INTERNET OF THINGS (IoT) BASED AIR QUALITY INDEX MEASUREMENT SYSTEM FOR DHAKA CITY

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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract/ Executive Summary

Air pollution is a burning question for the environment nowadays, requiring paramount interest. Air pollution can be controlled by monitoring the level of pollutant gases (NO_2, SO_2, CO_2, CO, O_2, PM 2.5, PM 10, etc.) in a periodic manner. Sensing air quality is a major concern for environmental monitoring. In this study, the air quality has been measured for 5 points of Dhaka city by using air quality sensors using IoT platform. The sensed data is then sent to the Thinkspeak cloud platform. The collected data is first processed and then analyzed for obtaining the value of the air quality index (AQI). The generated results are then visualized by the graphical representation. On the basis of this, an individual can take precautionary measures for a healthy life. Finally, the overall scenario for a monthly analysis has been depicted in a location-based mapping. The studied areas are Mirpur 6, Uttara Sector 6, Mohakhali Wireless, Nikunjo 2, and Uttara 12. All the setups are located in the residential areas. The result shows that the Mohakhali has the highest AQI value which is unhealthy for the inhabitants according to the standard index. The real-time data can be observed remotely by using the IoT platform. The output of the study can be further utilized for public health monitoring purposes.

Keywords: IoT; Air Quality; Environment; ThingSpeak; Data; Health Issue.

Dedication

This research is solely dedicated to our parents and faculties, who were nothing but supportive during all these months, helped us, guided us and lent us strength. The moral support we got from them is beyond measure.

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List of Acronyms

AQI	Air Quality Index
AQLI	Air Quality Life Index
PM	Particulate Matter
PPM	Parts Per Million
PPB	Parts per Billion
CO	Carbon Monoxide
CO_2	Carbon Dioxide
SO_2	Sulfur Dioxide
Pb	Plumbum (lead)
NH4	Ammonia
CH4	Methane
CFC	Chlorofluorocarbon
NOx	Nitrogen Oxide
NO2	Nitrogen Dioxide
O3	Ozone
LPG	Liquefied Petroleum Gas
µg/m3	Micrograms per Cubic Meter
EPA	Environmental Protection Agency (US)
IoT	Internet of Things
WHO	World Health Organization
NMOS	N-channel metal-oxide semiconductor
NodeMCU	low-cost open source IoT platform
UART	Universal asynchronous receiver-transmitter

Chapter 1

Introduction

1.1 Introduction

Air quality in Bangladesh in 2020 was ranked the worst in the world [1]. As Bangladesh moves towards middle income status, we cannot forget that progress should not come at the cost of life. China is currently incurring huge costs to mitigate the poor quality in its industrial zones and Bangladesh has the opportunity to learn from China's mistakes of mass industrialization which lead them to the problem of smog.

Air pollution has the world's largest environmental risks to health, leading to millions of deaths around the world each year [2]. According to the WHO, 4.2 million people die each year from inhaling pollutants in air outdoors [3]. Bangladesh is a developing country; multiple sources show that developing countries, especially frontier markets like Bangladesh, have the highest percentage of these deaths. Bangladesh has another disadvantage of being a deltaic region, meaning that climate change will have compound the already present environmental risks to everyone, especially people living in vulnerable regions of the country. Air pollution affects health in a myriad of ways. While everyone is at risk from air pollution, statistics show children, the elder population and patients of lung and heart diseases are particularly affected.

Dhaka city has a total area of 306 square kilometers. The city has a population of over 21 million at present and has a rapid growth rate of three percent per year primarily to the mean of migration from the rural regions [4]. Dhaka has four rivers demarcating the city and a subtropical climate with high humidity rates, temperature and distinct seasonal fluctuations. The climate is an added proponent of trapping pollutants, which are mostly present from automobile congestion, construction and rapid industrialization with poor planning for urban safety or containment. Bangladesh, particularly Dhaka has an air quality index which averages at 168- (unhealthy) and reaches higher than 300 throughout the year [5]. This is more than enough to raise alarm and concern government agencies into devising sustainable solutions but, so far, not enough is being done, especially when the scale of urbanization is taken into account. Our project, through measuring industrial grade air quality, aims to inform the public on the pollutants they are inhaling and thereby lead to actionable change demanded through citizen awareness.

1.2 Background

The Atmosphere is composed of several gases, water vapor, dust particles and so on. The important gases are nitrogen, oxygen, argon, carbon di oxide, neon helium, hydrogen ozone etc. By volume nitrogen is 76% and oxygen is about 21%. Together these two gases make about 99% volume of the atmosphere. The rest 1% are many other gases and particulate matters which are very less in volume but they are very important to refer. As the ratio in our breathable air determine if it's polluted or not. As stated, all these gases and particles stay in a certain concentration or ratio in the air. A change on them means that the air has become polluted.

Air pollution consists of chemicals or particles in the atmosphere that poses serious health and environmental threats. Some air pollution comes from natural sources, like volcanic eruptions, wild fires, or allergens [3]. But most air pollution results from human activities. This sort of air pollution is known as anthropogenic air pollution. Energy used in agriculture is also a source of air pollution caused by human. There are different types of human-made air pollution. When fossil fuels are burnt to produce energy, they release greenhouse gasses into the air [4]. These emissions such as carbon dioxide, methane, and nitrous oxide and fluorinated gasses trap heat from the sun in earth's atmosphere leading to a rise in global temperatures [5]. This creates a cycle where air pollution contributes to climate change. And climate change creates higher temperatures. In turn, higher temperatures intensify some types of air pollution which later plays a big role in creating smog and acid rain.

Smog is a type of intense air pollution. It is mainly consisted of smoke and its harmful elements. This word has been referring since early 20^{th} century to refer smoke and fog together. It is basically a smoky fog with smoke like opacity. There are various causes of Smog which can be enlisted as coal burning vehicular emissions, Industrial emissions, forest fires agricultural fire Photochemical reactions Volcano eruptions and so on. The major Components of Smog is Nitrogen Oxides, Sulfur Oxides, Ground Ozone, Smoke, Carbon Monoxide, CFCs, and Dust particles [5].

China is dealing with the problem of Smog for a long time now. After the big bump in their industrialization, it had been an alarming issue for them. Smog had been a big issue for China from the start of their industrialization [6]. China’s smog “airpocalypse” is out of control. People are buying up canisters of air harvested from the Canadian Rocky Mountains. It also has flavors one is known as Banff and the other one is Lake Louise/ Canadian Startup vitality air knew they were onto something when a Ziploc bag full of air sold on eBay for $0.99. As Beijing issues its second-ever red alert Vitality Air’s $30.70 twin packs have sold out on a Chinese website [7].

According to the report of world health organization, 9 out of 10 people breathe polluted air. This means, 90% of the whole populations in the world breathe polluted air. A lot of country is facing this problem, but if we talk about Bangladesh, the situation is much worse. The capital city of Bangladesh, Dhaka is ranked at no: 08 in the list of 25 most polluted city in the world [8]. The AQI rating of Dhaka is of the charts.

Bangladesh is a developed country and smog followed by the industrialization of this country. Smog is now a hindrance to public health for people living in Dhaka capital of Bangladesh since it had been rated no 8 in the most polluted cities across the world [6]. During the early stage of Corona situation, the air pollution problem of Dhaka improved quite a bit. Which leads to the equation that, most of its pollution is due to vehicles and industries that burn fuel. But putting the Corona Situation subsided people of Dhaka city has moved on with their life that has put the air pollution on its toll again.

According to an article that studied the emission of NO_2, SO_2, CO and O_3 the exact gases that we are working on this project, back during the lockdown was imposed had fascinating results. The concentrations of NO_2, SO_2, and CO_2 were analyzed from 1 February to 30 May in 2019. The study revealed that the decreasing SO_2 and NO_2 concentrations had a negative effect on the air quality in some cities. This resulted in the concentrations of SO_2 and NO_2 in Dhaka decreased by over 70% and 68%, respectively [9].

The Particular matter is a big concern for the people living in Dhaka since it is one of the prime things that is making Dhaka inhabitable. Concentrations of particulate matter and trace gases were measured at five sites in greater Dhaka, Bangladesh, from January to April 2006. The total average concentrations of NO_2, SO_2, CO_2, and O_3 were 48.2, 161.0, and 28 g meters–3. These levels were significantly lower than the annual average values of the WHO. The mass of PM2.5 in Dhaka is about 88% of the PM10 mass. It shows that fossil fuel is the main cause of PM in the city. The concentration of Pb in Dhaka has decreased, presumably due to the ban of the use of leaded fuel in the city. This data is similar to those in other major cities in Southeast Asian countries [10].

This imposes the necessity of real time data rating of this city. To address this whole situation and to make people realize and understand the adverse situation they are in right now a system consisting of SDS0111 PM Sensor and 4 SPEC sensors that collect reading for NO_2, SO_2, O_3 and CO is used to setup a project that will give us real time data. The Raspberry pi processes all the data that is sent to it via a USB hub consisting of four SPEC sensors and the PM sensor. Raspberry pi is sort of a mini computer which uses very low power and is quite affordable [11]. Through collecting and analyzing the Data from our sensors we can assume which sort of pollutants is affecting our air accurately and we can also see in which season what sort of pollution is at peak.

To make this whole process more accessible to everyone we have used cloud computing known as Internet of things (IoT). Until recently access to the internet was limited via devices like the desktop tablet or smartphone. But now with the internet of things aka IOT, practically all appliances can be connected to the internet and monitored remotely. It is a system of interconnected devices that transfer and exchange data over a wireless network without any human intervention [12]. The things in internet of things could be the ac doorbell thermostats smoke detectors water heaters security alarms and more [12]. By using these tech users will be able to access the data remotely that is stored on the cloud via the Raspberry Pi and uses the data for various purposes [11][13]. By making the Thinkspeak Channel Public (server) and providing the link to the channel, anyone and everyone can access the data that is stored. This makes the whole analyzing and correlating data as a whole since it can be remotely done and it’s very helpful for everyone especially in dire situations like Covid-19.

IoT based AQI systems had been out there for quite a long time now. This is why we can see a lot of work regarding these systems. There are a lot of geographical differences around the world but the general standard is same for all over the world. Industrialization and the increasing popularity of home-based air quality monitoring have brought about the development of systems that can provide real-time data analysis and monitoring of air quality. The concept of an NMOS system was presented in this work by author Truong Tuyen and others in their research paper [14]. These works encouraged other researches to work towards systems that monitors and displays real time air quality of countries. Such as Taha E

Al-jarakh and others following all the standard requirements worked on a system which monitors air pollution of Iraq. It's a stepping stone towards building smart cities. In their work the concept of distributed computing was used to develop a system that combines web services and embedded sensing units. The web services provide the system with real-time data collection and analysis [15].

Vijayakumar Sajjan and Pramod Sharma on their Research on an IoT Based Air Pollution Monitoring System implemented an IoT based framework where the air pollution observing framework is itself the IoT based framework. Their research incorporates a series of MQ sensors and a NodeMCU to send the readings to a ThingSpeak cloud [16]. With all these studies and researches the next stage comes with this whole system to attain more mobility and portability. Keeping this on mind Ajitesh Kumar along with other authors on their project came with the idea of this whole system to be portable and more mobile. Their paper presents an IoT based air quality monitoring system which uses a mobile device to collect data from the surrounding local areas and detect pollution levels. It can as well inform people living in the area with a buzzer about the high pollution levels. It can be set up in households and small offices as well as they claimed [17].

1.3 Aims and Objective

The sole aim of the project is to let people of Dhaka know what sort of a danger the polluted air of Dhaka city possess while breathing in the air. To make this whole thing viable certain necessary parameters and specific particle concentration measuring had been done in this project. The results had been compared with authentic and reliable sources to verify our acquired values and results from our designed system modules. This project also aims to let people around Dhaka city monitor live data from cloud server via different means.

1.4 Scope of the Project

A system had been made with highly reliable SPEC sensors pairing with raspberry pi and cloud server to measure and calculate the necessary parameters for AQI. The acquired results at the same time had been compared with authentic sources to verify them properly. All the values that we acquired from our modules are from different area environment which is almost same as the authentic results that we used to compare with. We have deployed five different modules on different areas of Dhaka city to get a comprehensive idea of the overall situation. Although these modules had been deployed post lockdown for COVID-19 but the result analysis gave some astonishing results while they were compared with different time segment and area.

1.5 Thesis Organization

This thesis book has been organized in such a way that; Chapter 1 gives an overall idea of whole system. This consists of an introduction of the system along with background, aim and scope of the project. The Chapter 2 is a detailed discussion of the theoretical background of this project. In Chapter 3 we have shown the experimental setup along with the methodology of the whole system. The experimental data and the authentic data had been analyzed and discussed in this segment of Chapter 4. Last but not least in Chapter 5 presents the conclusion of this entire thesis and the future plans with the system which has been designed.

Chapter 2

Theoretical Background

2.1 Air Pollution and the Environmental Toxicity

The most alarming factor for the entire world nowadays is environmental issues as well as the ecological balance. A new environmental pollution record is set every day somewhere, Bangladesh being one of the most polluted ones. Since the start of last year Bangladesh's environmental status has worsened significantly day after day. Bangladesh's heavily crowded capital has indeed ranked first in terms of international cities having the worst air quality. According to a worldwide assessment DS on March 18, 2021, Bangladesh's air quality has been the worst in the world, and its center Dhaka is the second most polluted city in terms of air pollution in 2020. [18] Because of a large number of vehicles and new giant projects having been built and implemented, the heart of the country is no longer viable. As per newly revealed worldwide statistics of Air Quality Life Index, each of the country's 64 districts' pollution levels were determined to be hazardous as well as at least three times higher than World Health Organization standards. [19] Research into this topic has shown that Bangladesh's environmental contamination is mainly caused by air particles and gases that pollute. We have therefore attempted to find out how gas toxicity spends reading in the air, what the sources are of impact on life. According to the newest publication of the Energy Policy Institute at Chicago's Air Quality Life Index, polluted air reduces the typical Bangladeshi's expected lifespan by 5.4 years (AQLI). [20] Thus, we in the following research have attempted to determine how the toxic gases spread in the atmosphere and what the causes and the consequences on people's life.

2.2 Assessment of Air Quality

Air is polluted in numerous ways, as we have all learned since childhood, but the sources of air pollution and the amount of pollution emitted by those sources are unknown and frightening. One of the major sources of pollution is transportation, both public and private. Particulate Matter (PM10 and PM2.5), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Sulfur Dioxide (SO_2) and Ozone (O_3) are the five types of pollutants used to calculate the total AQI in Bangladesh. Over the last ten years, the percentage of private cars and motorcycles has more than doubled, and due to the rapid increase in all modes of public and private transportation, air elements like NOx, CO, and PM 2.5 are increasing in concentration day by day, causing air pollution [21].Then, from the growing industries and garment sectors in Bangladesh, chemical discharges are not the same as they were previously. Pollutant gases from there are also acting as a dangerous and threatening object to air quality. Not only that, there are numerous other reasons why our environment is becoming increasingly polluted on a daily basis. As a result, to get a better understanding of what gases are being polluted and how to measure them, we came across AQI, which is the Air Quality Index, which was introduced by the EPA in the United States. Initially known as the PSI (Pollutant Standard Index), it was renamed AQI in 1999 and is now measured in accordance with EPA standards all over the world.

2.3 Air Quality Index (AQI)

Air quality index (AQI) is a numerical scale used to determine daily air quality in terms of the environment and human health. This AQI number is used by the government to show its citizens how the air quality changes over time. Each government determines AQI using its own scale based on its own air quality standards. The Environmental Conservation Rules, 1997 contain the initial ambient air quality standards for Bangladesh. [22] The Environmental Protection Agency's (EPA) Air Quality Index (AQI) measures the quantity of contaminants in the atmosphere. The greater the portion, the more pollutants there are in the air, and the riskier it is for human health. The AQI is color-coded into six groups, beginning with green, which indicates that the quality of air is safe for all to be outside. The indicator then progresses through yellow, orange, red, purple, and maroon in ascending order of contamination. The color maroon corresponds to an AQI of more than 300, signifying a health emergency in which the air is unsafe for anyone to consume [23]. AQI can tell us how polluted our environment's air is and how much it can harm our health. The higher the AQI index, the more dangerous our air is. The AQI focuses on the health effects you'll experience after breathing polluted air for a few hours or days. It aids in warning vulnerable populations that they must take appropriate measures to reduce their exposure to ambient air, as well as in informing the general public that there are serious problems with air quality that must be addressed as a societal responsibility to the entire population [24]

2.4 Safety Assessment of AQI

The safety of the air we breathe is determined by local air quality. The air quality index (AQI) can vary from one location to the next. It is based on exposure to all of the criteria pollutants (PM, CO, O_3, SO_2, and NO_2), with the AQI based on the worst concentration of any of these pollutants. As a result, we need to know how toxic the air particles are. AQI levels are classified into six categories for our convenience.

These are the individuals:

- Good: When the AQI value is between 0 - 50, the air in the area is safe to breathe. In this case, he air is not overly polluted.
- Moderate: An AQI value of 50-100 indicates that the air is slightly polluted, but that this level of pollution is acceptable.
- Unhealthy (for some): When AQI values range between 101 and 150, members of vulnerable groups may suffer health consequences. As a result, they are more likely to be affected than the general public. People with lung disease, for example, are more vulnerable to ozone exposure, whereas people with either lung or heart disease are more vulnerable to particle pollution. When the AQI is in this range, the public is unlikely to be affected [25].
- Unhealthy: An AQI value of 150-200 indicates that it has progressed to the unhealthy stage. Everyone is in grave danger in this kind of air. Any ordinary person could face serious difficulties. People who are hypersensitive will suffer more serious health consequences. When the AQI reaches this level, the government or its agencies must acknowledge its people.
- Extremely Dangerous: When the AQI value is between 200 and 300, it poses a threat to all types of people. This means that everyone inhaling Oxygen from this air will suffer from health problems.
- Dangerous: If the AQI value exceeds 300, everyone in the surrounding area is in grave danger. The entire population will be fabricated.

2.4.1 Sulfur Dioxide

Sulfur dioxide (SO_2) is a sulfur and oxygen-containing gaseous air pollutant. When sulfur-containing fuels such as coal, oil, or diesel are burnt, SO_2 is produced. Sulfur dioxide is also converted in the atmosphere to sulfates, which contribute significantly to fine particle pollution. Sulfur dioxide is present in the atmosphere as a result of both direct SO_2 emissions and emissions of other molecules, such as reduced sulfur compounds or sulfides, which are transformed to SO_2 through chemical processes in the atmosphere.

