A Very Low Cost, Open, Wireless, Internet of Things (IoT) Air Quality Monitoring Platform

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***Abstract* - Since the recent epidemic rise of smog outbreaks across the country, it has become more crucial than ever to monitor and regulate the quality of air in the atmosphere. The established solutions so far are widely inaccessible for the general public and restricted specifically to organizational use due to high cost and less usability. In this paper we propose a standard solution based on Internet of Things (IoT) technology, which is a cost-effective alternative to traditional air quality monitoring systems. To realize this cost effectiveness, we have used NodeMCU system on chip which is a low cost, low energy, open, wireless LAN platform. Through the proposed solution, we demonstrate air quality monitoring by collecting data using temperature, humidity, carbon monoxide and nitrogen dioxide sensors and subsequently performed data analysis to infer the relationship of pollutant gases with weather parameters influencing the air quality. Through this research we support the concept of "Going Green" to sustain healthy, and cleaner environment for current and future generations.**

Index Terms - Air Quality, Internet of Things, Arduino.

SECTION 1: INTRODUCTION

Air is one of the major human requirements and a breathable atmosphere is in fact one of the vital aspects that makes Earth inhabitable and different from other planets in the solar system. Thus, it is essential to understand the importance of preserving a certain standard of the air quality in the atmosphere. Certainly, better quality of air positively influences the human health. As a repercussion of poor air quality, not only the human health but the economy is also adversely affected.

Issues related to managing the air quality have been prevalent since a long period but due to lack of swift measures made in this regard, the situation has worsened to an alarming level. Even US, which is known to be one of the most empowered and well off nations, is facing drastic circumstances with abundance of pollutants such as lead, ozone and particulate matters, exceeding quality standards in a major part of the country [1]. Considering the severity of the issue, it is expected from the public and private sector organizations to take remedial actions and become the front runner in managing the air quality. Yet air quality is an issue that is often undermined in discussions of environmental protection and generally one doesn't even see many consumer products dedicated to monitoring this dire issue [2]. The truth is that while air quality monitoring and management is definitely a recognized problem in Pakistan, very insufficient work has been done locally to actually make strides to present the common consumers with products that help in this regards. The understood reason for this is the lack of education of the general public in this pressing matter. Organizations would much rather not develop consumer products that they know would not catch on because the buyer does not think of the issue as a priority. It would be much more sensible for manufacturers to develop products that are actually assured a selling pitch, rather than first educate the public on the matter and then pitch the air quality product. This is why we could see products in this line of use be highly system specific products which are tailor made for companies that ordered them. In doing this, they also become specifically expensive, and unsuited for consumer selling.

The Environmental Protection Agency (EPA) of Pakistan has taken some initiatives to record and monitor the quality of air by publishing the readings of particular substances such as SO2, NO2, and PM2.5, paired with temperature and humidity on their web portal [3]. However, the readings were in an extremely raw form; uninterpretable by the common audience, and ultimately remained less effective to make a difference in public awareness. Making use of an established Air Quality Index (AQI) system would make it easier for the public to understand the readings and take required actions. Thus we will discuss a simple Arduino based Internet of Things solution for this unique predicament to simultaneously monitor air quality, analyze it and subsequently educate the consumer on the issue.

III. Literature Survey

Owing to the gravity of the matter, there has obviously been previous research work done on this specific issue. In this section, we present work carried out in this domain and discuss the differences and issues that make our proposed solution better to the more recent times.

A method to accumulate the Air Quality Index (AQI) i.e. grey incidence analysis is discussed in [4] instead of taking a max of the Individual Air Quality Index (IAQI). An idea is proposed to take an absolute degree of incidence so that each IAQI is taken into account to tabulate the AQI instead of just passing the Maximum Air Quality Index as the AQI. This method definitely yields different results from the general method but it is to be argued that the amount of detail that goes into this analysis might be overwhelming for the newbie user; especially in a place such as Pakistan where the public is so disconnected to the issue. So the simple and easier to

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understand methodology of the normal algorithm that singles out the risks and precautions instead of just rate the air would be perhaps more suited to the public in context.

