Quality Monitor using Wearable Sensors"; this will involve the careful selection of components to be used, implementing their use to accurately measure and represent the KPIs. The main materials being discussed in this literature review are in relation to defining the aspects of air quality, the best way to represent the results, methods to measure these indicators and any implementations previously used.

II. REVIEW AND ANALYSIS OF PRIOR WORK

As stated in the introduction and abstract of this paper, the different aspects of air quality and measurement methods will be discussed. This is further broken down into, Air Quality Indicators, Measurement Methods, and Current Implementations.

A. Air Quality Indicators

The World Health Organisation (WHO) provide a list of pollutants regarding air pollution and the causes of the release of these pollutants [1]. Different sources of information correlate with the list provided by the WHO [2] [3]. This suggests that the list of elements is a good starting point to indicate ambient air quality. The elements mentioned are Particulate Matter (PM), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Ozone (O3) [1]. These pollutants have different concerns for the health of humans, the snippet in Figure 1 shows the health effects listed in [3]. In observing the table provided in Figure 1, there are differing health concerns depending upon the pollutant in prolonged contact with. The different pollutants show, hence cause concern for the health of individuals.

Air Quality Guidelines and Standards, Table 5 Summary information on criteria air pollutants regulated as NAAQS[a] by the USEPA

Pollutant	Sources	Key effects of concern	Subpopulations of concern
Ozone	Photochemical oxidation of nitrogen oxides (primarily from combustion) and volatile organic compounds (from stationary and mobile sources)	Decreased pulmonary function, lung inflammation, increased respiratory hospital admissions	Children, people with preexisting lung disease outdoor-exercising health people
Nitrogen dioxide	Photochemical oxidation of nitric oxide (primarily from combustion of fossil fuels) and direct emissions (primarily from combustion of natural gas)	Respiratory illness, decreased pulmonary function	Children, people with preexisting lung disease
Sulfur dioxide	Primarily combustion of sulfur-containing fossil fuels; also smelters, refineries, and others	Respiratory injury or death, decreased pulmonary function	Children, people with preexisting lung disease (especially asthma)
Particulate matter	Direct emission of particles during combustion, industrial processes, gas reactions and condensation and coagulation natural sources	Injury and death	Children, people with preexisting heart and lung disease
Carbon monoxide	Combustion of fuels, especially by mobile sources	Shortening of time to onset angina and other heart effects	People with coronary artery disease
Lead	Leaded gasoline (prior to phase-out in gasoline);point sources such as Pb mines, smelters, and recycling operations	Developmental neurotoxicity	Children

Figure 1: Sources and health effects of the pollutants outlined (Includes lead) [4]

PM is characterised quite well in [3] and [2], these are particles that are of a specific size. PM of diameter 10µm or less are represented as PM_{10}, whereas PM of diameter 2.5µm or less is represented as $PM_{2.5}$. This is the common notation of representation for PM, the most common PM sizes: 10µm, 2.5µm and 1µm. The sizes of PM can have different health effects, [2] provides an excellent diagram displayed in Figure 2 that shows the depth different PM sizes can be deposited within the respiratory system.

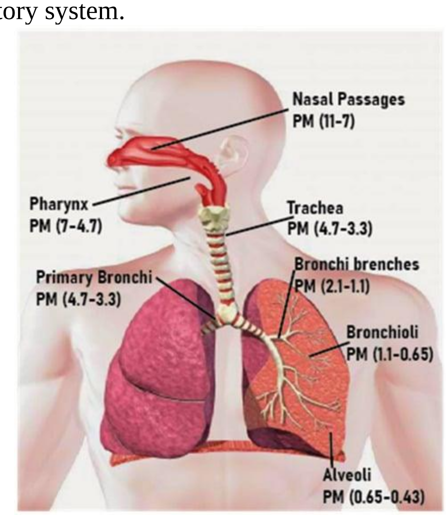

Figure 2: Deposition location of PM according to size [2]

The paper written in [2] provides an excellent overview of the different pollutants, their sources and health impacts. This paper does concur with the list of pollutants provided by the WHO [1] while also looking at Volatile Organic Compounds (VOCs). This addition to a list of pollutants is justified, USA's Environmental Protection Agency (EPA) also indicates this as a pollutant [5] and defines it as; gases emitted that have a particularly high vapour pressure [5]. VOCs are an indicator of indoor air quality rather than outdoor air quality; this is due to the production of VOCs outdoors being regulated by a governing body since they contribute to smog production (The level of regulation is dependent upon the country) [6].

The Air Quality Index (AQI) is an indicator that is used by national health departments to convey to the public the quality of the country's air. Different methods of calculating AQI has led to different standards for this indicator. The differing standards of AQI has led to different scales to represent the raw data. Due to this, companies that make commercially available air quality monitoring devices (Atmotube and Plume Labs) have defined their own version of AQI. In [7], the different standards defined by; Canada, USA, Europe, United Kingdom, Australia, South Korea, Singapore, Hong Kong, China, and India are listed showing how to interpret the scales of the measurements and the pollutants being represented. These scales all differ significantly, Europe's Common AQI (CAQI) is measured on a scale of 1-100 which is intuitive and easy to interpret whereas USA's scales are from 0-300+ and are not as intuitive to read [7].