Table 2.1: Sulfur Dioxide Levels and Their Symptoms [26].

Concentration	Health Concerns
Moderate (0.1–0.2 ppm)	People who are unusually sensitive should avoid lengthy or strenuous outdoor activity.
Unhealthy for Sensitive Groups (0.2–1.0 ppm)	Active children and young people, as well as those with lung diseases such as asthma, should limit their time spent outside for extended periods of time.
Unhealthy (1.0–3.0 ppm)	Adults and children, as well as those with respiratory diseases such as asthma, should prevent excessive or strenuous outdoor activity. All the others, especially youngsters, should limit lengthy or strenuous outdoor activity.
Very Unhealthy (3.0–5.0 ppm)	Any outdoor activity should be avoided by children and adults, as well as those with lung diseases such as asthma. All the others, particularly youngsters, must limit lengthy or strenuous outdoor activity.
Hazardous (> 5.0 ppm)	Health alerts of emergency situations are triggered. It is more likely that the entire population will be affected. Stay indoors and avoid outside activity. If Civil Defense directs you to leave the area, do so.

Volcanoes and wildfires are the most significant natural sources of SO_2. The major anthropogenic source of SO_2 is fossil fuel burning, and industrial chemical manufacturing, as well as pulp and paper manufacture, are sources of reduced sulfur compounds that are transformed to SO_2 in the atmosphere. Anthropogenic sources of SO_2 emissions that contribute to SO_2 levels in the atmosphere are largely big facilities, such as coal-fired power plants [26].

2.4.2 Carbon Monoxide

Carbon monoxide is a colorless, odorless, and tasteless gas produced by the combustion of gasoline, wood, propane, charcoal, or other fuel. Improperly ventilated appliances and engines, particularly in a tightly sealed or enclosed space, may allow carbon monoxide to accumulate to dangerous levels.

Table 2.2: Carbon Monoxide Levels and Their Symptoms [27].

Concentration	Health Concerns
50PPM	There's none for healthy young individuals. According to the Occupational Safety & Health Administration (OSHA), this is the highest allowed quantity for healthy individuals in any eight-hour period of sustained exposure.
200PPM	After two to three hours, there may be a little headache, tiredness, dizziness, and nausea.
400PPM	Frontal headaches after one to two hours. After three hours, the situation became life-threatening.
800PPM	Frontal headaches after one to two hours. After three hours, the situation became life-threatening.
1600PPM	Within 20 minutes, one will experience headache, dizziness, and nausea. Death occurs within an hour.

When carbon monoxide accumulates in your bloodstream, it causes carbon monoxide poisoning. When there is an excessive amount of carbon monoxide in the air, your body replaces the oxygen in your red blood cells with carbon monoxide. This can result in severe tissue damage or even death [28]. The chart depicts the toxicity level of CO. Even trace amounts of Carbon Monoxide are harmful to our bodies. If the concentration reaches 400 PPM, it may even endanger our lives.

2.4.3 Ozone

When pollutants emitted by automobiles, power plants, industrial boilers, refineries, chemical plants, and other sources react chemically in the presence of sunlight, ozone is formed in the Earth's lower atmosphere, near ground level. Ozone is a hazardous air pollutant at ground level.

OSHA's website [28] lists several workplace ozone guidelines:

- 0.2 ppm for a maximum exposure time of 2 hours
- 0.1 ppm for an 8-hour day of light work exposure
- 0.08 ppm for 8 hours of moderate work per day exposure
- 0.05 ppm for an 8-hour day of heavy work exposure
- OSHA workplace O_3 guidelines are time-weighted averages. The following average for ozone levels should never be exceeded: 0.10 ppm (parts per million) exposure for 8 hours per day See the bullet points below [29] for more specific information on safe ozone levels. Our health can be harmed by ozone in the air we breathe. Children, the elderly, people with asthma, and outdoor workers are the most vulnerable to ozone exposure.

2.4.4 Nitrogen dioxide

Nitric oxide is colorless and oxidizes to nitrogen dioxide in the environment. Nitrogen dioxide has an odor and is an acidic, extremely corrosive gas that will harm our health and the environment. Nitric oxide levels that are too high can harm human airways and make people more susceptible to respiratory infections and asthma. Chronic lung disease can be caused by long-term exposure to high amounts of nitrogen dioxide. It can also have an impact on a person's senses, for example, by impairing their ability to smell [30].

Nitrogen dioxide air quality guidelines are as follows:

- 0.12 ppm for a 1-hour exposure period
- 0.03 ppm for an annual exposure period

This standard was created to safeguard vulnerable people, such as children and asthma patients. Outdoor nitrogen dioxide levels are typically much lower than per hour, and exposure to these levels does not often worsen respiratory problems.

2.4.5 PM2.5

PM 2.5 is defined as particulate matter with a diameter of less than 2.5 micrometers floating in the air. Because these particles are so small, they can only be seen through a microscope. If the concentration of PM 2.5 rises significantly, it may also harm us [31].

Table2.3: Levels of PM2.5 [32]

PM 2.5	AQI Level	Health Effects
0-12	Good	There are little to no hazards.
12-35.4	Moderate	Individuals with unusually sensitive respiratory systems may have respiratory system problems.
35.5-55.4	Unhealthy for sensitive group	Increased risk of respiratory symptoms in sensitive people, worsening of heart or lung illness, and early death in those having cardiopulmonary disease and the elderly.
55.4-150.4	Unhealthy	Enhanced aggravation of heart or lung illness and early death in those with heart and lung diseases and the elderly; increased breathing difficulties in the general population.
150.4-250.4	Very Unhealthy	Considerable worsening of heart or lung disease, as well as early death in those with heart and lung diseases and the elderly; substantial increase in respiratory effects in the normal community.

PM 2.5	AQI Level	Health Effects
250.4-500	Hazardous	Significant worsening of heart or lung illness and early death in those having cardiopulmonary disease and the elderly; significant threat of respiratory complications in the normal community.

Fine particulate matter (PM2.5) is an air pollutant that is hazardous to people's health when levels in the air are high. PM2.5 pollutants are tiny particles in the air that reduce visibility and make the air appear hazy when levels are high. Fine particles can be found both indoors and outdoors. Outside, fine particles are primarily emitted by car, truck, bus, and off-road vehicle (e.g., construction equipment, snowmobile, locomotive) exhausts, as well as other operations involving the combustion of fuels such as wood, heating oil, or coal, and natural sources such as forest and grass fires. Fine particles can also form as a result of the reaction of gases or droplets in the atmosphere from sources such as power plants. These chemical reactions can take place thousands of miles away from the source of the emissions. [33].

2.4.6 PM10:

PM10 particles, often known as fine particles, have a diameter of 10 micrometers. PM10 is also referred to as repairable particulate matter [34] by an environmental specialist. Because the particles are so tiny, they behave like a gas. They reach the lungs deeply when inhaled [35]. The amount of PM10 in the air is rising, resulting in air pollution and raising the risk of disease.

The health effects of PM 10 particulate matter is discussed in the table below, along with the AQI level condition:

Table 2.4: PM10 Concentrations and Associated AQI Classes [36].

PM10 (ppm for24 Hours)	**AQI Level**	**Health Impacts**
0-54	Good	As the air is not heavily contaminated, it is suitable for breathing.
55-154	Moderate	Adults who are in good health have none.
155-254	Unhealthy for Sensitive group	People who are elderly or have had previous health difficulties may be concerned.
255-354	Unhealthy	People of all ages can experience health effects such as coughing and wheezing.
355-424	Very Unhealthy	When anyone is sensitive to air pollution, such amount of concentrations will make living inside the area more difficult. The general public will also be affected by the hostile climatic conditions.
425-604	Hazardous	High blood pressure, heart attacks, strokes, and early mortality can all be caused by exposure to such level of PM10.

The remaining AQI parameters include NO_2 and SO_2, but due to a lack of sensor and data, we opted to leave those out of our study. However, of all the air quality measures we considered, $PM_{2.5}$ is the best, and CO and Ozone are the two most harmful pollutants. In this instance, NO_2 and SO_2 have a lower impact on identifying contaminants.

2.5 AQI Calculation

In various regions, the Air Quality Index is calculated differently. Canada, Hong Kong, the United Kingdom, and a few other nations calculate AQI in their respective method. Nevertheless, in our study, the AQI based on the United States is utilized, and the following is the EPA's calculation methodology for AQI:

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} \times (C_{high} - C_{low}) + I_{low} \quad \text{..............................(2.1)}$$

Here,

I=Air Quality Index

C=Pollutant concentration

C_{high}=Concentration breakpoint that is higher than C

C_{low}= Concentration breakpoint that is lower than C

I_{high}=Index breakpoint corresponding to C_{high}

I_{low}=Index breakpoint corresponding to C_{low}

The goal of this formula is to determine the AQI level; however there are a few factors that are unidentified. The EPA uses these to calculate the AQI based on the amounts of particular gases. The accompanying table, which displays a fixed value for individual particular gases per time in the atmosphere, must be used to get the quantities of such unidentified variables C_{high}, C_{low}, I_{high}, and I_{low}.

Table2.5: Air Quality Calculation Chart from the EPA [37] [38].

O3(ppb)	**PM2.5(μg/m^3)**	**PM10(μg/m^3)**	**CO(ppm)**	**SO2(ppb)**	**NO2(ppb)**	**AQI**	**AQI**
Clow-Chigh	*Clow-Chigh*	*Clow-Chigh*	*Clow-Chigh*	*Clow-Chigh*	*Clow-Chigh*	*Ilow-Ihigh*	Category
0-54 (8-hr)	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106–200 (8-hr)	150.5-250.4 (24-hr)	355–424 (24-hr)	15.5-30.4 (8-hr)	305–604 (24-hr)	650-1249 (1-hr)	201-300	Very Unhealthy
405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	

2.6 Brief description of different components of our system

Environmental concerns are now the most important element in the globe. This aspect does not appear to be improving. It's becoming progressively worse. Every day, the level of pollution in the environment rises to unprecedented heights. Bangladesh is one of several countries whose environmental conditions are deteriorating at an alarming rate. We have reason to be concerned since, according to the World Air Quality Index (AQI) Study released earlier this year, the South Asian country has recently been classified as the most polluted country in the world, with its capital Dhaka ranking as the second most polluted city. [39] For years, air pollution has wreaked havoc on Bangladesh, claiming lives and creating financial damage as well as ecological threats connected to contamination, prompting experts to be concerned about the future. South Asia remains the most polluted area in the world, as per the AQI study, with Bangladesh, India, and Pakistan occupying 42 of the world's 50 highly polluted cities. [40] As a result, it has been demonstrated that Bangladesh's air quality is deteriorating. Then the topic of how air pollution is increasing day by day may arise. To identify the answer, we must first determine the primary sources of pollution. We discovered that various hazardous air particles and gases are present after conducting some research on air pollution. So we attempted to figure out how toxicity of gases in the air works, where they come from, and how they influence our life. That is why we require real-time data. We can calculate the current condition and predict future outcomes using real-time data. The project's main goal is to collect AQI data in real time.

2.6.1 SPEC Sensors

SPEC Sensors was created to provide the gas sensing knowledge that enables this trend and to make gas sensing a part of people's daily life. Based in California near Silicon Valley, they merge their vast expertise in dependable and time-tested gas sensing technological innovations with unique production methods to create gas sensors which are tiny and will go anywhere while maintaining the high performance required delivering useful information. They are proud of their rich heritage in gas detection as well as their extensive participation in cutting-edge technologies. [41] We discovered that SPEC gas sensors are superior to others for university projects. We employed both analogue and digital gas sensors to construct our prototype. We begin with an analogue sensor. With the analogue sensor, we had some difficulty in creating a circuit since, due to the covid-19 scenario; we did not have the opportunity to work in the laboratory and could not obtain the required components. That is why we chose digital sensors, which were simple to attach. There are numerous more reasons to select SPEC digital gas sensors.

They are (As per standard conditions):

- Low power consumption (100µW in standby mode)
- Fast response (less than 30 seconds)
- Measurement accuracy is 15% of reading
- Measurement range is 0 to 5 ppm
- Easy way to add gas sensing to the IoT
- Simple digital UART interface
- Robust 10 year estimated life

We have selected the following SPEC sensors for our research work:

1) DGS-CO 968-034 sensor for detecting Carbon Monoxide
2) DGS-O3968-042 sensor for detecting Ozone
3) DGS-H2S968-036 sensor for detecting Hydrogen Sulfide
4) DGS-NO2968-043 sensor for detecting Nitrogen Dioxide

The majority of the parameters in this research were monitored using SPEC gas sensors. All of the sensors operate with the Raspberry Pi in the same way, and their integrations are similarly comparable. Female socket connectors are used to make electrical connections to these digital gas sensors. On one end of the board, this connection also offers mechanical stiffness. To offer an extra mechanical connection, a through-hole is put on the other end of the board.

The effect of temperature of zero shifts is measured in parts per million (ppm). The sensitivity is given in relation to the sensitivity at the calibration temperature of 20 °C. When using temperature compensation, first adjust the temperature influence on the offset and then rectify the sensor's sensitivity [42].

Calculation:

The method for the targeted gas concentration:

$$C_x = \frac{1}{M}(V_{gas} - V_{gas0}) \qquad (2.2)$$

Where,

C_x – Gas Concentration (ppm)

V_{gas} – Voltage output gas signal (V)

V_{gas0} – Voltage output gas signal in clean air

The method for 'M' is:

$$M\left(\frac{V}{ppm}\right) = \text{Sensitivity code}\left(\frac{nA}{ppm}\right) \times \text{TIAGain}\left(\frac{kV}{A}\right) \times 10^{-9}\left(\frac{A}{nA}\right) \times 10^{3}\left(\frac{V}{kV}\right) \qquad (2.3)$$

Where,

TIA Gain = the gain of the trans-impedance amplifier

The method for '$Vgas_0$' is:

$$V_{gas0} = V_{ref} + V_{offset} \qquad (2.4)$$

Where,

V_{ref} = the voltage output reference signal

V_{offset} = voltage offset factor

A rectangular female socket connector is used to make electrical connections to the digital gas sensors. On one end of the board, this connection also offers mechanical stiffness. To give extra mechanical data, a through-hole is positioned on the other side of the board. [43]

Table 2.6: Interface Specification of SPEC sensors.

PIN	Function	Notes
1	N/C	Not connected
2	RX	RX of UART
3	TX	TX of UART
4	N/C	Not connected
5	N/C	Not connected
6	GND	Ground
7	N/C	Not connected
8	V+	Voltage Supply Input: 3.0 to 3.6V

Figure 2.1: Basic SPEC sensor [44].

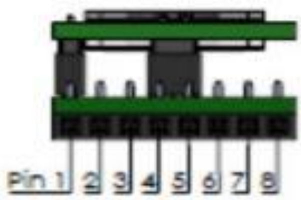

Figure 2.2: Pin out of SPEC sensors [44].

A potentiostat is a circuit that regulates the potential of the active electrode and transforms the working electrode current to voltage. Here is a modified layout of a sensor and a potentiostat. A steady voltage at U1, pin 2 establishes the potential of the reference electrode (RE). A steady voltage at U2, pin 5 establishes the potential of the working electrode (WE).The bias potential of the sensor is defined as the voltage at WE with respect to RE. The operational amplifier, U2, converts the working electrode (WE) current to a voltage. The op-amp, U1, creates a voltage at the counter electrode (CE) that is adequate to supply a current that is precisely equal to and opposite to the current at the working electrode [44].

Firstly, when powered up after a lengthy period of inactivity, the sensor must stabilize in clean air to its zero-offset current. We must wait at least one hour in fresh air to ensure that the USB port has not gone to sleep. One method to ensure this is to sample in continuous mode. When the DGS is connected to V+ and GND, the microcontroller of the module will automatically setup the sensor and circuit for function, output a measurement, and afterwards engage a low power stand-by mode. Critical sensor circuitry stays active in stand-by mode to assure the high precision for future sensor measurements. If the module is turned on and in low-power stand-by mode, any data received on the UART interface will TRIGGER a measurement that is sent via UART. There is a one-second delay between when the module gets a command and when it transmits a response due to the high-accuracy ADC sampling method. Following that, the module will revert to low-power stand-by mode. I mentioned earlier that we are utilizing digital sensors, and all of them function in the same way with the Raspberry Pi and have comparable integrations. Initially, we linked all of our sensors to a USB hub, and then we attached the USB hub to the Raspberry Pi's USB port. Finally, we put our programs into action to obtain the data we need from the sensors [44].

2.6.2 PM Sensor

The Nova PM sensor (SDS011) includes a built-in fan to guarantee optimum air circulation to a chamber with a laser diode that determines the size and quantity of PM. There are a few important aspects that drew us to this sensor [45].

They are:

- Provides precise and dependable results with good consistency; response time is less than 10 seconds; and it is simple to integrate: UART output.
- g/m3 to 999.0 g/m3
- 5V is the rated voltage.
- 70mA (10mA) rated current
- PM2.5 and PM10 measurement parameters
- Up to 8000 hours of service life

It operates on the basis of laser scattering. The air reaches through the air intake, where a source of light highlights the particles and a photo detector converts the scattered light into a signal. These signals are amplified and analyzed to determine PM2.5 and PM10 particle concentrations. It has a concentration range of 0.3 to 10m in the air. There is a preset setup for real-time data that monitors at a frequency of one time per second [45].

Table 2.7: Interface Specification of PM sensor.

PIN	Function	Comment
1	N/C	Not Connected
2	1µm	PWM Output
3	5V	5V Input
4	2.5 µm	PWM Output
5	GND	Ground
6	RX	RX of UART @3.3V
7	TX	TX of UART @3.3V

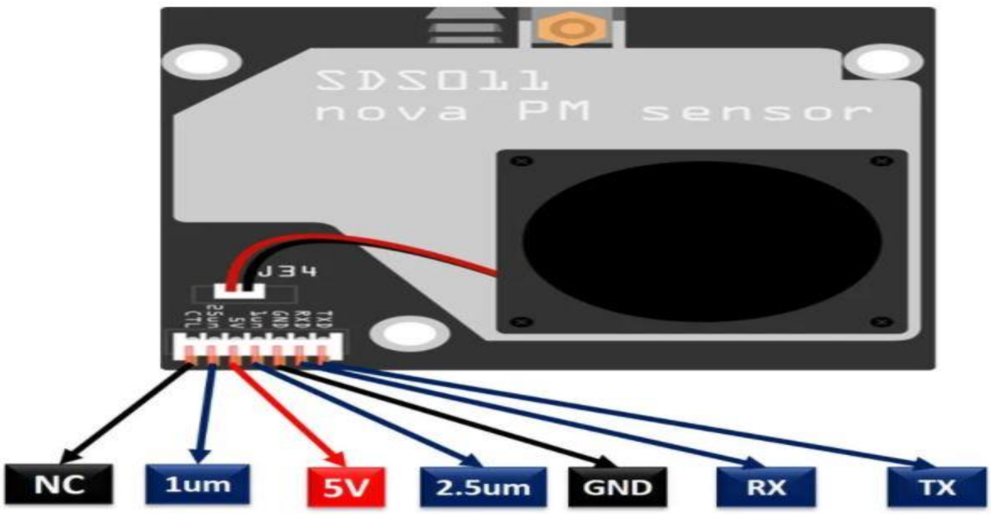

Figure 2.3: Pin out of PM sensor [46].