A similar attempt to our proposed solution can be found in [5] where a system is designed using off-the-shelf components to design an air quality monitor for the masses. The system described in [5] depends on active participation by the community to gather data and send it to the cloud.

Possible further expansion of our proposed solution can be observed in [6] by presenting an idea to automate home air purifiers and exhausts to find the perfect blend between maintaining a clean air and saving energy. The problem in [6] states that keeping indoor air clean also uses up energy which, paradoxically, leads to a worse off quality of air outdoor.

The air quality evaluation methods commonly in use include fuzzy comprehensive evaluation method, gray clustering method, artificial neural networks, etc. The fuzzy theory was applied in air quality evaluation according to the air quality standards [7]. The common AQI in Thessaloniki, Greece was evaluated based on artificial neural networks and decision tree models [8]. To analyze the atmospheric environment pollution more quantitatively, the new standards “Ambient Air Quality Standards (GB 3095-2012)” [9] were published in the year 2012, instead of the old “Ambient Air Quality Standards (GB 3095-1996)” [10]. Meanwhile the AQI was introduced, which replaced the once used “Air Pollution Index” (API).

It is not to say previous work has not been done relevant to this issue. The GAIA air quality monitors designed by Earth Sensing labs is one such line of products that offers a large variation in functionality across the board [11]. Prices range from $100 to $1000 depending on the features one would be getting. However the GAIA line of products offered effective quality monitoring which was essentially intended for personal consumer use and did not intend to provide information to public. There exist limitations that prompted us to devise a solution more relevant to the issue at hand of monitoring air quality and raising public awareness rather than simply monitoring air quality for individual users.

A significant issue of the lack of a standardized approach towards evaluating air quality is discussed in [12]. While for our proposed solution we make use of the US standard algorithm to model an AQI, there is a significant variety of algorithms to measure this; each with features unique to it. We have discussed one method previously as the grey incidence analysis.

Another similar product is discussed in [13] with fundamental differences. This product relies on a Raspberry Pi microcomputer and network adapter interfaced with an Arduino Uno to carry out processing and transmission of data. This is different from our proposed solution which relies solely on a cheaper NodeMCU with an ESP8266 with inherent connectivity capability and processing carried out on the cloud instead of on the device. This saves up cost of the system while maintaining functionality.

The rest of this paper is organized as follows: Section 2 presents the basic principles and concepts that our proposed product utilizes to function in a desired manner. Section 3 describes the proposed system and how it works using core concepts. Section 4 presents a Case Study where we present the data collection process and subsequent analysis carried out on the collected data to infer useful results. Section 5 discusses the future direction of this work and further developments.

To conclude, we were able to put forward further different approaches to solving the issue at hand. The many AQI accumulation approaches help identify one suitable for use in our prototype. Also, previous similar work was able to inspire us to further possible expansions.

SECTION 2: AIR QUALITY MONITORING

I. Air Quality

To understand the significance of monitoring air quality, we must first and foremost establish what actually air quality is. “Air quality” refers to the condition of the air within our surrounding. Good air quality pertains to the degree to which the air is clean, clear and pollution free. According to the medical standards and human health safety, pure air is a mixture of several gases which consists of about 78% nitrogen, 21% oxygen, and less than 1% argon [21]. But urban areas suffer from significant deviation from this standard, causing poor air quality and several health issues. So what accounts for the fall from standard is what we will now focus on. Air pollution is the increase in foreign matters in the air that affect the health of organisms. Table 1 describes some of the various major air pollutants, their source, and their effects on the human health [21].

II. Air Quality Index

In recent years, air quality information is provided by governments to the public in a number of forms like annual reports, environment reviews, and subject specific analyses. These generally have a limited audiences and also require time, interest and necessary background to digest its contents. Thus, a more practical tool has been developed to communicate the health risk of pollutant concentrations using Air Quality Index (AQI). The AQI is a color coded tool for telling the public how clean or polluted the air is. It recommends steps that can be taken to reduce their daily exposure to pollution. The AQI delivers a number between 0 and ~500 used by government agencies to communicate to the public, how polluted the air is. The greater the AQI, the poorer the air quality. Cities and states use the AQI for reporting and forecasting air quality. Each country has its own air quality indices, corresponding to their individual unique quality standards. Canada for example may have a different set of indices, corresponding to their better overall air quality standard and general public sensitivity, as compared to China. The national uniformity helps keep the AQI relevant to the public across the country. It is perhaps relevant to identify that there is no existing international body to identify and assign these standards to each country and they are formulated by every country’s government agencies independently. While the AQI standards vary, the formula to tabulate these indices also vary.