There are other interpretations of AQI not listed by [7], such is the AQI Health (AQIH) defined by the Irish governmental agency Environment Protection Agency (EPA) [8]. There are a set of tables given to convert the raw data recorded into the corresponding value for AQIH. This is represented on an easy to interpret scale of 1-10 ranging from Good to Very Poor [8]. The tables shown in Table 1 and Table 2, show the levels of each referenced pollutant to the AQIH scale. The scales being broken into brackets for each pollutant makes this easy to calculate if a subset of pollutants being monitored.

Band	Index	O3 (μg/m^3)	NO2 (μg/m^3)	SO2 (μg/m^3)
Good	1	0-33	0-67	0-29
	2	34-66	68-134	30-59
	3	67-100	135-200	60—89
Fair	4	101-120	201-267	90-119
	5	121-140	268-334	120-149
	6	141-160	335-400	150-179
Poor	7	161-187	401-467	180-236
	8	188-213	468-534	237-295
	9	214-240	535-600	296-354
Very Poor	10	241 +	601+	355+

Table 1: AQI Table provided by Irish EPA continued *[8]*

Band	Index	PM$_{2.5}$ (μg/m^3)	PM$_{10}$ (μg/m^3)
Good	1	0-11	0-16
	2	Dec-23	17-33
	3	24-35	34-50
Fair	4	36-41	51-58
	5	42-47	59-66
	6	48-53	67-75
Poor	7	54-58	76-83
	8	59-64	84-91
	9	65-70	92-100
Very Poor	10	71+	101+

Table 2: AQI Table provided by Irish EPA continued [8]

B. Methods of Measuring Air Pollution

The different elements that constitute air pollution in the list above can be represented in different ways: parts per million/billion (ppm or ppb) or in mass per volume (μg/m^3). There are different measurement methods available to measure the various pollutants, which may result in the differing formats. In [2] the measurement methods are discussed and gives a good overview of different sensor types for both gases and PM. Likewise in [4], also gives an excellent in-depth view of the available methods to measure gases and PM in greater detail. Both sources point out the positives and negatives of each relevant measurement method.

Metal oxide semiconductor (MOS) sensors use the properties of a metal oxide's conductivity to determine the level of oxidizing pollutants in the air. In clean air, the Oxygen will bind with the metal oxide, reducing the free electrons available, thus the conductivity is reduced [2]. Whereas if there are oxidizing pollutants present, the pollutants will bind with the oxygen particles, freeing electrons in the depletion layer and increasing the conductivity of the material [2]. These sensors have a high level of sensitivity but also are highly dependent upon temperature; temperature is a key component of the rate of absorption and desorption in the metal-oxide [4]. This type of sensor is useful for measuring oxidizing pollutants like O3, NO2, CO and SO2 [4]. These sensors are particularly useful if used in conjunction with a temperature and humidity sensor to monitor changes in temperature so not to misinterpret higher readings when the temperature is increased.

Non-dispersive infrared (NDIR) sensors take advantage of Beer-Lamberts' equation to use an IR light source and a photodetector to be able to determine the concentration of a gas according to the absorption of the IR light [4] [2]. This is a cheap sensor that has low power consumption, making it ideal for an application in a battery powered system, this is commonly used to measure CO2 [4].

Both [4] and [2] concur that small sensors that don't require user input to measure PM can be done by shining a laser and detecting the light being scattered from that laser using a photodiode. This allows the amount of mass per concentration of the chamber to be calculated. This is represented visually in Figure 3.

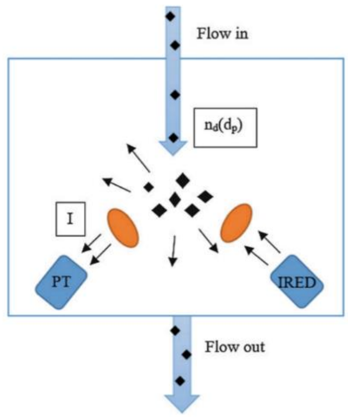

Figure 3: Image of inner working of PM detector using a laser and photo detector [4]

C. Current Implementations

There are some existing implementations that are somewhat in-line with the desired outcomes of this project. As mentioned, Plume Labs have created a portable Air Quality monitor that is capable of monitoring different pollutants and displaying the results in the form of their own AQI. Also mentioned is Atmotube's commercially available products, similarly they have a product available for users to monitor different pollutants and display the resulting measurements in terms of its' own Air Quality Score (Scored 0-100, where 100 is good and 0 is bad). Both products are constructed to perform the desired tasks as this project and appears to be designed with space constraints in mind as well as power consumption. The key difference between these products and this project's aim is the wearable aspect, these devices are not designed to be wearable or use wearable sensors but are designed to be portable.