Calculation:

The UART communication protocol [47]:

Bit rate	9600
Data bit	8
Parity bit	NO
Stop bit	1
Data Packet frequency	1Hz

Table 2.8: UART communication protocol of PM sensor [47].

Number of bytes	Name	Content
0	Message header	AA
1	Commander No.	C0
2	DATA 1	PM2.5 Low byte
3	DATA 2	PM2.5 High byte
4	DATA 3	PM10 Low byte
5	DATA 4	PM10 High byte
6	DATA 5	ID byte 1
7	DATA 6	ID byte 2
8	Check-sum	Check-sum
9	Message tail	AB

The method of Check-sum:

Check-sum=DATA1+DATA2+ DATA3+ DATA4+ DATA5+DATA6......(2.5)

The method of $PM_{2.5}$ value:

$PM_{2.5}$ (µg /m3) = (($PM_{2.5}$ High byte *256) + $PM_{2.5}$ low byte)/10..................(2.6)

The method of PM10 value:

PM10 (µg /m3) = ((PM10 high byte*256) + PM10 low byte)/10.................(2.7)

As previously stated, the SDS011 sensor provides us with a digital value. First, we attach this sensor to the Raspberry Pi using a USB adapter, and then we write the code to extract useful data from it.

2.6.3 Raspberry Pi:

The Raspberry Pi is a small card-shaped computer built by the Raspberry Foundation in the United Kingdom that connects to your computer display or TV and utilizes a normal keyboard and mouse. It's a tiny, powerful gadget that teaches individuals of all ages how to navigate computing and write in languages like Scratch and Python. We can carry out all of the operations we anticipate on your desktop PC. This tiny gadget's characteristics make it a strong IoT device. The Raspberry Pi 4 Model B is the most powerful Raspberry Pi model ever created [48].

Our project used a Raspberry Pi 4B model with 4GB RAM. We chose Raspberry Pi because we have an IoT-based project. It includes Wi-Fi functionality so you can store your data in the cloud.

Figure 2.4: Raspberry Pi 4 Model B [49].

The Raspberry Pi 4 is powered by a Broadcom BCM2711 SoC with a 1.5 GHz quad-core ARM Cortex-A72 CPU and 1 MB shared L2 cache. Some more hardware features are listed below:

- Bluetooth 5.0, WLAN 2.4GHz/5.0GHz, and Gigabit Ethernet connection • 4GB LPDDR4 SDRAM memory
- There are two USB 3.0 ports and two USB 2.0 ports.
- A 40-pin GPIO Header connector.
- Two micro-HDMI ports (up to 4Kp60 UHD supported).
- H.265 decoding (4kp60) H.264 decoding (1080p60)

The latest Raspberry Pi flagship, the fourth-generation Raspberry Pi 4 B, has Wi-Fi and Bluetooth. Its predecessor, the Raspberry Pi 4 B, offers dual-band 802.11acn Wi-Fi that can operate at either 2.4GHz or 5GHz. It also includes Bluetooth 5.0.The first step is to connect the Raspberry Pi to a terminal. This is accomplished by connecting your Raspberry Pi to a display and keyboard. Every time you read this network name and password in the instructions, replace them with the local network's network name and password. We may simply connect to the internet via Wi-Fi by following this easy approach. In June 2019, the Raspberry Pi 4 Model B was released, featuring a 1.5GHz64-bit quad-core ARM CortexA72 processor, onboard 802.11ac Wi-Fi, Bluetooth 5, full Gigabit Ethernet (throughput is unlimited), 2 USB 2.0 ports, 2 USB 3.0 ports, 2-8 GB of RAM, gigabit ethernet port, raspberry pi camera port, and micro-HDMI with up to 4K resolution (Dual monitor support via HDMI Type D) port pair. The Raspberry Pi 4 is fueled by a USB-C connector that delivers 5V at 3A [50].

GPIO Pin: The Raspberry Pi's row of GPIO (general purpose input/output) pins at the top of the board is a valuable feature. The term "GPIO" refers to a signal pin on an integrated circuit or board that may be utilized to conduct digital input or output tasks. It has no specified purpose by design and may be utilized by the hardware or software developer to accomplish any functions they choose. All Raspberry Pi boards now include a 40-pin GPIO header. Any of the GPIO pins can be defined as an input or output pin (in software) and utilized for a variety of applications [51].

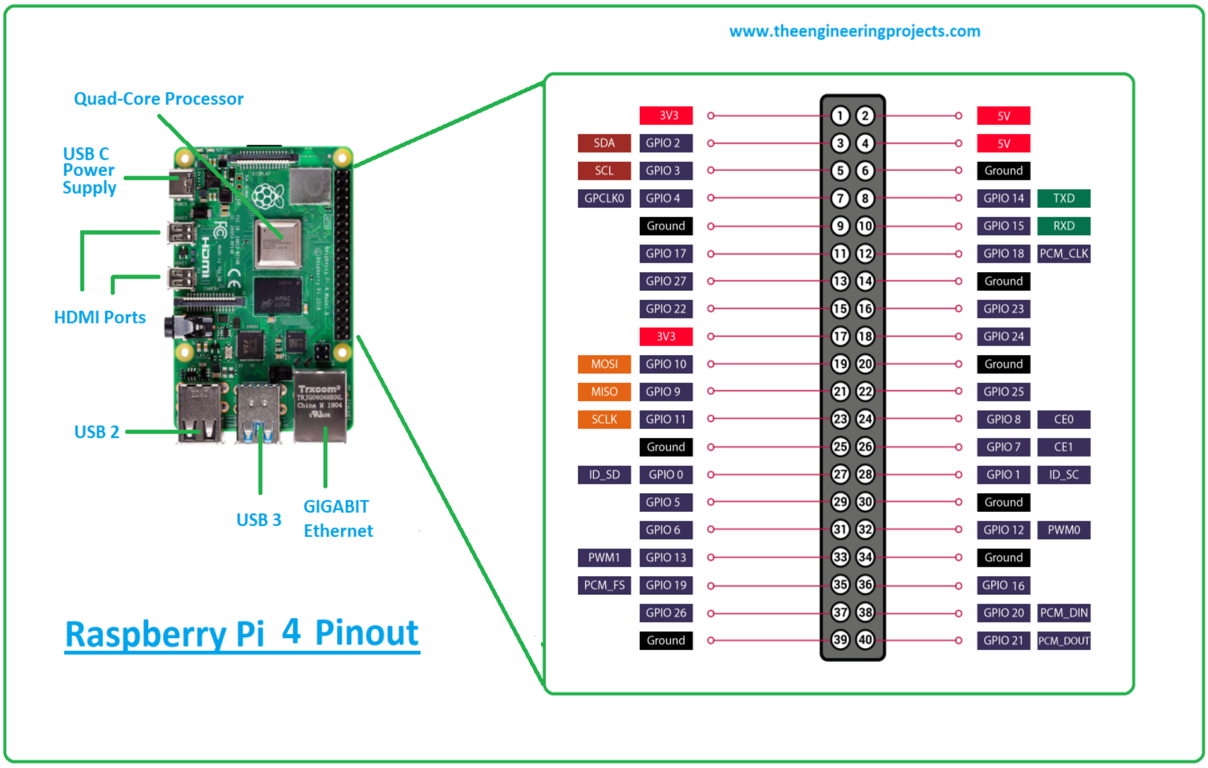

Figure 2.5: Interface and pin out of raspberry pi [52].

2.6.4 Python

Different sorts of programming languages are used to create the software and applications that we use every day. Programming languages such as C, C++, Java, VHDL, and others are available nowadays. Humans study and write all of these computer languages. Each language has distinct characteristics that distinguish it from others. As technology advances, we can witness changes in these languages that provide improved services to consumers. According to the TIOBE Index for May 2021 [53], Python is such a popular language that it is ranked first. As a result, you can guess how user-friendly, simple, and useful this software is.

Guido Van Rossum, a Dutch programmer, was the first to create Python. It began in 1980 and was officially introduced in 1991, ten years later. Python is a high-level, interpreted, and general-purpose programming language that is open-source. This is incredibly user-friendly and simple to operate. It is also regarded as an efficient language. Python allows you to construct programs quickly. Python is used to create desktop graphical user interface (GUI) applications, websites, and web applications, as well as System Software, Game Development, App Development, Computer Graphics, and server-side programs. Python is a computer language similar to C and C++, although it is more user-friendly. It has a distinctive syntax that makes it incredibly user-friendly. Many programmers can learn and translate Python code, which is much easier than other programming languages. Python has a dynamic type system and automatic memory management, allowing you to save money on program maintenance and development. A Python group can interact and collaborate since comprehending each other's code with its unique syntax is very simple.

Many big shots use it since it is an extremely efficient language. YouTube, Quora, Google, Instagram, Pinterest, and other social media platforms are examples. Modules and packages can be used with the Python language. That is to say, programs developed in this language are modular and capable of performing a variety of critical functions. These modules can be used in a variety of projects. Importing and exporting them is really simple.

Python is an object-oriented programming language that may be used to build and create software. Python is also an interpreted language, which means that you don't have to compile the code to make it computer readable before running it. In other languages, you must transform the source code to object code before it can run. Python may be run on practically any computer by using this interpreted technique. It is a platform-agnostic language that may be used on Windows, Mac OS X, and Linux. Artificial intelligence and data science are two fields where this language is employed. A large number of internet protocols are supported by Python's standard library. HTML, XML, JSON, IMAP FTP, and other similar technologies are examples. Because it is an open platform language, the language code is reusable and always available to all users. Users will be able to download and change it individually. Other languages such as C and C++ can be used with it.

2.6.5 Case, Fans and Heat sink

We use a case to protect the Raspberry Pi from injury and to keep all of the sensors in one location. We've also included a copper heat sink to assist drain heat from the Raspberry Pi's processor and keep it cool so it doesn't overheat and shut down. We must ensure that our Raspberry Pi does not turn off due to external variables, one of which is heat, in order to obtain consistent and trustworthy data.

We've also included fans to keep the processor cool, as heat dissipation alone won't be enough to keep the Raspberry Pi running. It consumes some power, but this is inconsequential because the Raspberry Pi has enough power to run its USB ports.

2.6.6 ThingSpeak

ThingSpeak is a cloud-based data platform that allows you to send and receive data. There are additional systems that function similarly to ThingSpeak. There are a few unique elements to it, however there are many other platforms where you can accomplish the same thing, such as EXOSITE, xively, carriots, nimbits platform, and you can even utilize Microsoft Azure to construct your own platform like this or Google cloud computing. However, one feature of ThingSpeak is that it integrates well with MATLAB because it is owned by the parent firm math works, allowing ThingSpeak to be easily connected with MATLAB [54].

IoT ready: A fairly general use case for ThingSpeak includes the presence of a sensor someplace. This might be a wireless sensor network or an array of sensors linked to a microcontroller or CPU. And ThingSpeak serves as an information database or repository, to which we may transmit and retrieve data. We will need a computer to access this data, and all of this processing will take place on the cloud.

However, the fundamental concept is that we have a Raspberry Pi that collects SPEC and PM sensor data and is capable of sending HTTP requests to the cloud and adding it to ThingSpeak.com [55]. ThingSpeak accepts these HTTP requests and includes the data from the Raspberry Pi in the database. Of course, when we submit an HTTP request, we want to make sure that we get a response indicating that our request was received and processed appropriately. So, the Raspberry Pi sends this request to ThingSpeak, and ThingSpeak responds with the proper response. ThingSpeak now has some data in its database from the Raspberry Pi SPEC, PM sensor that was attached to it and now, wherever we are in the cloud, we can send HTTP requests to ThingSpeak over the cloud from a laptop, computer, mobile device, or even another Arduino or microcontroller. ThingSpeak will then reply by sending the data set back over the cloud to the device that requested the data, where it can be shown on a graph or recorded in a table or anything similar. So, essentially, ThingSpeak offers us with a means to store data collected by our Raspberry Pi and then see that data from anywhere on the internet.

2.6.7 VNC Viewer

VNC is an abbreviation for Virtual Network Computing. It essentially allows users to access their computer, laptop, or other mobile devices from other laptops and desktops. This software was designed to allow us to remotely control another computer. One must ensure that we have installed the VNC server software on the device that we wish to manage or access. [56] To for it to function correctly, we needed to install the VNC server on the device, created an account, and set a password. We ensured that we remembered the password. To gain access to our preferred device, we installed VNC viewer on the device. We then opened to login to the device using the password you created previously. With this program, anyone can accomplish nearly anything. It can even be turned off remotely.

Chapter 3

System Description & Methodology

3.1 System Description:

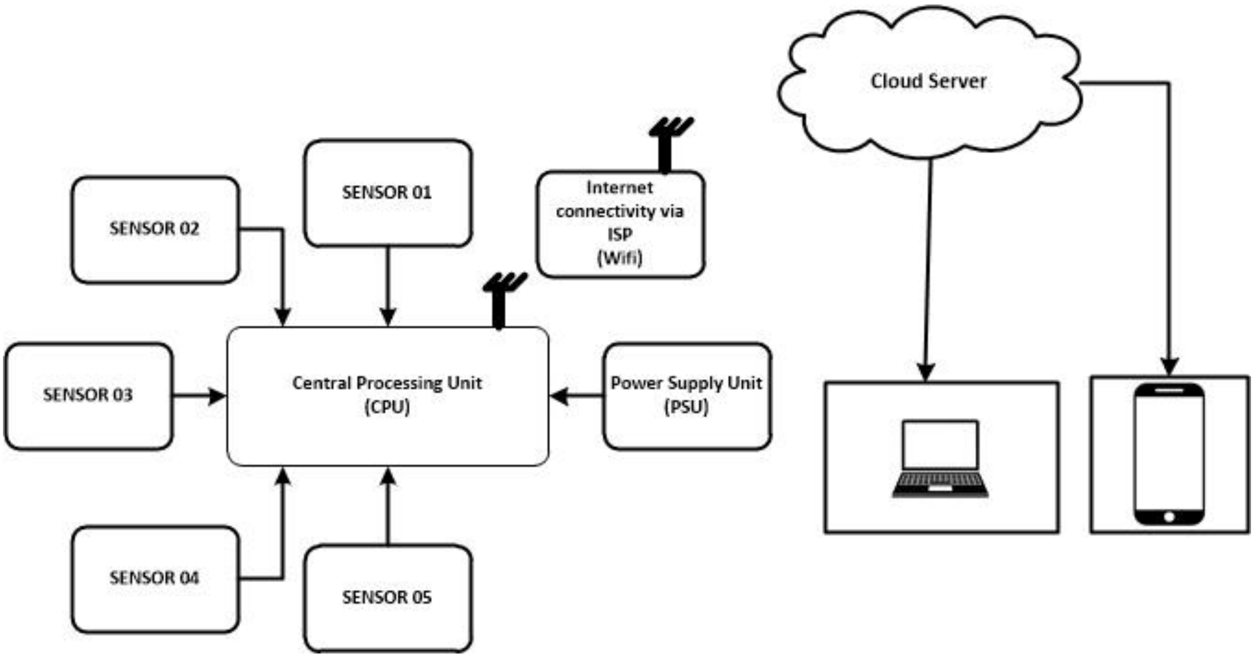

Figure 3.1: Concept Block diagram of the proposed IoT Based AQI Measurement Module.

As we know, air is a basic thing to us to live by. But the matter of sorrow that, this air is polluting in many ways. Day by day it's getting worse. There are several gases and particulate matters are responsible for air pollution. We know that Carbon Di Oxide (CO2) is the most dangerous for public health and nature. Carbon Monoxide is another poisonous gas which can cause brain damage and directly contributes for air pollution [57]. There are some other gases like Ozone, Sulfates, and Methane which can cause air pollution [58]. To pollute the air particulate matter (PM) has most significant contribution. In Dhaka this particulate matter is the most harmful for public health and the environment compared to other pollutants [59].

To design the proposed IoT based Air Quality Index (AQI) Measurement Module we need several components.

They are:

1. Sensors
2. Power Supply Adapter
3. Raspberry Pi 4B as CPU
4. Internet connectivity via Wi-Fi
5. Cloud Server

At first, we will power up the CPU through the power supply adapter and then connect the CPU with internet through Wi-Fi or Ethernet cable. Sensors will be connected to CPU and directly send data to CPU. Afterward, CPU will store data on its memory and send to the cloud server. It will continue same process again and again because we need real-time data. Finally, we can see the data by using a laptop or a mobile.

Approach-01:

At the very first stage, we have built a prototype based on proposed design. To build this prototype we have used low-cost sensors which are available in local market. The purpose was to check the module's total functioning system. The prototype was working good and able to send data to the cloud server remotely. Fig 3.2 shows the concept block diagram of the hardware module. Fig 3.3 shows the pin out diagram of the prototype considering all the elements and Fig 3.4 shows the image of the prototype.