The US, for example, has the United States Environmental Protection Agency which developed the country's AQI as shown in Table 2 and devised a piecewise linear function for individual pollutant concentrations as given in equation 1 [14].

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \qquad (1)$$

where:

I = the (individual Air Quality) index,

C = the pollutant concentration,

C low= the concentration breakpoint that is ≤ C,

C high= the concentration breakpoint that is ≥ C,

I_{low}= the index breakpoint corresponding to C_{low},

I_{high}= the index breakpoint corresponding to C_{high}.

Table 1. Pollutant and sources

Pollutant	Source	Effects
Carbon monoxide	Fuel Combustion	Suffocation, reduced blood Oxygen
Lead	Paint	Lead poisoning, stunted brain development
Ground level Ozone	Emissions from industrial facilities and electric utilities	Asthma, cough, shortness of breath
Nitrogen dioxide	Fuel Combustion	Coughing, colds, flu and Bronchitis, impaired visibility
PM 2.5 (particles with an aerodynamic diameter < 2.5 μm)	Mining and Combustion engines	Respiratory problems, decreased lung functions
Sulfur dioxide	Fuel Combustion, industrial smoke	Nausea, vomiting, diarrhea, stomach pain.

It is to be noted that the average year round AQI for the city of Lahore in Pakistan is 161, while it rose to a hazardous 300+ upon the recent smog incident. [15].

III. Nowcasting

The AQI is used to deliver a daily air quality report which means at the end of the day, we attain an effective reading for the air quality but this also means that we defeat the purpose of the AQI in the first place. The AQI is intended to help users take immediate actions if air is of harmful quality. This is where the Nowcasting algorithm comes into place. A mixture of the words "now" and "forecasting", Nowcasting in air quality is a method to give readings for concentrations of harmful substances in the air in a form that immediately usable. Obviously, simply giving a reading for a harmful concentration in an environment of frequently changing air would be misleading as the immediate reading would in most cases present just an anomaly to an overall cleaner air than what is depicted. This means that even on days when the AQI forecast at the end of the day predicts unhealthy conditions, it is possible that pollution levels might be lower during some parts of the day and vice versa. Thus the NowCast allows current condition maps to align more closely with what people are actually seeing or experiencing. The technique of Nowcasting is to, instead of taking the average of the last relevant span of time, take a weighted average[16]. Equation 2, is used to Nowcast a concentration at any given time [17-18].

$$NowCast = \frac{\sum_{i=1}^{12} w^{i-1} c_i}{\sum_{i=1}^{12} w^{i-1}} \qquad (2)$$

where:

- *w = (min conc.) / (max conc.) for the hourly period*
- *c = hourly concentration for the substance in context*
- *i = hour (12 would be the latest hour and 1 the earliest*

So to separate the two, for momentary AQI readings, Nowcasting is used; whereas for a daily report the general formula is practiced

SECTION 3: PROPOSED SYSTEM

The issue at hand requires a unique set of functionalities. Not only must our proposed system be able to sense what the composition of air is, but it must also be able to identify the major harmful components in the air that have been discussed previously. It must assess the AQI of the atmosphere from this data and then evaluate how safe or harmful the air is. On top of this, the proposed solution must also be mobile as to be movable to whichever location the user wants to place it. Of course it must also be able to sense when it is being moved to evaluate the AQI averages accordingly. Obviously with mobility comes a requirement of a compact system to accommodate such mobility. Finally it must be able to communicate all this information to the web, perform analysis, and present the information in an interpretable manner, easily comprehended by the general public.