There also exists some published papers and projects along the same lines of this project. There is a project that was completed to create an IoT air and noise pollutant monitor [9], which gives a good overview of the system design but not an in-depth view of the reasoning for the monitoring of just SO2. The article outlining the design of a system in [10] gives a good overview as to why PM is monitored and provides a good overview of the design itself. This implementation differs from this project as it is not designed using small form factor sensors or embedded systems [10].

In [2], there is a discussion around the works done in the space of monitoring air quality. There is a great discussion around the available products like those made by Atmotube and Plume Labs, as well as other research papers that delve into this topic [2]. There are clearly some existing implementations researched and thought through, MyPart have designed a wrist wearable device to monitor PM using a specially designed PM detector for a smaller form factor [2]. This section of [2] provides an excellent view as to what currently exists, and what directions can be taken to develop this project.

III. Relation of Prior Work

The reviewed literature has indicated directions that may be explored depending on different constraint factors of a system. There is a clear set of possible contaminants to monitor. If a system does not have a sizing constraint, setting out to measure as many of the list of pollutants will result in the best representation of air quality. Some of the higher end commercial products available from Atmotube and Plume Labs do this. In this scenario, it may be best to use an AQI that will encapsulate all the measured variables. Some of the papers discussed in Section C. Current Implementations, do show implementations of an air quality monitor with limited data collection.

The reviewed implementations currently in place do show methods of designing a similar monitor to the desired outcome of this project but these all differ significantly. There are designs that give a good overview of a system design to monitor PM as the air quality indicator [10]. In [2], there are multiple different projects commented on. Multiple projects from this look to implement a similar desired design to the aims of the project, particularly the project referenced that was completed by MyPart [2]. Although, this project will not have the scope to design smaller PM detectors, which will lead this project design to be larger. These reviewed implementations have given a good indication to the direction needing to be moved towards.

Seeing as this project is space and power constrained by aiming to use wearable sensors, this will need to be portable. As is the case in reviewed applications [10] and [9], it is best not to measure all pollutants but to measure a subset of the pollutants. From this, it is easy to determine that it is better to use an AQI index that can be calculated with minimal pollutants being measured.

IV. Conclusion

Moving forward it is best to consider PM as the main contaminant or KPI to monitor, if spacing constraints permit, can then move to measure more pollutants for accurate portrayal of air quality. As outlined in A. Air Quality Indicators, an AQI that can be calculated with a limited set of pollutants measured, the Irish AQIH may be used moving forward. This will also allow for correlation between measurements performed and published by the EPA in Ireland. This will allow for an air quality monitor that can adequately portray the status of the air quality in an easy to interpret format for the user.

References

[1] World Health Organisation, "Ambient (outdoor) Air Pollution," 19 12 2022. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health. [Accessed 12 01 2023].

[2] S. Bernasconi, A. Angelucci and A. Aliverti, "A Scoping Review on Wearable Devices for Environmental Monitoring and Their Application for Health and Wellness," *MDPI Sensors*, vol. 22, no. 16, p. 5994, 2022.

[3] M. E. Goodsite, M. S. Johnson and O. Hertel, "Air Quality Guidlines and Standards," in *Air Pollution Sources, Statistics and Health Effects A volume in the Encyclopedia of Sustainability Science and Technology, Second Edition*, New York, Springer, 2021, pp. 7-47.

[4] M. E. Goodsite, M. S. Johnson and O. Hertel, "Low-Cost

Sensors for Indoor and Outdoor Pollution," in *Air Pollution Sources, Statistics and Health Effects A volume in the Encyclopedia of Sustainability Science and Technology, Second Edition*, New York, Springer, 2021, pp. 423-455.

[5] "What are volatile organic compounds (VOCs)?," 27 12 2022. [Online]. Available: https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs. [Accessed 12 1 2023].

[6] EPA, "Technical Overview of Volatile Organic Compounds," 28 3 2022. [Online]. Available: https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds. [Accessed 12 1 2023].

[7] "Standards for Air Quality Indices in Different Countries (AQI)," Atmotube, 12 5 2021. [Online]. Available: https://atmotube.com/blog/standards-for-air-quality-indices-in-different-countries-aqi#:~:text=Atmotube%20AQS&text=AQS%20scores%20air%20quality%20on,5%2C%20and%20PM10.. [Accessed 19 1 2023].

[8] EPA, "Air Quality Index for Health," 2021. [Online]. Available: https://airquality.ie/information/air-quality-index-for-health#:~:text=The%20Environmental%20Protection%20Agency's%20Air,of%20you%20or%20your%20child.. [Accessed 16 01 2023].

[9] T. Manglani, A. Srivastava, A. Kumar and R. Sharma, "IoT based Air and Sound Pollution Monitoring System for Smart Environment," in *2022 International Conference on Electronics and Renewable Systems (ICEARS)*, Tuticorin, 2022.

[10] G. O. Avendano, J. C. Dela Cruz, A. H. Ballado, L. G. Rommel Ulyzes, A. C. Paras Atienza, B. J. G. Regala and R. C. Uy, "Microcontroller and app-based air quality monitoring system for particulate matter 2.5 (PM2.5) and particulate matter 1 (PM1)," in *IEEE 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, Manila, Philippines, 2017.