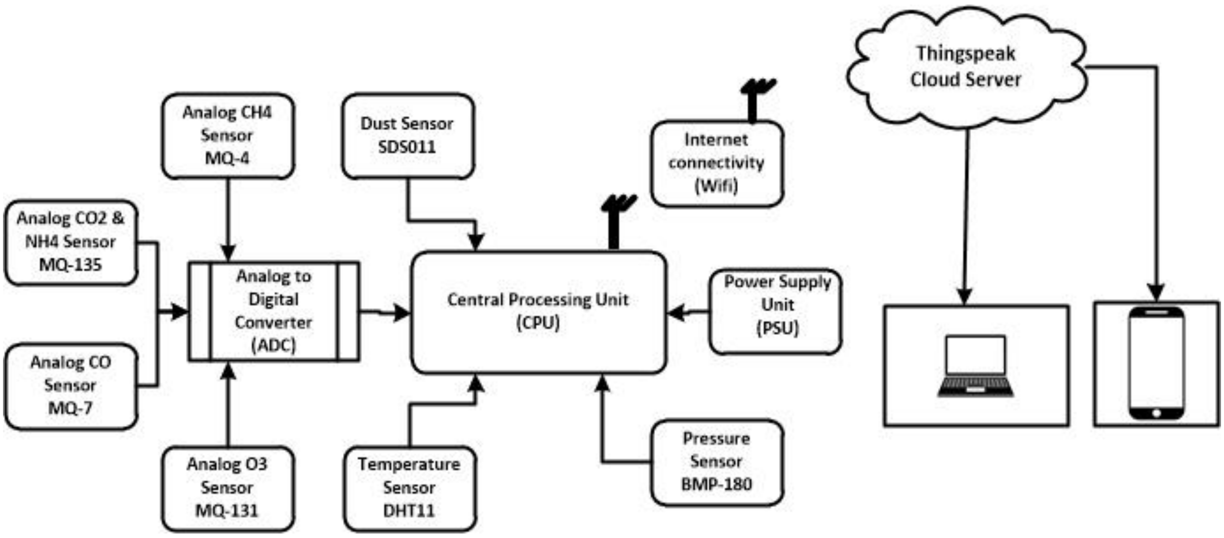

Figure 3.2: Approach-01 Block diagram of the proposed IoT Based AQI Measurement Module.

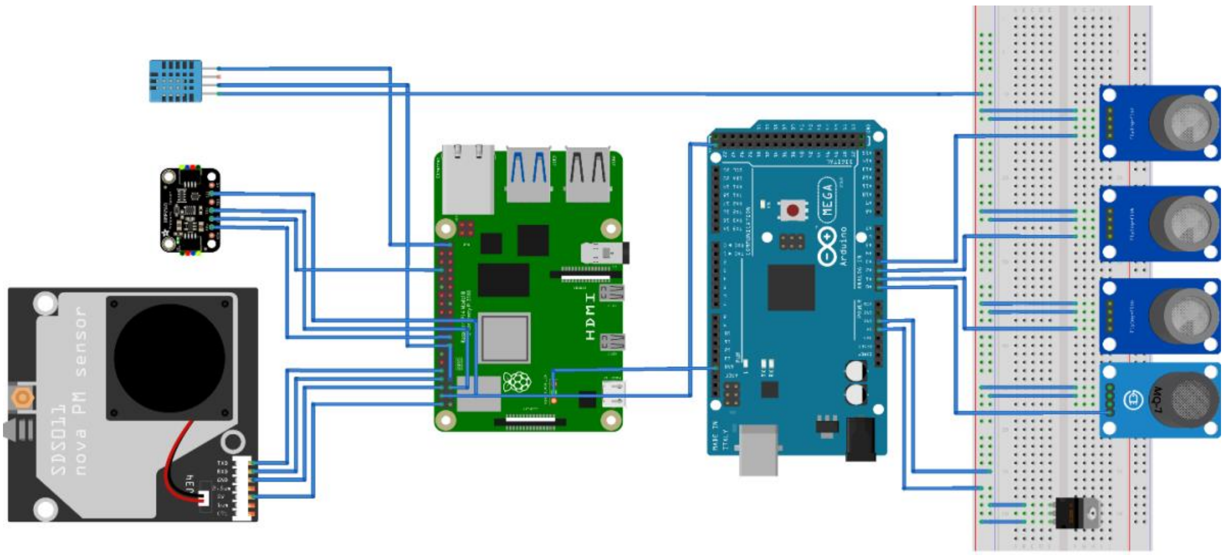

Figure 3.3: Pin out diagram of Approach-01.

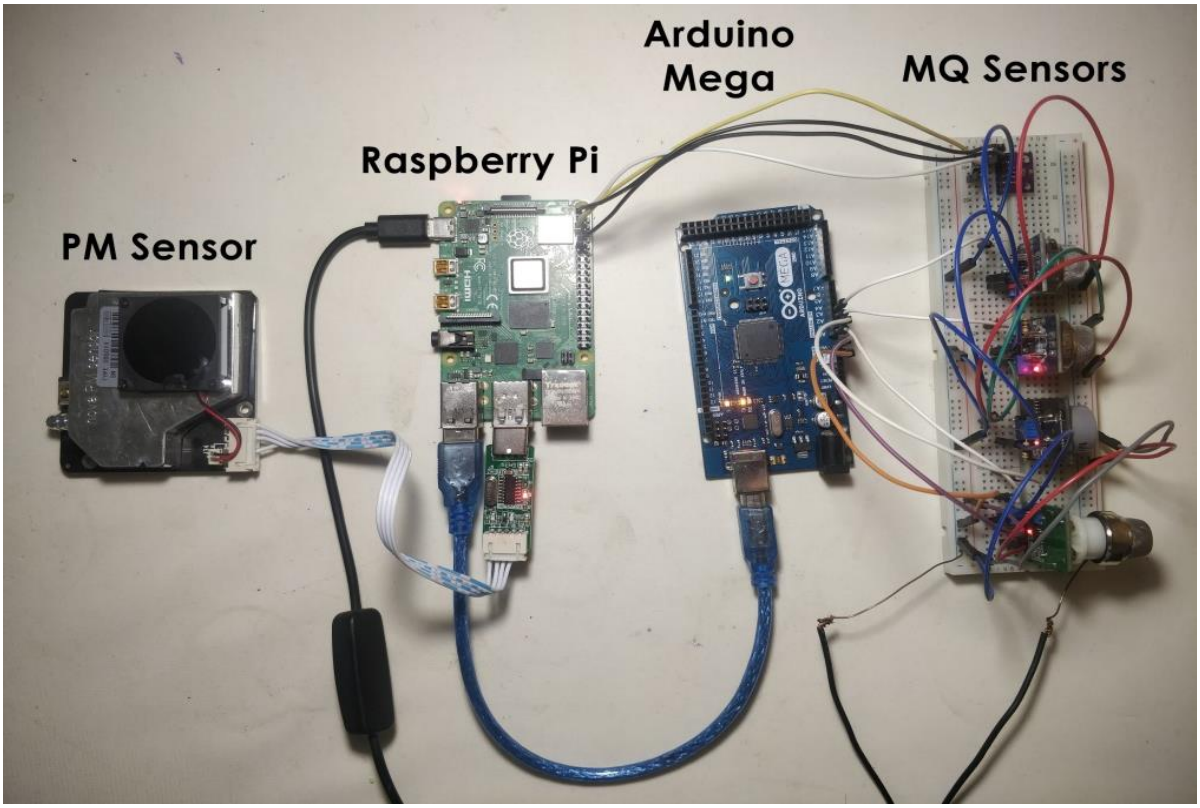

Figure 3.4: The snapshot of the module.

We had implemented the project with the help of a Raspberry Pi and an Arduino. For detection, there was a dust sensor along with some MQ sensors. We had tested the sensors individually and then we implemented the whole setup. We used an Arduino as analog to digital converter (ADC) because all MQ sensors were analog sensor. Arduino was used to read the analog sensor data and send to the Raspberry Pi which is the main working medium. The Raspberry Pi receives the digital data from the Arduino and sends it to the Cloud Server. A 5V 4000mAh charging power supply (through adapter) works as the principle power supply of the whole system.

These following components were taken in use:

Table 3.1: Components of Approach-01.

Serial No.	Component Name	Specification/Model
1	Raspberry Pi	Pi 4 model B (4GB Ram)
2	Arduino	Arduino Mega
3	PM Sensor	SDS011
4	CO2 & NH4 Sensor	MQ-135
5	O3 Sensor	MQ-131
6	CO Sensor	MQ-7
7	CH4 Sensor	MQ-4
8	Pressure Sensor	BMP280
9	Temperature and Humidity Sensor	DHT11
10	Raspberry Pi Power Adapter	C-type 5V 3A
11	Wire	-
12	Breadboard	-
13	Potentiometer	-
14	Voltage regulator	-

Approach-02:

At this stage, we had modified the design based on proposed design. To build this prototype we have used mid-cost sensors which are available in local market. The purpose was to check the module with better sensors. We had faced several problems when modifying the module. Fig 3.5 shows the concept block diagram of the hardware module. Fig 3.6 shows the pin out diagram of the prototype considering all the elements. Fig 3.7 shows the image of the modified module.

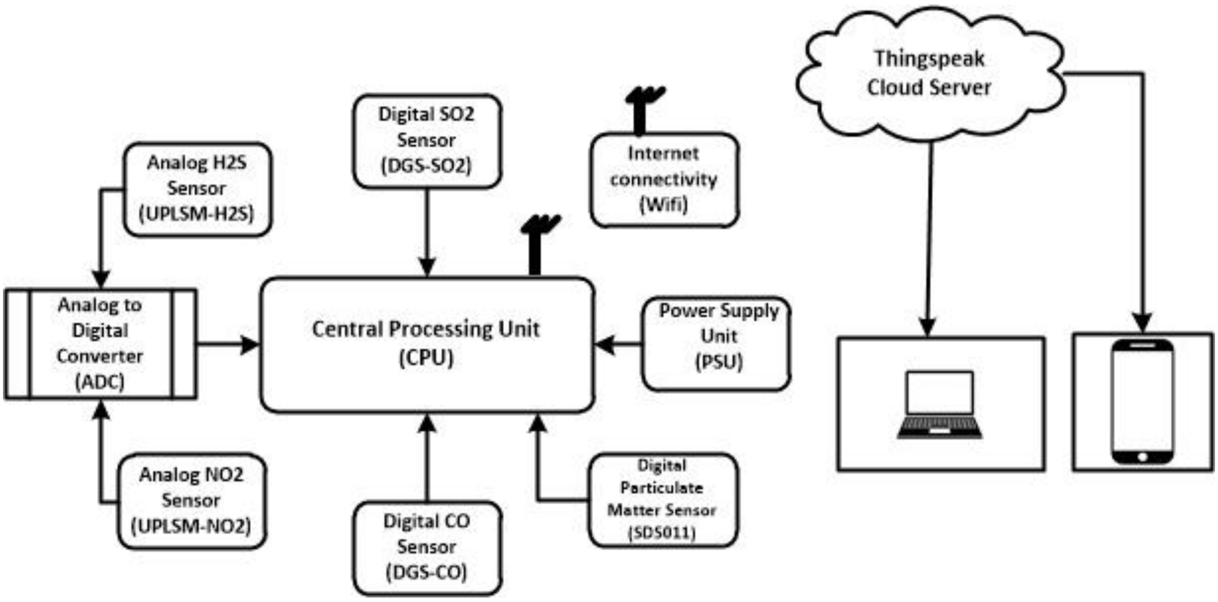

Figure 3.5: Approach-2 Block diagram of the proposed IoT Based AQI Measurement Module.

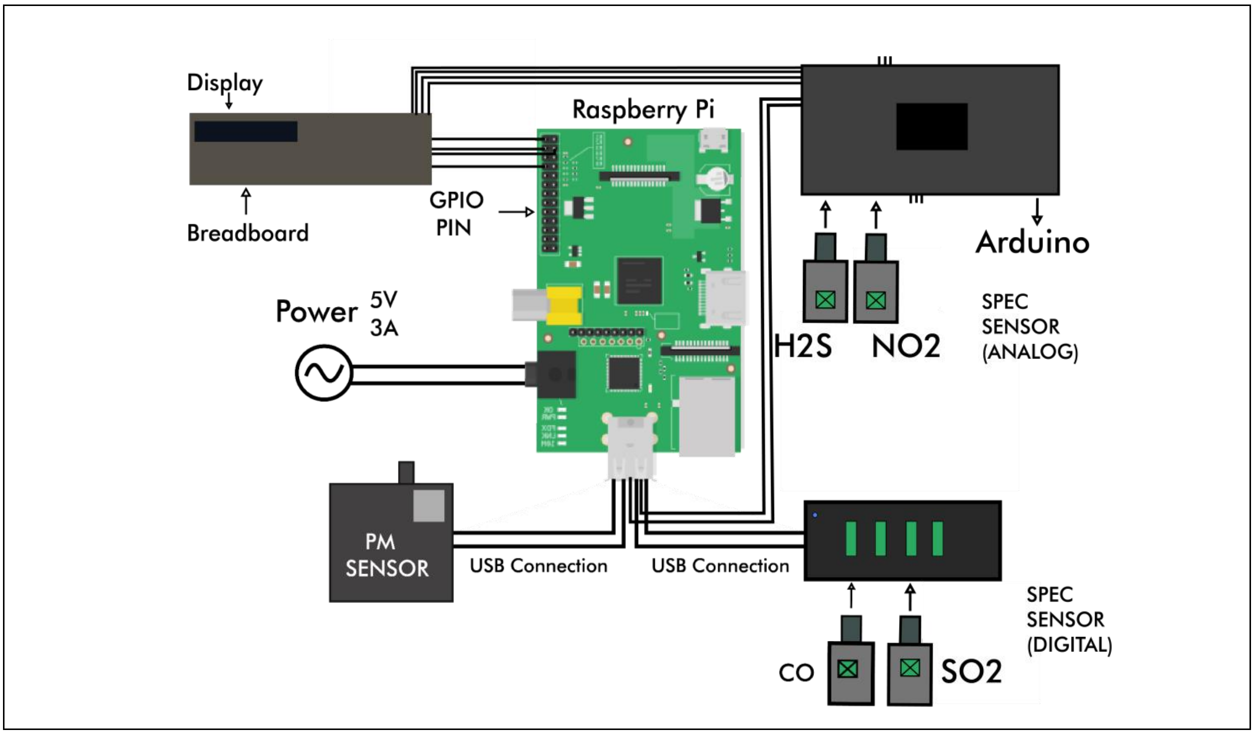

Figure 3.6: Pin out diagram of Approach-02.

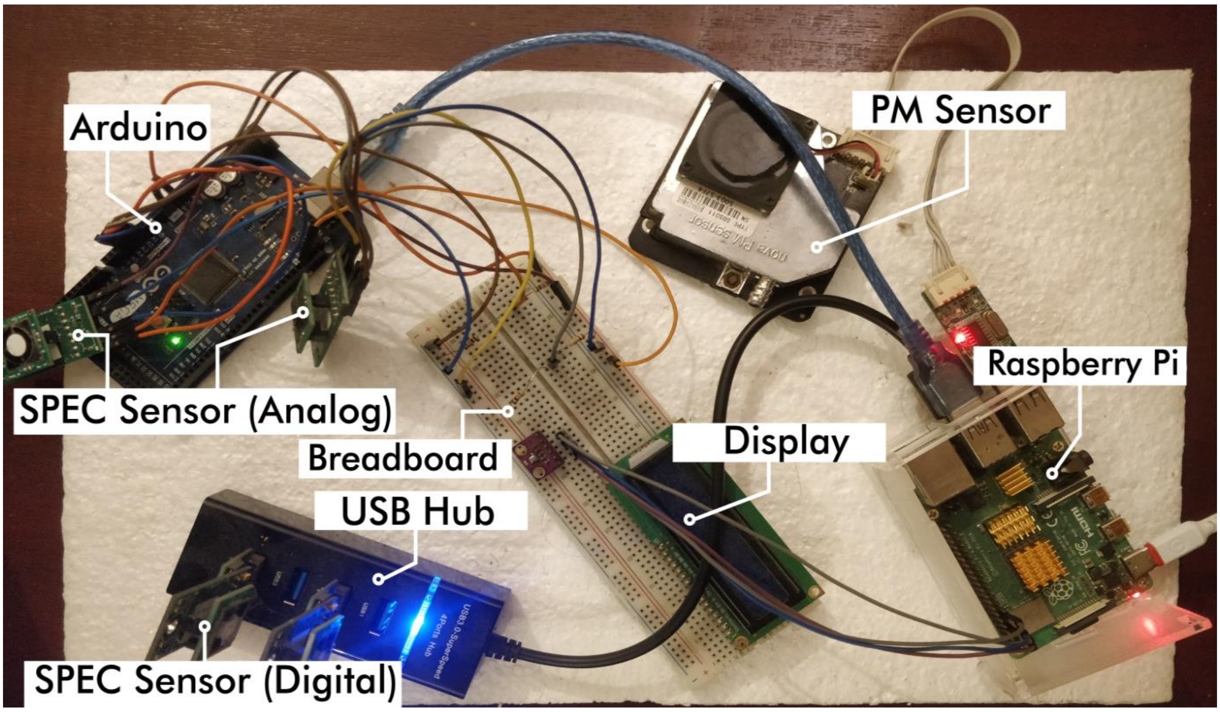

Figure 3.7: The snapshot of the module.

We had used similar methodology for our second approach. We had used both analog and digital sensor. But the thing is we were not getting our desired value from the analog sensors. We wanted to try different microcontrollers as ADC instead of Arduino but we couldn't. Because of the Covid-19 situation we did not get laboratory facility and also lockdown was going on. On the other hand, digital sensors were working nearly perfect and also able to send data to the cloud server remotely. These following components were taken in use:

Table 3.2: Components of Approach-02.

Serial No.	Component Name	Specification/Model
1	Raspberry Pi	Pi 4 model B (4GB Ram)
2	Arduino	Arduino Mega
3	PM Sensor	SDS011
4	Digital gas sensor module for SO2	DGS-SO2
5	Digital gas sensor module for CO	DGS-CO
6	Analog Gas Sensor Module for H2S	ULPSM-H2S
7	Analog Gas Sensor Module for NO2	ULPSM-NO2
8	Raspberry Pi Power Adapter	C-type 5V 3A
9	USB Hub	4 channel

Final Approach

After being successful with the digital sensors, we decided to design out final module with the mid-cost digital gas sensors. Fig 3.8 shows the concept block diagram of the hardware module. Fig 3.9 shows the pin out diagram of the final module considering all the elements of the block diagram. Fig 3.10 shows the image of the final module.