I. Hardware Layer

To accommodate all mentioned functionality, we have devised a compact toolkit comprising of a small NodeMCU fitted with modules to perform various tasks at hand. The NodeMCU is the ESP8266 Microcontroller Unit (MCU) that contains an integrated Wifi chip which helps it stand out as a suitable choice. Though Arduino Uno is more popular, it is bulky, costs more and has no integrated wireless network support, causing it to not stand up with the requirements.

As is evident in Figure 1, even an initial prototype is being able to achieve all required functionality within a small amount of components, building towards a form factor little over the size of a normal smartphone.

At present, the prototype is composed of a multi channel gas sensor to detect the presence of Carbon Monoxide (CO) and Nitrogen Dioxide (NO2). Additionally, the prototype includes

Table 2. Individual AQI ranking ranges for pollutants corresponding to concentrations

O_3 8hr (ppb)	O_3 1hr (ppb)	PM 2.5 24hr ($\mu g/m^3$)	PM10 24hr ($\mu g/m^3$)	SO_2 1hr (ppm)	NO_2 1hr (ppb)	CO 8hr (ppm)	AQI	Rating
0-54	-	0.0-12.0	0-54	0-35	0-53	0.0-4.4	0-50	Good
55-70	-	12.1-35.4	55-154	36-75	54-100	4.5-9.4	51-100	Moderate
71-85	125-164	35.5-55.4	155-254	76-185	101-360	9.5-12.4	101-150	Unhealthy for sensitive
86-105	165-204	55.5-150.4	255-354	186-304	361-649	12.5-15.4	151-200	Unhealthy
106-200	205-404	150.5-250.4	355-424	305-604	650-1249	15.5-30.4	201-250	Very Unhealthy
-	405-604	250.5-500.4	425-604	605-1004	1250-2049	30.5-50.4	251-500	Hazardous

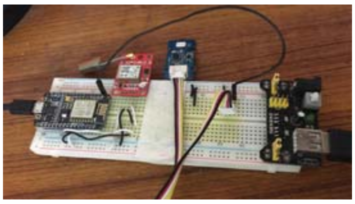

Figure 1. The prototype

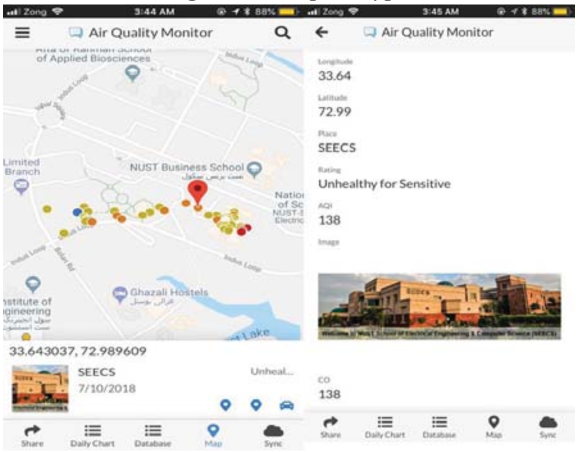

Figure 2: Phone app in action portraying AQI distribution

temperature and humidity sensor (DHT sensor) and a GPS sensor which is able to obtain the geolocation of the module where it is set up. As the sensors sense the environment and capture data, it is then received by the connected NodeMCU, which uses its embedded software and ESP8266 chip to send an html request embedded with this data to the web every hour.

II. Storage and Logic Layer

On our server side, we have set up a Google Sheets to store the data that acts as a database. This database is integrated with web scripts to fetch the html requests sent from the NodeMCU toolkit. Once our web script fetches this request, it extracts the data and performs calculations on it. First of all, we use our chosen AQI aggregation formula in Equation 3.