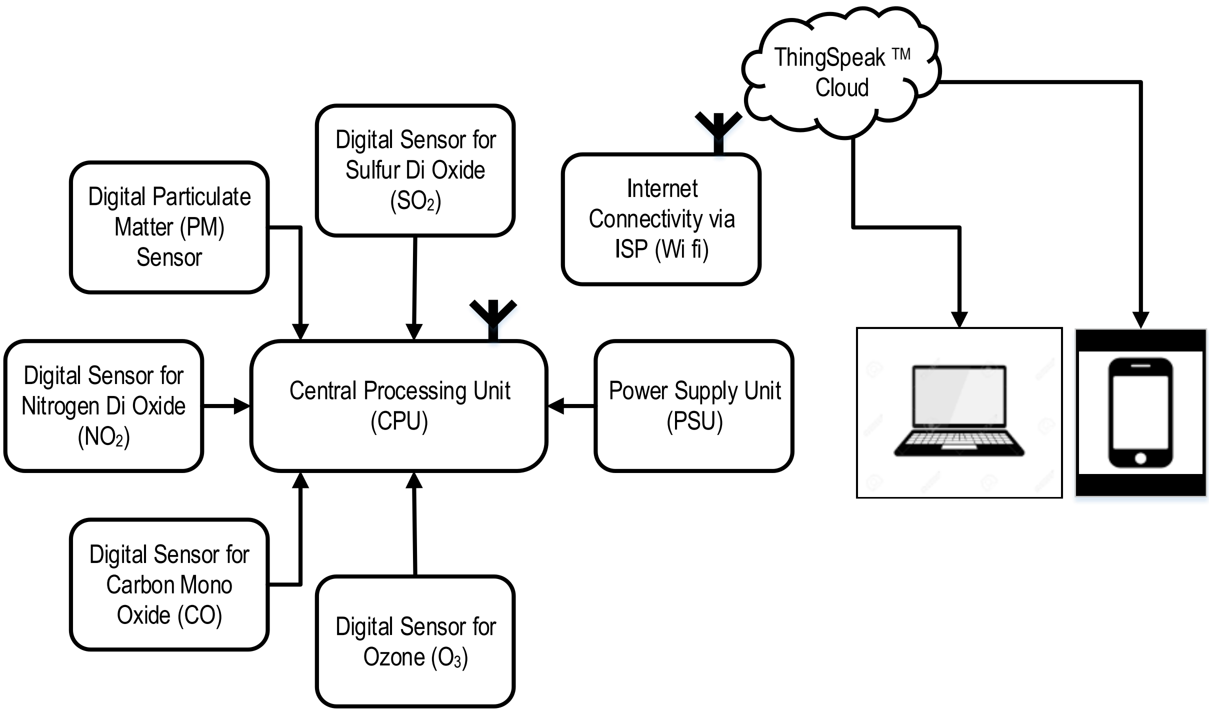

Figure 3.8: Simplified Block diagram of the proposed IoT Based AQI Measurement Module.

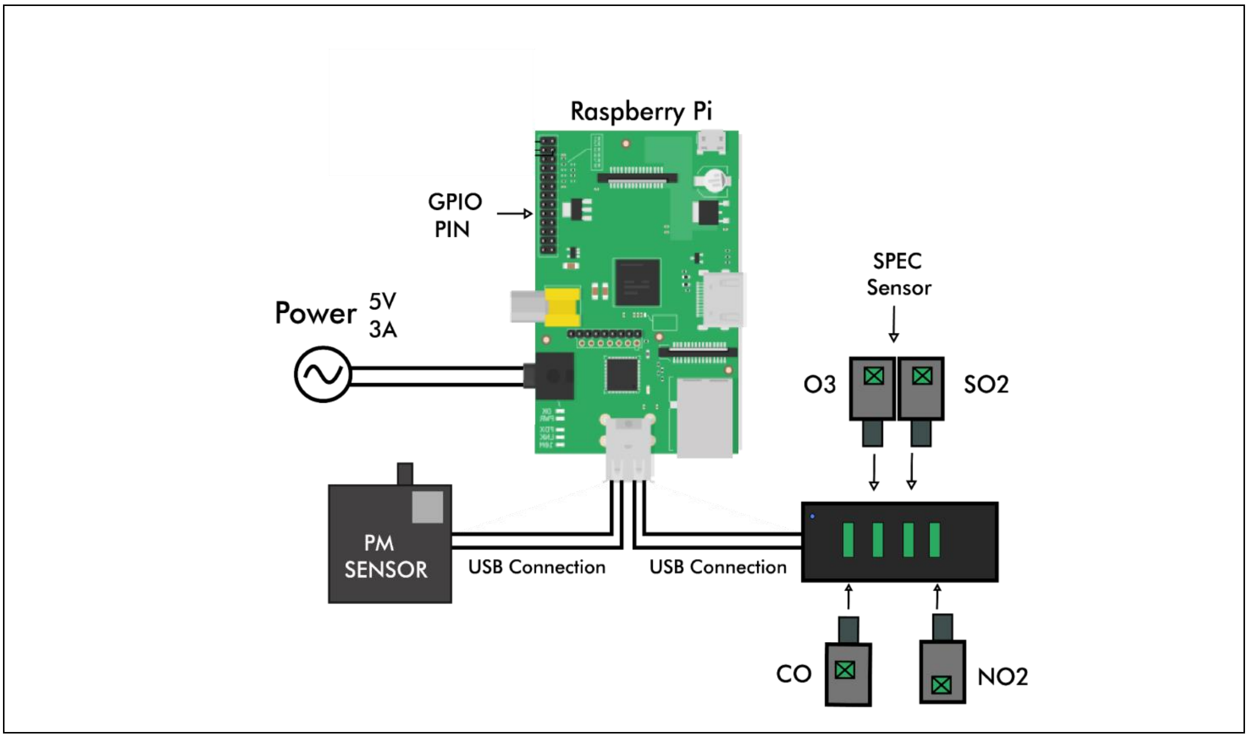

Figure 3.9: Pin out diagram of the modified design.

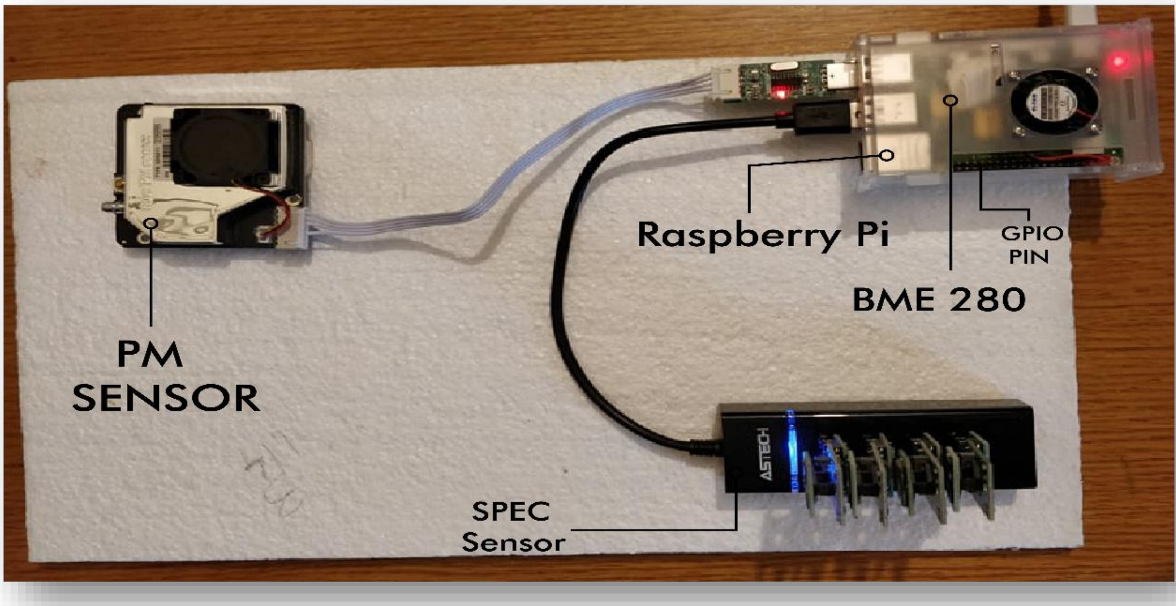

Figure 3.10: The snapshot of the modified design of the module.

We have already chosen our components and other stuffs. So, we can start implementing them. At first, we tested the sensors individually and calibrate them through clean air by the help of air purifier. After getting successful result we implemented the whole setup. Because of digital gas sensors, we directly connected to Raspberry Pi which is the main working medium in this project. The Raspberry Pi receives the digital data from the sensors and sends it to the Cloud Server. A 5V, 3Amp power supply adapter for raspberry pi works as the principle power supply of the whole system.

These following components were taken in use:

Table 3.3: Components of Final Approach.

Serial No.	Component Name	Specification/Model
1	Raspberry Pi	Pi 4 model B (4GB Ram)
2	Raspberry Pi Power Adapter	C-type 5V 3A
3	USB Hub	4 channel
4	PM Sensor	SDS011

Serial No.	Component Name	Specification/Model
5	Digital gas sensor module for SO2	DGS-SO2
6	Digital gas sensor module for CO	DGS-CO
7	Digital gas sensor module for NO2	DGS-NO2
8	Digital gas sensor module for O3	DGS-O3
9	Micro SD Memory Card	32GB
10	Heat sink kit Raspberry Pi 4	-
11	Raspberry Pi Acrylic Case with Fan	-

3.2 Methodology

The aim of our prototype is to develop an IoT based AQI measurement system that can read data of different air parameter from the air using SPEC sensors and store those data on cloud server to present real-time values of the parameters over the internet on any lot platform. In order to implement the whole setup, we had to integrate and interconnect all the SPEC sensors. After that we had to connect all those sensors along with PM sensor to the Raspberry Pi. We will supply power to the raspberry Pi from a source using its power adapter which is our main power medium. The raspberry pi will store all values and send them in IoT platform. This platform will provide us the concentration values and graphical presentation of the data by the help of the web browser and on Smartphone through a app for us to view in real time.

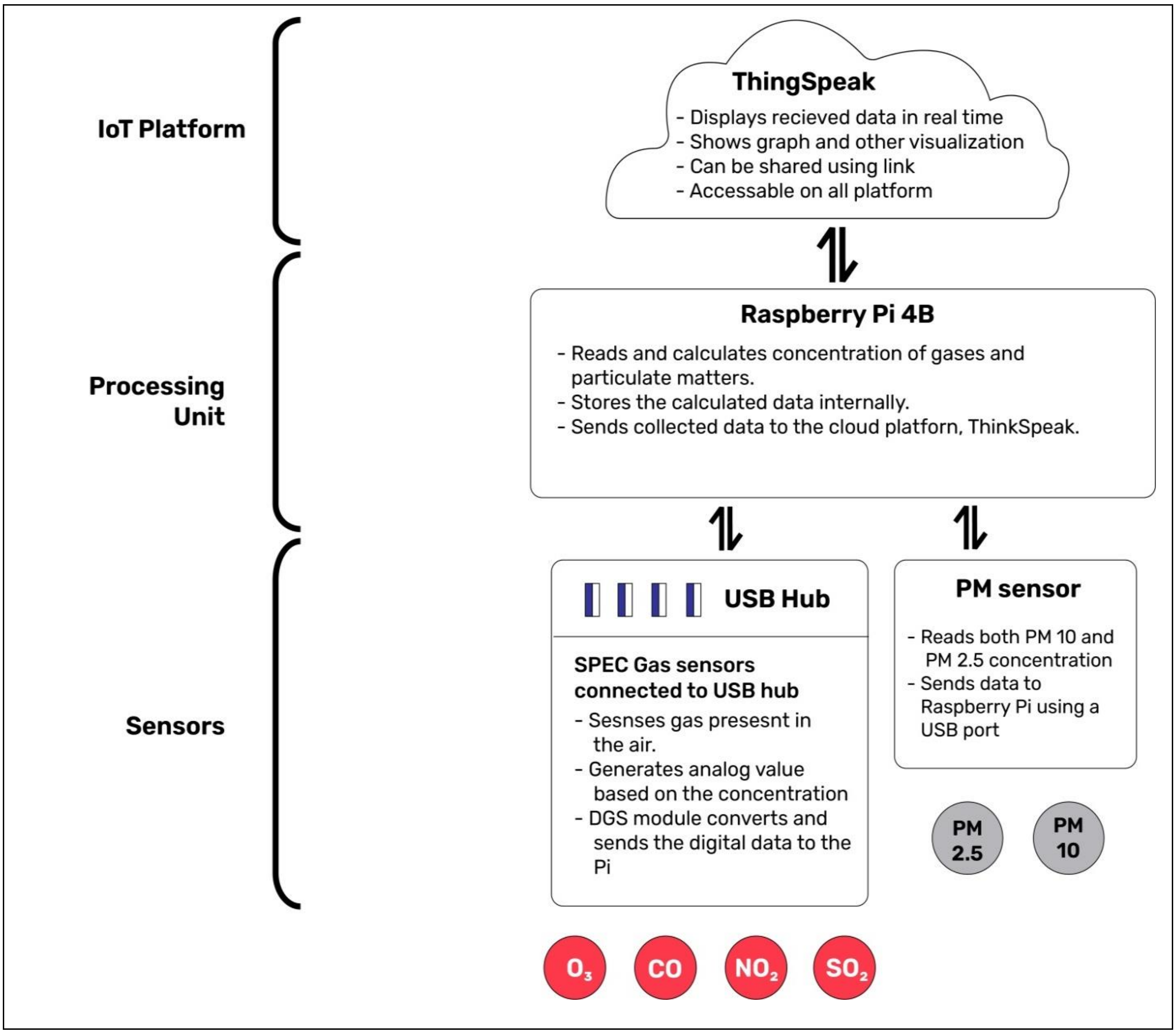

Figure 3.11: Integration of the system.

3.3 Hardware Setup

3.3.1 SPEC Digital gas sensors

For our hardware setup we choose the SPEC sensors. We start with analog sensors. We had some difficulty with analog sensor because we did not have opportunity to work in the laboratory because of Covid-19 scenario and we also couldn’t find the needed components. So, we chose digital sensors since they were simple to connect. SPEC sensors we have chosen for this project are:

- DGS-CO 968-034 sensor for detecting Carbon Monoxide.

- DGS-H2S 968-036 sensor for detecting Hydrogen Sulfide.
- DGS-NO2 968-043 sensor for detecting Nitrogen Dioxide.
- DGS-O3 968-042 sensor for detecting Ozone.

A 4-port USB 3.0 hub connects all four SPEC digital sensors SO2, CO, O3, and NO2 to the Raspberry Pi 4's USB 3.0 connector. We linked each USB device in a precise way, preserving a specific serial, since Raspberry Pi allocates a distinct port number to each attached USB device, and that port number is embedded in the code to access data. The Raspberry Pi 4 has four USB ports, one of which is connected to a 4-port USB hub to support the four SPEC gas sensors, while the other three are connected to the Pi Nova SDS011. Across all five systems, all four SPEC sensors are connected to the USB hub's four ports. This setting permanently assigns a USB port address to each SPEC gas sensor. If the specified setup is maintained, the port address will remain the same even after the Pi reboots, giving the code efficiency and the data collected reliability.

Table 3.4: Specified connection and serial port address for the SPEC sensor

SPEC Sensor’s name	Port name in the 4-port USB hub	USB port number in Raspberry Pi
DGS-O3	USB-1	ttyUSB0
DGS-CO	USB-2	ttyUSB1
DGS-NO2	USB-3	ttyUSB2
DGS-SO2	USB-4	ttyUSB3

3.3.2 Nova SDS011 – Particulate matter (PM) sensor:

The Nova PM sensor gives accurate and reliable values with good consistency. The Nova PM sensor (SDS011) has a built-in fan to provide proper air circulation to a chamber containing a laser diode, which is used to assess the size and amount of PM. For reading and delivering data, the Nova SDS011 uses a UART connection protocol. The PM sensor, like the SPEC sensors, is connected to the Raspberry Pi through its USB port. We attached the PM sensor in such a way that its USB port number does not change even after the Pi reboots, using the same method. The following is the connection protocol:

Table 3.5: Nova SDS011 (PM Sensor) connection protocol.

Sensor name	Connected to:	USB port number in Raspberry Pi
Nova SDS011	Raspberry Pi USB port that has been pre-configured	ttyUSB4

The digital data sent by the sensor is then coded to give raw value for PM10 and PM2.5 in $\mu g/m^3$ form.

3.3.3 Raspberry Pi 4B

The Raspberry Pi serves as the system's brain, collecting digital data from all of the sensors and computing the concentrations of all of the target elements. Given its size and functionality, the Pi is configured in such a way that the entire system becomes practically deployable, making it a true transportable, easy-to-integrate system. When connected to a network, the visual output of the Raspberry OS from the Raspberry Pi may be accessed on any computer connected to the same network, which is simply configured by putting the network's name and password directly to the Pi's SD card using a card reader. Furthermore, each pi can be viewed remotely using VNC Viewer from any location. The Pi records the gathered data internally as.csv and sends it to the cloud platform over the internet, ensuring that data is continuously recorded even if there is a weak or non-existent internet connection, preventing data from being sent to ThingSpeak. Furthermore, in order for the Pi to run our code automatically every time it reboots, we have automated the written code with the Pi's system, allowing us to execute the code with ease. Because the system will be running for days, delivering all of the necessary power to the sensors from the Raspberry Pi, it is critical to ensure that the Pi does not get too hot or collect dust, as this could cause the Pi to shut down, restart, or malfunction, compromising the system's stability. To solve the problem, we encased the Pi in a casing with a fan. Furthermore, for improved heat dissipation, we have bonded heat sinks to the Pi's crucial component.

3.3.4 Power supply

Our SPEC sensors required 3V to operate, which it gets automatically when we connect our sensors with raspberry pi. The Raspberry Pi requires a consistent 5V 3A DC power supply; it is supplied independently to its power input through an adapter with the specified ratings.

3.4 Software Setup

3.4.1 Python

Given that python is an object-oriented open platform programming language, it is vastly used in most of the microprocessors and computers. One of the main reasons for this popular programming language to be the only medium to program in the raspberry pi is because of its versatility. It is easily understandable and the SPEC digital sensors plays really well with it. The whole code is designed with this open platform language, which is why it is editable to the vast media if we allow them to.

3.4.2 Thingspeak

ThingSpeak is a cloud-based data platform that allows you to send and receive data. There are additional systems that function similarly to ThingSpeak. There are a few unique characteristics to it, but there are a slew of other systems that can do the same thing, like EXOSITE, Xively, Carriots, and the Nimbits platform.

However, one feature of ThingSpeak is that it integrates well with MATLAB, which is owned by the parent firm math works. This allows ThingSpeak to function seamlessly with MATLAB. It's simple and straight forward to use, but it still has enough features to allow apps to store and show data.

When we registered an account on ThingSpeak, we also built a channel on the platform that allows us to write and read data using the write and read API. The data input on the platform is ensured by including the API in the code. A free account allows you to record up to 8 fields for displaying and saving data. We filled in those fields with the names of the gases and components that we're collecting on the Raspberry Pi, keeping track of the order so that the Raspberry Pi can provide concentration data in the correct sequence. The channel is open to the public, allowing anyone to view the data in real time from any location. The channel can be viewed on a browser, as well as on Android devices via the app Thingsview.

Figure 3.12: Presentation of values in the IoT platform thingspeak using web browser.

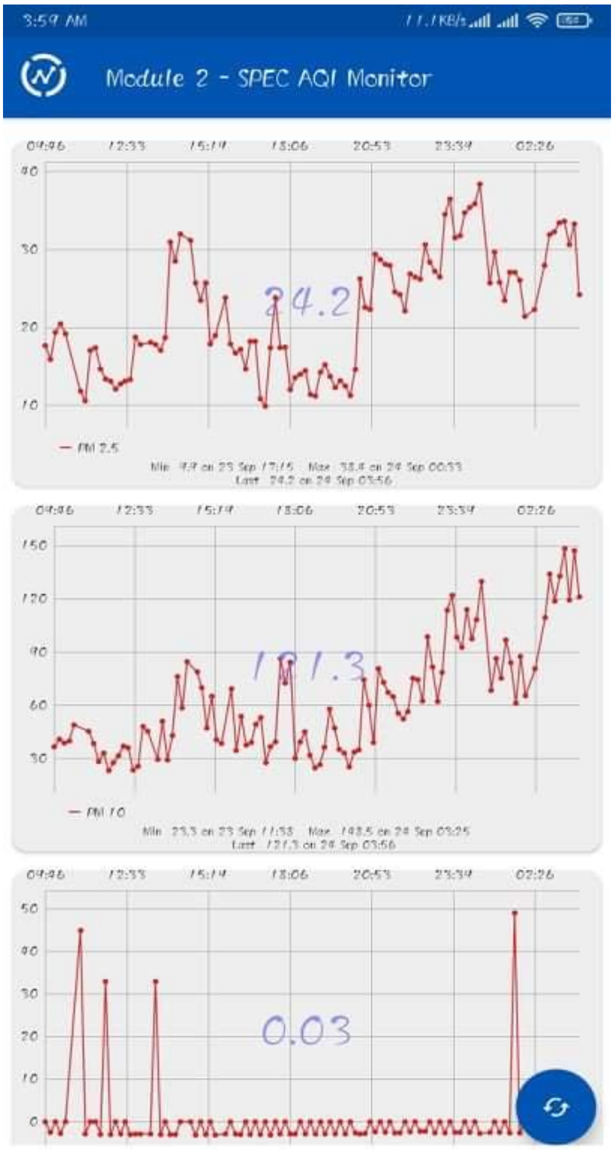

Figure 3.13: Presentation of values in the IoT platform thingspeak using android application.

3.4.3 VNC Viewer

In our system design it was imperative that we could check and log in to our raspberry pi from time to time in order to keep everything in check. VNC viewer played a huge role in this aspect with which we had a constant control over our raspberry pi's system as we could control and see the Raspbian OS in real time. Nevertheless, we could detect any and every anomaly and take measures accordingly.

Chapter 4

Result & Analysis

4.1 Data Analysis

In this segment of the thesis book we have presented some data analysis and comparison with our collected data from the deployed modules. For instance we have selected module 3 from Khilkhet, Dhaka for the whole analysis. To compare and verify the validity of our data we have selected few authentic sources such as Accuweather and IQAir. Now for the graphs we have labeled them as figures and figure 4.1-4.11 shows the analysis of Module 3. Where figure 4.1-4.5 shows the hourly and daily analysis. The figure 4.6-4.8 shows the weekly analysis and figure 4.9-4.11 shows the monthly analysis. Additionally a figure labeled as 4.12 shows the monthly AQI rating of all five modules we have deployed. Last but not the least figure 4.13 had been attached to show the daily data of module 3 that we have analyzed.

4.1.1 Daily Data Analysis

For all the provided figures we have selected a particular date to assess the data that we have collected through authentic medium. In this case fig 4.1-4.5 represents the daily data of module 3 and the data that we collected from sources. Module 3 was located in Nikunja-2 which is a pretty crowded place as it is very near the Dhaka - Mymensingh Highway, thus the rating is a bit on the higher side. For instance, if we take a look at figure 4.3 we can see that the data reading of the Module 3 had the most fluctuations. When it got at peak for a certain time it always overtook the IQAir rating. This scenario occurred because the IQAir reading is from residential area which is quite far from the highway. On the next consecutive figures, we had a clearer picture where we observe that the average rating is a bit higher for the module 3 for obvious reasons. So, the results are affected with the module or the system being overly exposed to dust particles and other gases.

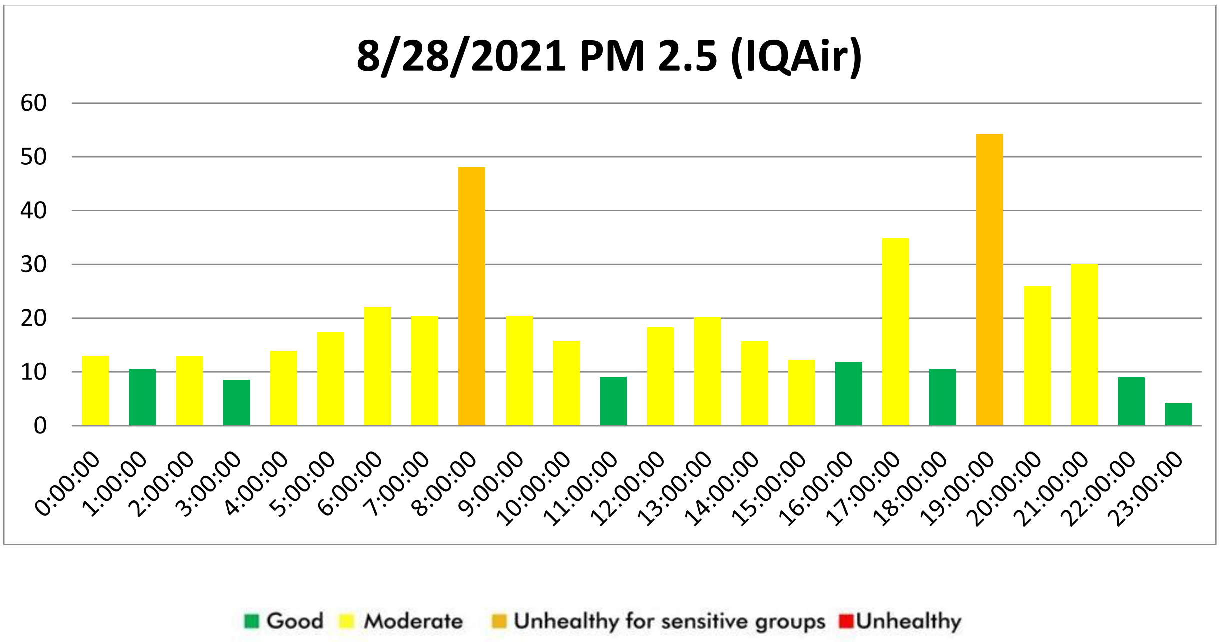

Figure 4.1: Hourly data Collected by the IQAir (Banani) on 28th August 2021.

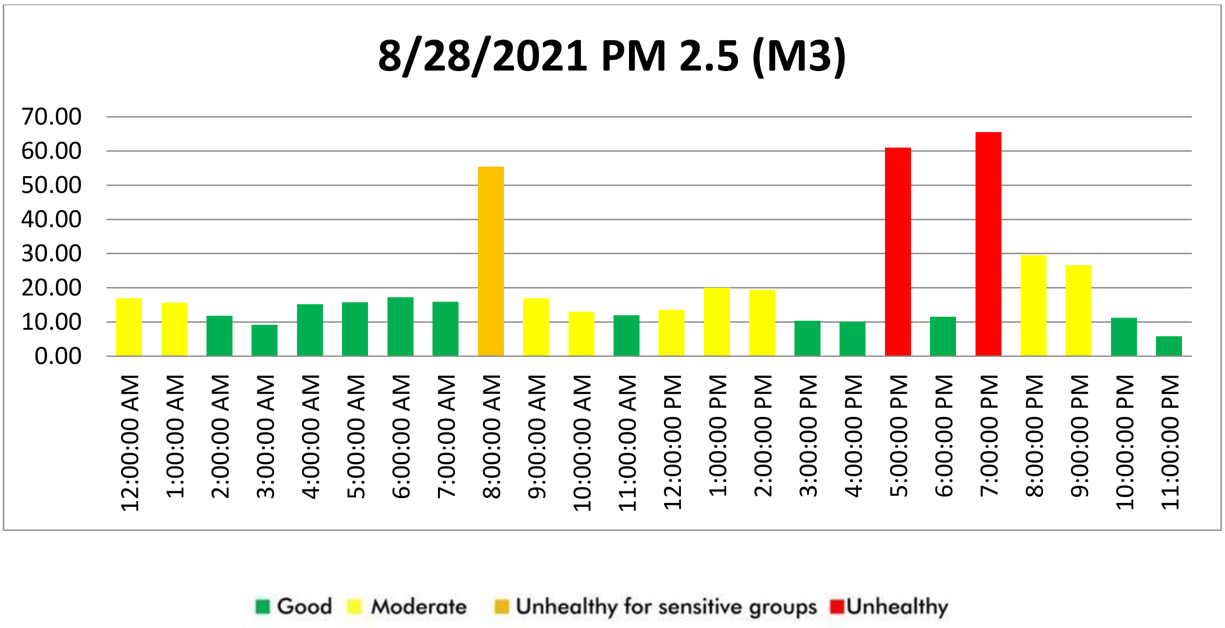

Figure 4.2: Hourly data Collected by the Module 3 (Nikunja-2) on 28th August 2021.

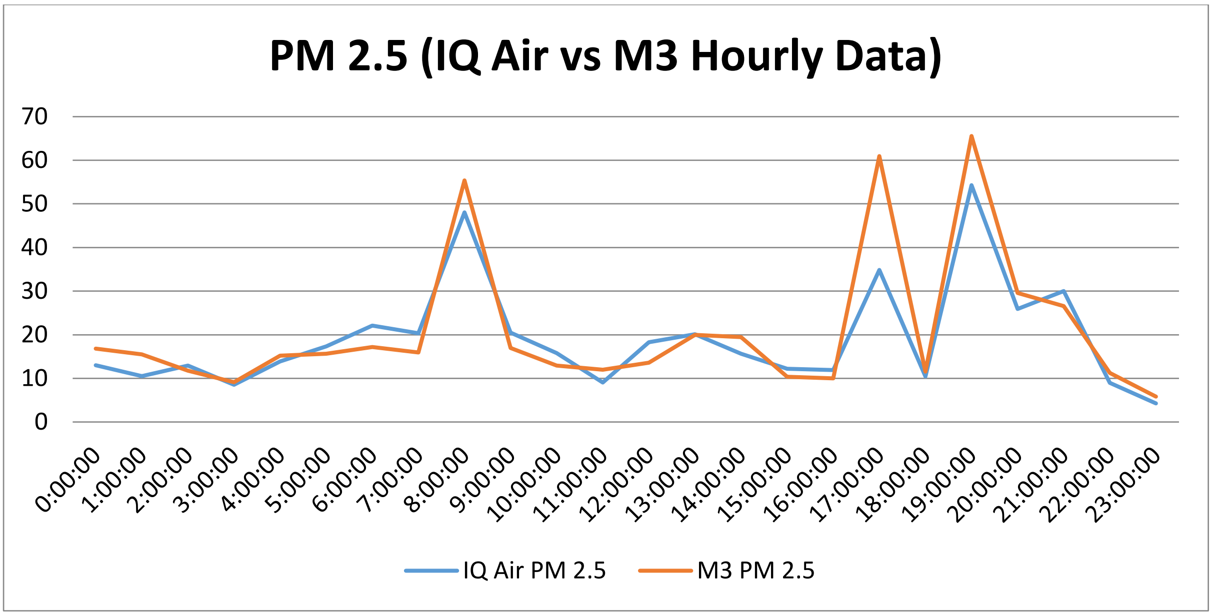

Figure 4.3: Hourly Data Comparison between IQAir and Module 3 (Nikunja 2).

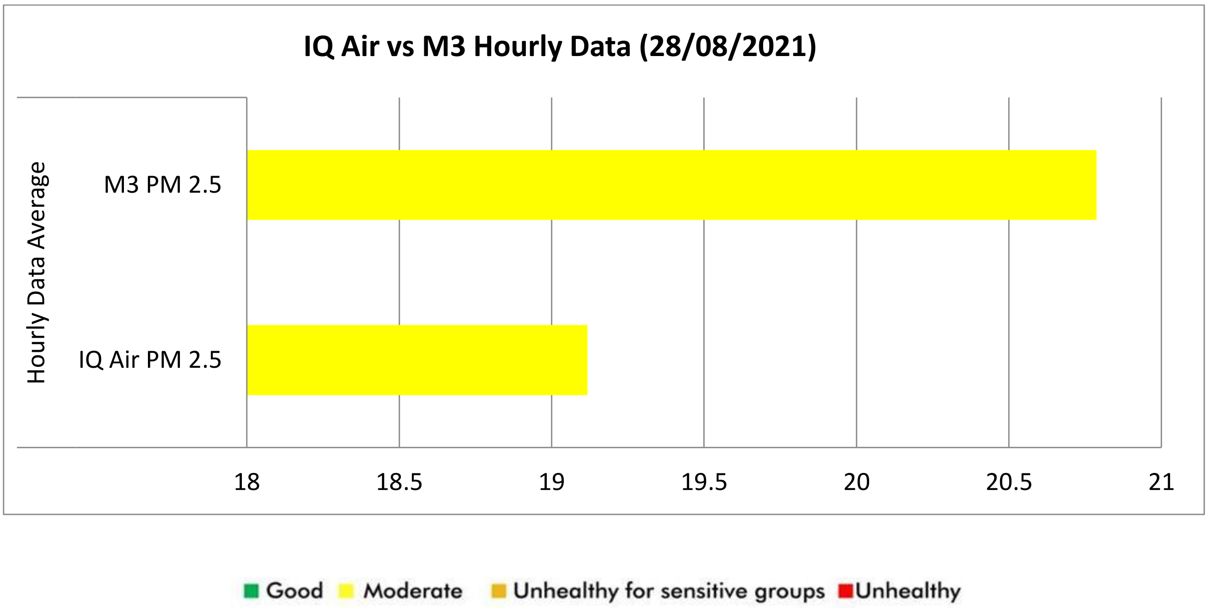

Figure 4.4: Average Daily Data of IQAir and Module 3 (Nikunja-2).

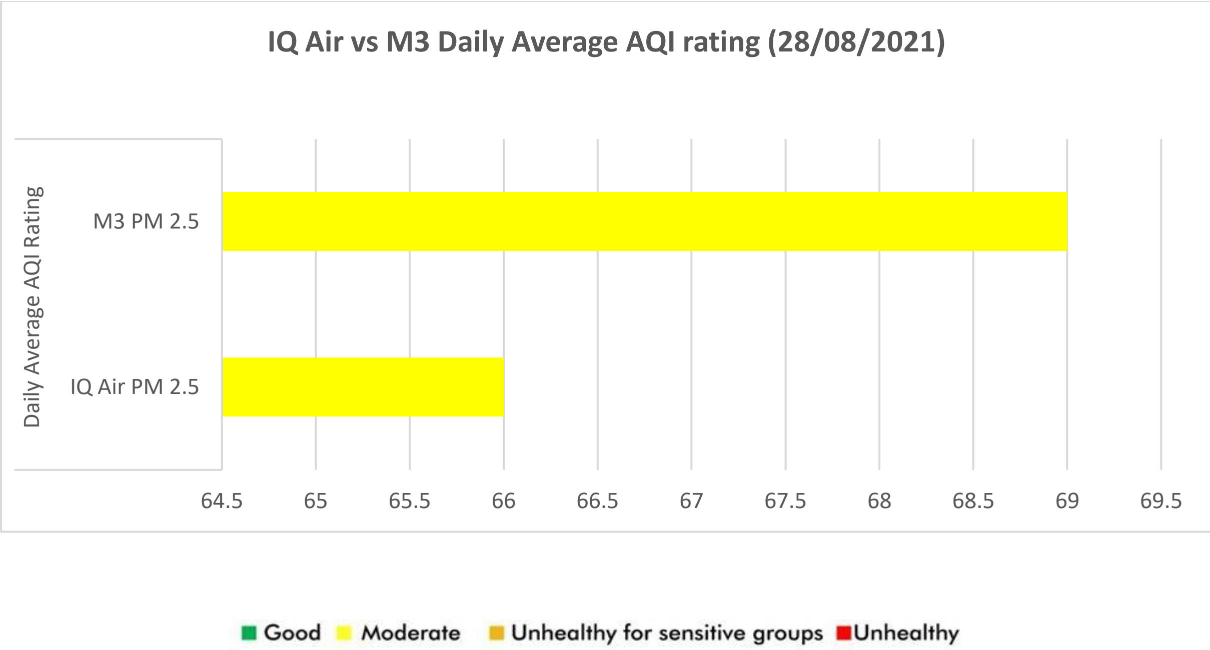

Figure 4.5: Daily Average AQI Rating.

4.1.2 Weekly Data Analysis

As mentioned before the weekly data analysis graph is projected via figure 4.6-4.8. Where in figure 4.8 we have shown a comprehensive difference between the collected data from sources and our own module's data for all the gas and pm sensor reading. Although, in most of the cases our module 3 gave a higher rating but NO2 and O3 rating was higher for Accuweather. But the weekly PM10 rating for Module 3 was of the charts at an average of 37.7979894 whereas the rating for accuweather was sitting way back at 16.86. We are assuming this phenomenon happened because of the vehicle emission since the module is too exposed to smoke. For the PM 2.5 the reading for Module 3 is a bit on the higher side but it is almost as same as Accuweather's average where the difference is only of percentile of 1.24.