This specific way of calculating the AQI is one employed by the MEP (Ministry of Environmental Protection) China and USA. Once the AQI for the atmosphere of deployment is calculated, the database server makes use of the GPS readings to calculate where the specific reading is coming from. In such a manner, it groups data according to locations. Furthermore, the database classifies the AQI readings into level of hazards. At this point, our database has sufficient amount of data.

$$AQI = max(IAQI) \quad (3)$$

Where:

- *AQI= Aggregated Air Quality Index*
- *IAQI= Individual Air Quality Indices assigned to each pollutant*

III. Interface Layer

Now comes making the data presentable for the user. To cater to this requirement of our system, we have deployed a smartphone app using the AppSheet web service tool [19]. A small snippet of the app is given in Figure 2. The main feature of our app is to make information from our database interpretable. For this purpose we map our AQI data onto a map using the obtained latitude and longitude readings directly inside the app developed by [19]. For further intuitivity, we have color coded our markers on the map. The darker the color of the marker, the more hazardous the atmosphere is. Once the user taps on one of these markers, he will be presented with further detailed information of the atmosphere in context, including the AQI, its rating, IAQIs, the pollutant most contributing to AQI and spatial data. In such a way, the user will be alerted of the air quality levels at specific areas and can work towards managing it. The app further provides daily AQI readings in the form of a histogram and a pseudo database if the user wants to observe raw unprocessed data for research purposes. Figure 2 shows snippets of the mobile application in action.

SECTION 4: CASE STUDY

A major motivation behind designing the proposed system was to address the lack of awareness in regards to air quality in Pakistan. With insufficient actual systems deployed hitherto to monitor such data, air quality is treated almost as a non-issue. This results in a general public ignorance towards the matter and ultimately no significant steps are taken to actually improve the concerning situation. As a case study we considered a selected section of Rawalpindi and Islamabad. The dataset we were able to obtain upon deployment of our prototype managed around 25000 samples that were collected for the month of August 2018 for a road segment of Rawalpindi leading to Islamabad. This dataset had the attributes `Date', `Time', `Temperature', `Humidity', `NO2', `CO', `Latitude' and `Longitude'. Table 3 shows the correlation among the attributes that significantly contribute towards air quality. The negative values mean that the attributes have an inverse relationship. Upon analysis, it is observed that humidity and temperature are negatively correlated against NO2 and inherently affect the NO2 balance in the air. This mainly happens as NO2 is a water soluble gas, the concentration of this gas declines during high humidity as well as during rain. Furthermore, it was found that the concentration of NO2 was relatively less during day time mainly due to its absorption by the plants through leaves [20].

Table 3. Correlation Matrix

	Temperature	Humidity	CO_AQI	NO2_AQI
Temperature	1.000000	0.167627	0.303176	-0.350311
Humidity	0.167627	1.000000	0.154211	-0.248852
CO_AQI	0.303176	0.154211	1.000000	-0.286331
NO2_AQI	-0.350311	-0.248852	-0.286331	1.000000

For advance analysis, a large dataset covering spatio-temporal variation would be required as a subsequent step.

SECTION 5: CONCLUSION & FUTURE DIRECTIONS

To conclude this research paper, we verify that air pollution is a major problem across the globe, and it affects several major aspects of life ranging from economy to health. The IoT methodology can help us develop cheap and effective solutions to monitor air quality and prevent potential hazards. Using the collected data, our app was able to analyse daily AQIs at different spatial intervals as well as showcase the IAQI most contributing to each. Classification and Presentation of AQI on top of the map was able to make interpretation of data for the user significantly easier. We were also able to correlate CO and NO2 levels against humidity and temperature and provide reason for such correlation.

We were able to identify a number of possible future expansions to our prototype that can help improve its quality and usability. For now, we have considered the US standard air quality indexing model to analyze our data but as [12] identifies, there is a huge variety of indexing models to present air quality data; each with unique features. In a further expansion, we can explore these various models and select the most suitable for the Pakistani atmosphere.

There is also the issue of Pakistan not having an established standard for air quality indexing which is why we have, for the time being, followed the US standards. But definitely, these standards are not perfectly applicable on the unique atmosphere and public of Pakistan. So, we must at one point evaluate Pakistani standards using data that we collect throughout our system lifetime. This would give ratings more customized to the Pakistani public.

Another further possible expansion is the integration of our system in a smart home environment as previously mentioned in [6]. This could include functions ranging from home automation to an alarm system for critical circumstances.

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