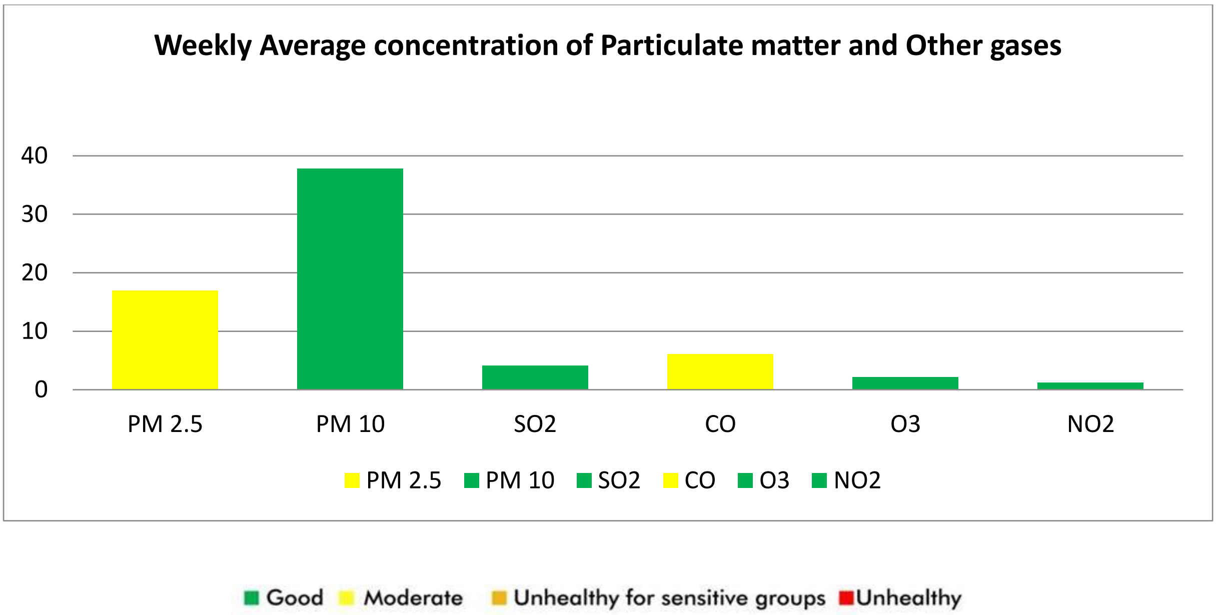

Figure 4.6: Module 3 (Nikunja-2) weekly Average of Particulate matter and other gases.

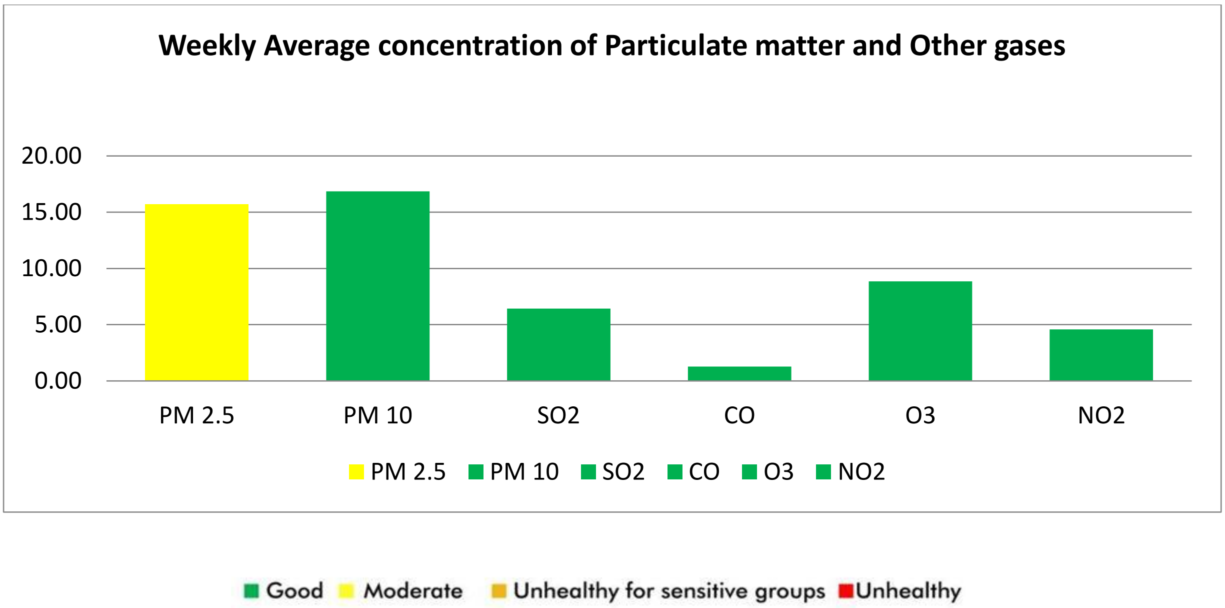

Figure 4.7: Accuweather' weekly Average of Particulate matter and other gases.

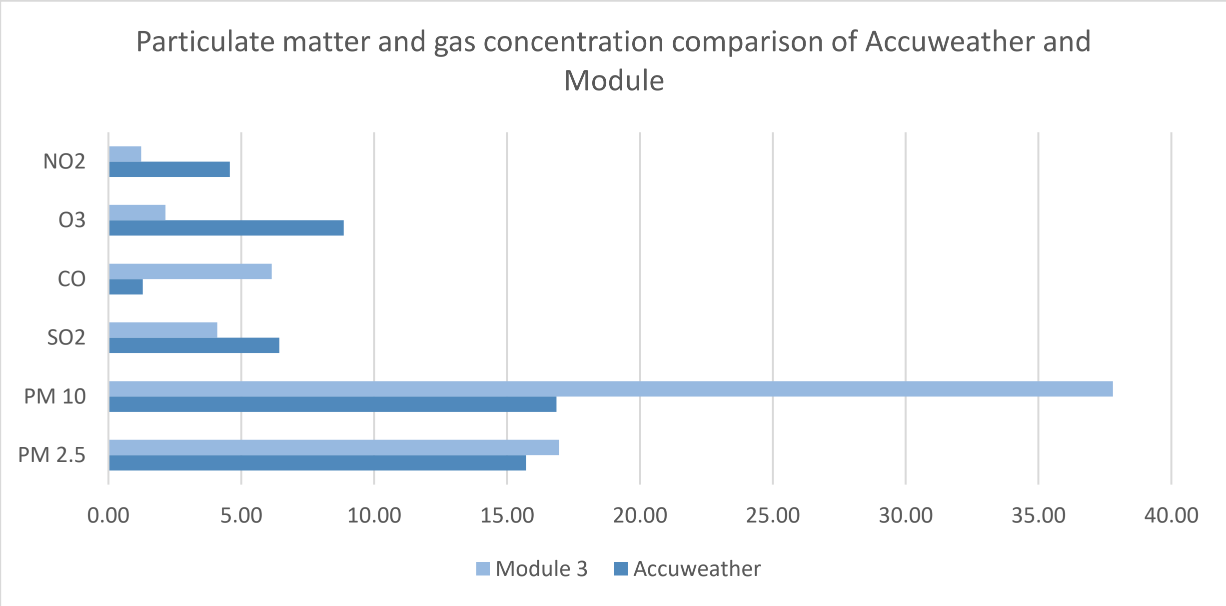

Figure 4.8: Weekly Particulate matter and gas concentration comparison of Accuweather and Module 3 (Nikunja-2).

4.1.3 Monthly Data Analysis

The rest of the figures that are labeled from figure 4.9 - 4.11 show the difference of monthly average data. Though we can assume monthly data by seeing the weekly data because the traits are too common but for the comprehensive comparison we can observe figure 4.11 closely. Other gas and PM10 sensor rating followed the same trait as before, putting module 3 much far ahead of the Accuweather's readings. Whereas we can see an anomaly in the PM 2.5 rating. The bar graph resemblance for monthly PM 2.5 rating for both the system is uncanny. Whereas for weekly average data we could see that it was almost the same with a difference of 1.24.

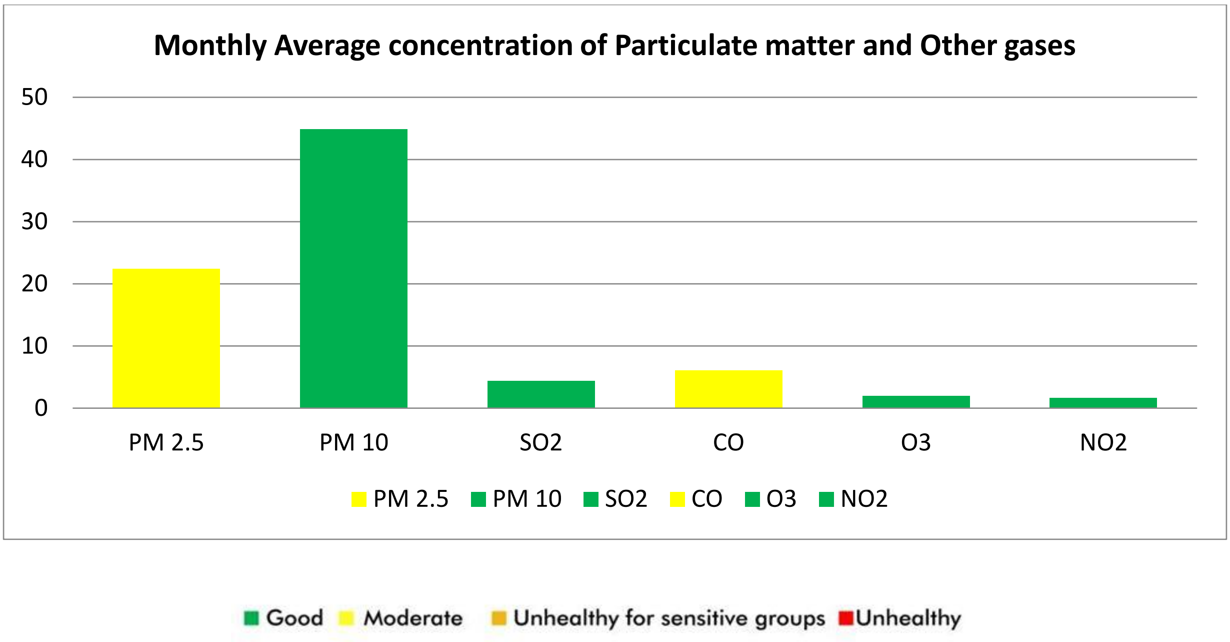

Figure 4.9: Module 3 (Nikunja-2) Monthly Average of Particulate matter and other gases.

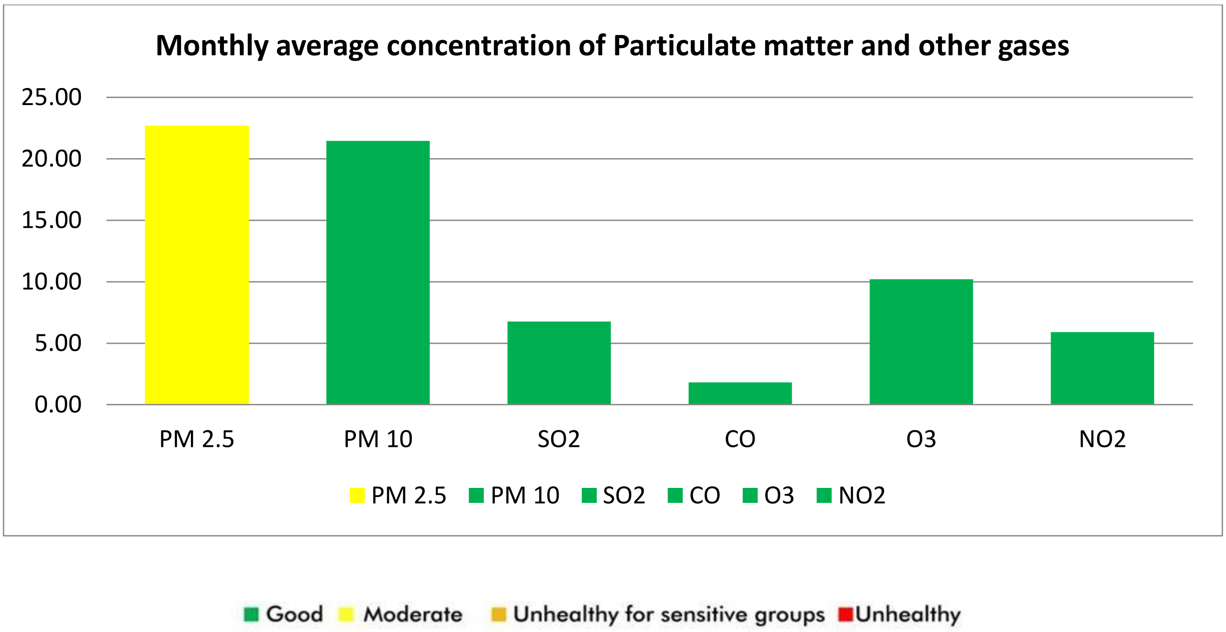

Figure 4.10: Accuweather's Monthly Average of Particulate matter and other gases.

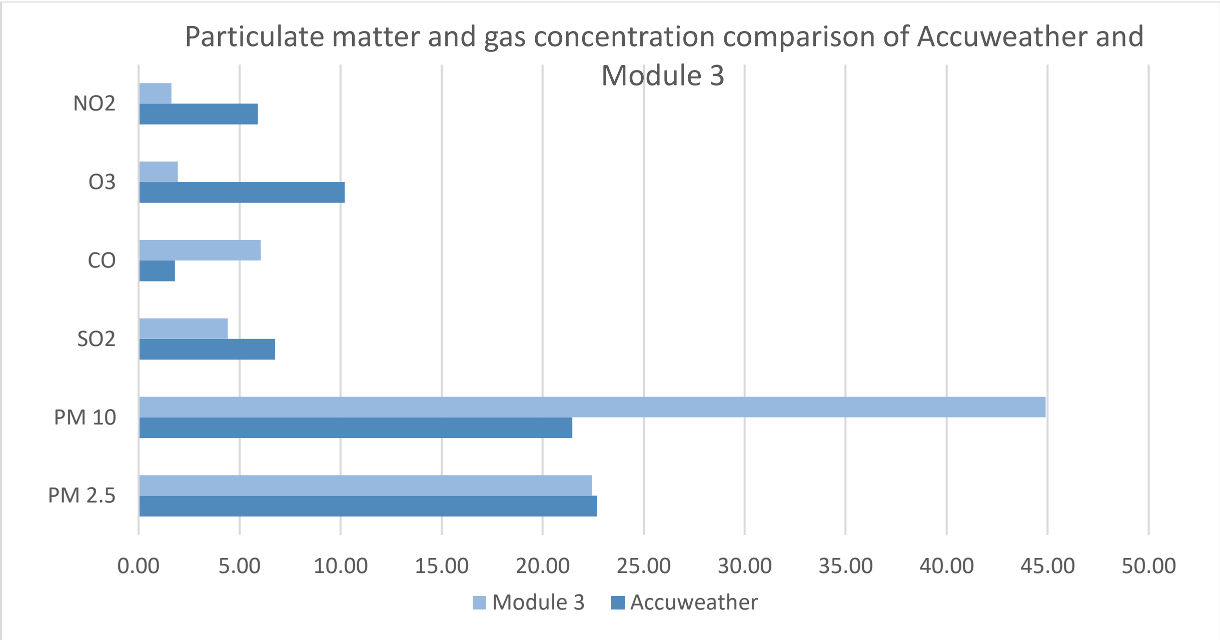

Figure 4.11: Monthly Particulate matter and gas concentration comparison of Accuweather and Module 3 (Nikunja-2).

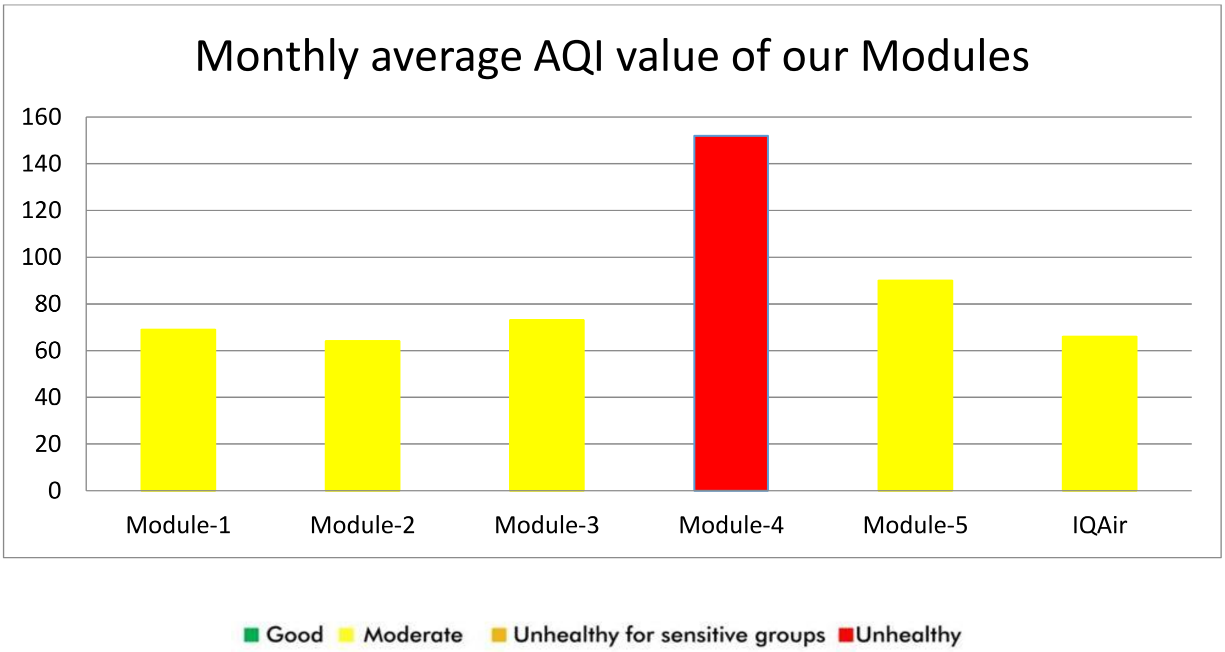

Figure 4.12: Monthly average AQI value of our Modules.

Date	PM 2.5	PM 10	SO2	CO	O3	NO2
8/29/2021	24.78028	54.78451	3.987206	2.531761	0.973803	1.067817
8/30/2021	27.91929	62.63786	5.218861	3.278929	1.911857	1.317571
8/31/2021	15.225	34.65143	3.676232	9.218643	1.533071	1.579
9/1/2021	24.50929	48.175	4.684384	4.722643	1.756714	1.2345
9/2/2021	25.83901	49.44894	7.012297	5.032482	0.398511	1.216596
9/3/2021	22.89783	40.56812	5.354603	7.228913	2.236642	1.394638
9/4/2021	39.25037	61.37481	4.943333	6.189333	2.487852	1.821259
9/5/2021	35.13643	61.60286	1.333239	6.173857	1.679143	2.426929
9/6/2021	18.65664	15.3318	2.71528	2.445887	1.909539	2.355603
9/7/2021	18.75141	41.39718	4.745395	10.58394	1.232535	1.118662
9/8/2021	15.56923	33.52692	0.03	3.474231	3.283846	0.349231
9/9/2021	26.70709	57.2227	5.837439	4.801064	2.065887	1.419291
9/10/2021	19.47107	38.89669	4.484561	5.31075	1.622397	1.388678
9/11/2021	16.24511	34.17744	6.177121	7.711515	2.414286	1.478045
9/12/2021	8.231206	23.74681	2.685441	7.004783	2.958148	1.072908
9/13/2021	13.72263	35.62482	4.753478	4.097313	1.478102	1.823504
9/14/2021	22.87714	52.28786	5.629178	6.818643	1.908571	1.045571
9/15/2021	13.19489	27.50584	5.38197	8.939853	3.405255	2.295182
9/16/2021	25.81986	50.50922	6.328571	7.630797	1.631915	1.564043
9/17/2021	22.79265	48.23456	4.701029	6.186866	2.153088	3.250074
9/18/2021	13.79714	32.19857	5.316761	5.61942	1.128214	1.290429
9/19/2021	15.9125	31.21354	5.796909	10.83063	2.292813	1.699479
9/20/2021	24.59929	49.28156	3.985082	6.219149	1.346738	1.91227
9/21/2021	24.3942	55.29783	4.350588	6.335652	2.21587	2.101304
9/22/2021	23.6	52.8	6.914478	8.1775	1.937286	1.745571
9/23/2021	30.35396	58.71583	3.272174	4.973768	3.660072	1.724532
9/24/2021	25.49023	46.5391	1.54322	6.958538	1.848195	1.563985
9/25/2021	21.73966	39.51034	4.847647	6.220957	1.526552	1.50069

Figure 4.13: Daily Data of One month.

As the operational region of all five modules along with the IQAir is in different places of Dhaka City, so the values differ from each other. But in any case they are quite similar as the ratings are all from residential area apart from module 4 which is in a corporate location. To address the anomaly we can closely observe Figure 4.12 and note that, Module 1 and 2 has a pretty similar rating because they are both from different sections of Uttara Residential Area. Whereas the rating of Module 3 is a bit on the higher side because it's located in Nikunja-2 residential area which is very close to the Dhaka-Mymensingh highway. On the other hand the rating of Module 5 which is located in Mirpur section-6 residential area is quite high because there are a number of garment factories in that area, and the metro rail project of the Mirpur area is putting a big toll on the rating.

All of these ratings are quite similar with the IQAir rating which is located in Banani residential area; they are all labeled as moderate according to the EPA standard Air quality calculation chart. But if we take a closer look at the module 4 which is located in Mohakhali Corporate area, we can see that the rating is really high. One of the reasons for this high rating is the vehicle emission in that area and there is a slum very close to that location which partially impacts the rating.

4.2 Area mapping

For getting a clearer picture of the whole scenario we can observe the following area mapping. Where we can see that module 1 and 2 which are located in Uttara has an AQI rating of 69 and 64 respectively. Coming to the bit on a higher side module 3 is showing 73 AQI rating from Nikunja-2 area and module 4 is showing a rating of 90 from Mirpur section-6 residential area. The only module from the corporate area is showing the highest rating (152) from Mohakhali where our reputed Brac University is as well located.

Figure 4.14: Area Mapping Based on AQI Ratings of One month.

Chapter 5

Conclusion & Future work

5.1 Conclusion

In a densely populated country like Bangladesh, the environmental consequence of air pollution is arguably significantly devastating. Bangladesh's heavily crowded capital remains to top on the list of global cities experiencing the worst environmental pollution. The factors affecting air quality as well as how these to threaten life are discussed in this study. Furthermore, Dhaka, the capital city of Bangladesh, has been evaluated using a comparison study comparing shutdown days to the quite routine weekdays as well as a combined comparison among the regular days has been approached.

During the shutdown of COVID-19 when a limited number of individuals have stepped out of their residences, there have been fewer vehicles on the road and relatively fewer manufacturing industries and offices were open. Moreover, less infrastructure construction was ongoing and so reduced air pollution has been monitored. Because of the shutdown, air quality improved in July and remained stable until August. However, since mid-August, when the shutdown got revoked, the situation has gradually started deteriorating. When we summarize the entire study, we demonstrate that the environment has been in the best condition once air pollution is limited.

Fresh air now signifies a lot for a state's or country's viability. Dhaka's air quality is labeled moderate across several areas because of tremendous air pollution from dust and poisonous substances leading the environment to no longer be healthy as before. In a study several consecutive photos were taken of both Dhaka cityscape and Cumilla. The results were surprising as the environment of Dhaka city seemed hazy and there was a clear indication of smog in the air. On the other hand nearly no smog was detected on the pictures of that were taken of Cumilla. Given that both of the districts fall under different divisions they are fairly close to each other in terms of distance and the difference of the environment is imminent. During weekdays the pollution rate of Dhaka city is sky rocketing on the other hand the situation in Cumilla is pretty normal. That's the distinction between an infectious and a contamination-free habitat. Clean air is absolutely essential for human survival, not just for comfort. Various diseases can emerge from contaminated air and affect health in both the short and long term. Fatalities can also occur as a result of breathing highly polluted air.

As per our research, toxic carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone and harmful particulate matter (PM 10 and PM 2.5) are present in Dhaka's air above the tolerance level. Individuals are losing the functionality of lungs and suffering from acute respiratory and cardiac illnesses because of increasing concentration of PM 10 and PM 2.5 in the air, whereas nitrogen dioxide increased the likelihood of emphysema and chronic bronchitis. Infections of the lungs are also caused by nitrogen dioxide. However, Carbon monoxide impairs oxygen supply into the human body causing frequent headaches and impairs visual perception and physical dexterity.

As a response, initiatives should be taken to reduce environmental pollution in Dhaka, as well as throughout the country. Various measures are being implimented by the authorities; however, overall effectiveness is unsatisfactory. Therefore, individuals must step up to avoid environmental degradation; else, everyone would suffer. Moreover, no detailed air quality guideline is available. Furthermore, in Bangladesh, only a few pieces of research have been conducted on air quality measurements and countrywide estimations of environmental contaminants. The authorities must properly implement emission restrictions and proper monitoring. Methods of reducing fuel demand and improving traffic conditions are indeed crucial in gaining net reduction in emissions and must be implemented along with digital preservation strategies.

The recommendations would be to grow enough city-based vegetation, prohibit using unfit automobiles which generate more carbon with immediate effect, using smart technologies for infrastructural development which spread little or no dust, monitor and control airborne disposals, keeping cities clean and eco-friendly and raise social awareness to reduce air pollution so that hardly a living organism is further endangered.

5.2 Future Work

Researching on atmospheric factors, we have discovered that certain contaminants are primary and others are secondary. Our prototype is quite beneficial for identifying the relative state of the air. Similarly, by analyzing AQI readings, one can assess the relative air quality of various areas. For example, if the AQI level at a certain place has increased, it indicates that the air quality has deteriorated, and vice - versa. The model could also be used to determine if the quality of air has deteriorated or improved over the course of a season.

These AQI values completely satisfy the air quality assessment requirements for any location. Here are even some secondary components of gas that we may analyze to obtain a better understanding of air quality. Our model and method can certainly be approached in upcoming projects to take data over a prolonged period, such as a full year or more to assess furthermore. A detailed study can also be conducted if we work with sound pollution as well. With the implementation of machine learning this IoT based system can also predict the level of pollution as well as AQI rating for at least few weeks. With in-depth research on this sector this project can be highly beneficial for specific group of people who has dust allergy and health problems. This means the developed system as well has a scope of working in public health for Bangladesh. Areas can be marked hazardous for certain group of people and locations can be marked to be safe for old people as well as children.

Furthermore, a free IoT server has been employed for our study. There could be no more than seven factors observed at a time. Furthermore, the data obtained in real-time had 15-second latency, which has been unsatisfactory for us. This occurred as a result of the usage of more sensors and a free server. There were 3 million free data counts; however, each data had to be taken for a millisecond period. It was necessary for us to create numerous profiles on a free server in order to determine whether or not the data was being transferred properly. However, we want to purchase server storage in the future so that we may store our infinite data saved on the cloud. We also want to create a personal Html-based website that will exclusively display sensor readings. Additionally, as a result of this research, we might concentrate on how to reduce airborne pollution from the standpoint of Bangladesh.

We believe that our research will demonstrate why immediate intervention is much needed to prevent air pollution, which currently appears to be the world's most serious environmental health concern.

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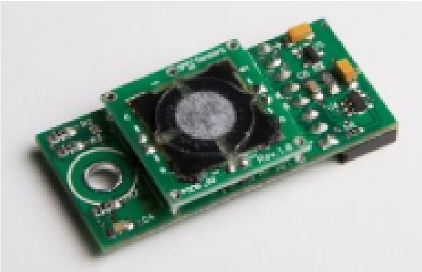
Appendix A.

SPEC SENSORS

DGS-CO 968-034

March 2017

Digital Gas Sensor – Carbon Monoxide



CO MONITORING APPLICATIONS

- Life Safety Levels
- Air Quality Levels

BENEFITS

- Low Power – 1 mW @ 1 minute sampling
- Fast Response – 15 seconds typical
- Calibrated & Temp. Compensated Output
- Simple Digital UART Interface
- Integrated T & RH Sensors
- Robust 10-year Estimated Lifetime
- ROHS Compliant
- Small form Factor
- UART to USB adapter provided
- Lightweight (< 2 oz.)

DESCRIPTION

SPEC Sensors now offers an easy way to add gas sensing to the Internet of Things. Combining our Screen Printed ElectroChemical sensor technology (SPEC Sensor™) with state-of-the-art electronics and algorithms, enables easy integration of small, lightweight, high performance, ultra-low power consumption gas sensing into wireless, portable, and networked solutions.

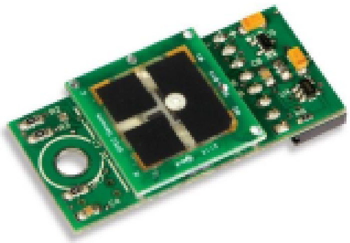
MEASUREMENT PERFORMANCE CHARACTERISTICS

Based on Standard Conditions 25 °C, 50% RH and 1 atm	
Measurement Range	0 to 1000 ppm
Resolution	0.1 ppm (1)
Zero Accuracy	± 1 ppm (2)
Measurement Accuracy	15% of reading
Measurement Repeatability (2)	< ± 3% of reading or 2 ppm, whichever is greater
T90 Response Time (100 ppm step)	< 30 seconds (15 seconds typical)
Power Consumption	1 mW for 1 minute triggered samples 12 mW for continuous sampling 5, 10 30, 60 second intervals
Expected Operating Life	> 5 years (10 years @ 25± 10C; 60 ± 30% RH)
Operating Temperature Range	-20 to 40 °C (-30 to 55 °C intermittent)
Operating Humidity Range	15 to 95% (0 to 100% non-condensing intermittent)
Mechanical Dimensions	1.75 x 0.82 x 0.35 in. (44.5 x 20.8 x 8.9 mm)
Weight	< 2 Ounces

DGS-NO2 968-043

August 2017

Digital Gas Sensor – Nitrogen Dioxide



NITROGEN DIOXIDE APPLICATIONS

- Air Purification Control
- Air Quality Monitoring
- Industrial Safety Sensing

BENEFITS

- Low Power – 100 µW in standby mode
- Calibrated & Temp. Compensated Output
- Fast Response < 30 seconds
- Simple Digital UART Interface
- Integrated T & RH Sensors
- Robust 10-year Estimated Lifetime
- ROHS Compliant
- Small form Factor
- UART to USB adapter provided
- Lightweight (< 2 oz.)

NEW!! Using SPEC's 110-508 NO_2 sensor with O_3 filter and improved low ppb performance!

DESCRIPTION

SPEC Sensors now offers an easy way to add gas sensing to the Internet of Things. Combining our Screen Printed ElectroChemical sensor technology (SPEC Sensor™) with state-of-the-art electronics and algorithms, enables easy integration of small, lightweight, high performance, ultra-low power consumption gas sensing into wireless, portable, and networked solutions.

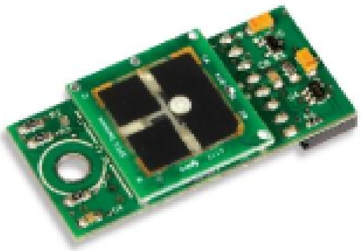
MEASUREMENT PERFORMANCE CHARACTERISTICS

Based on Standard Conditions 25 °C, 50% RH and 1 atm	
Measurement Range	0 to 5 ppm
Resolution	20 ppb (1)
Measurement Accuracy	15% of reading
Measurement Repeatability (2)	< ± 3% of reading
T90 Response Time (100 ppm step)	< 30 seconds
Power Consumption	100 µW in standby mode 14 mW in measurement mode
Expected Operating Life	> 5 years (10 years @ 25± 10C; 60 ± 30% RH)
Operating Temperature Range	-20 to 40 °C (-30 to 55 °C intermittent)
Operating Humidity Range	15 to 95% (0 to 100% non-condensing intermittent)
Mechanical Dimensions	1.75 x 0.82 x 0.35 in. (44.5 x 20.8 x 8.9 mm)
Weight	< 2 Ounces

DGS-SO2 968-038

March 2017

Digital Gas Sensor – Sulfur Dioxide



BENEFITS

- Low Power – 1 mW @ 1 minute sampling
- Calibrated & Temp. Compensated Output
- Fast Response < 30 seconds
- Simple Digital UART Interface
- Integrated T & RH Sensors
- Robust 10-year Estimated Lifetime
- ROHS Compliant
- Small form Factor
- UART to USB adapter provided
- Lightweight (< 2 oz.)

SULFUR DIOXIDE APPLICATIONS

- Air Purification Control
- Air Quality Monitoring
- Industrial Safety Sensing

DESCRIPTION

SPEC Sensors now offers an easy way to add gas sensing to the Internet of Things. Combining our Screen Printed ElectroChemical sensor technology (SPEC Sensor™) with state-of-the-art electronics and algorithms, enables easy integration of small, lightweight, high performance, ultra-low power consumption gas sensing into wireless, portable, and networked solutions.

MEASUREMENT PERFORMANCE CHARACTERISTICS

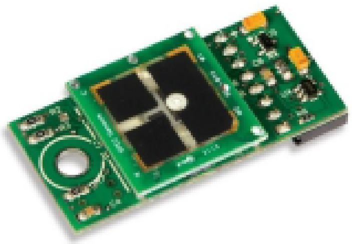
Based on Standard Conditions 25 °C, 50% RH and 1 atm	
Measurement Range	0 to 20 ppm
Resolution	50 ppb (1)
Measurement Accuracy	15% of reading
Measurement Repeatability (2)	< ± 3% of reading
T90 Response Time (100 ppm step)	< 30 seconds
Power Consumption	1 mW for 1 minute triggered samples 12 mW for continuous sampling 5, 10 30, 60 second intervals
Expected Operating Life	> 5 years (10 years @ 25± 10C; 60 ± 30% RH)
Operating Temperature Range	-20 to 40 °C (-30 to 55 °C intermittent)
Operating Humidity Range	15 to 95% (0 to 100% non-condensing intermittent)
Mechanical Dimensions	1.75 x 0.82 x 0.35 in. (44.5 x 20.8 x 8.9 mm)
Weight	< 2 Ounces

SPEC SENSORS

DGS-O3 968-042

August 2017

Digital Gas Sensor – Ozone



BENEFITS

- Low Power – 100 µW in standby mode
- Calibrated & Temp. Compensated Output
- Fast Response < 30 seconds
- Simple Digital UART Interface
- Integrated T & RH Sensors
- Robust 10-year Estimated Lifetime
- ROHS Compliant
- Small form Factor
- UART to USB adapter provided
- Lightweight (< 2 oz.)

OZONE APPLICATIONS

- Air Purification Control
- Air Quality Monitoring
- Industrial Safety Sensing

NEW!! Using SPEC's 110-406 Ozone sensor with improved stability and low ppb performance!

DESCRIPTION

SPEC Sensors now offers an easy way to add gas sensing to the Internet of Things. Combining our Screen Printed ElectroChemical sensor technology (SPEC Sensor™) with state-of-the-art electronics and algorithms, enables easy integration of small, lightweight, high performance, ultra-low power consumption gas sensing into wireless, portable, and networked solutions.

MEASUREMENT PERFORMANCE CHARACTERISTICS

Based on Standard Conditions 25 °C, 50% RH and 1 atm	
Measurement Range	0 to 5 ppm
Resolution	20 ppb (1)
Measurement Accuracy	15% of reading
Measurement Repeatability (2)	< ± 3% of reading
T90 Response Time (100 ppm step)	< 30 seconds
Power Consumption	100 µW in standby mode 14 mW in measurement mode
Expected Operating Life	> 5 years (10 years @ 25± 10C; 60 ± 30% RH)
Operating Temperature Range	-20 to 40 °C (-30 to 55 °C intermittent)
Operating Humidity Range	15 to 95% (0 to 100% non-condensing intermittent)
Mechanical Dimensions	1.75 x 0.82 x 0.35 in. (44.5 x 20.8 x 8.9 mm)
Weight	< 2 Ounces

Particulate Matter Sensor SPS30

The SPS30 particulate matter (PM) sensor represents a new technological breakthrough in optical PM sensors. Its measurement principle is based on laser scattering and makes use of Sensirion's innovative contamination-resistance technology. This technology, together with high-quality and long-lasting components, enables accurate measurements from the device's first operation and throughout its lifetime of more than eight years.

APPLICATIONS

The SPS3x has been designed for use in various applications and devices, such as:

- Air purifiers
- HVAC equipment
- Demand-controlled ventilation systems
- Air conditioners
- Air quality and environmental monitors
- Smart home and IoT devices

SENSOR SPECIFICATIONS

Particulate Matter Sensor Specifications	
Mass concentration accuracy[1]	± 10 μg/m³ @ 0 to 100 μg/m³ ± 10% @ 100 to 1'000 μg/m³
Mass concentration range	0 to 1'000 μg/m³
Mass concentration resolution	1 μg/m³
Particle detection size range	Mass concentration: PM1.0, PM2.5, PM4 and PM10 Number concentration: PM0.5, PM1.0, PM2.5, PM4 and PM10
Lower limit of detection	0.3 μm
Minimum sampling interval	1 s (continous mode)
Lifetime	> 8 years operating continously 24h/day
Dimensions	40.6 x 40.6 x 12.2 mm³
Operating temperature range	-10 to +60 °C
Storage temperature range	- 40 to +70 °C