Sensor Network For Pollution Monitoring
Master's Thesis Proposal

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Contents

Chapter 1

Introduction

Air pollution is a complex mixture of gases and particles whose sources and composition vary over space and time[7]. The burning of fossil fuels, exhaust from factories and industries, and mining operations are the major contributors to air pollution. The exposure to air pollution causes premature deaths, cardiovascular disease, stroke, and other respiratory diseases. The state of global air 2017 has discussed the effects of long-term exposure to harmful air pollutants such as particulate matter which contributes to over 4 million premature deaths and is estimated to double by 2050 if the issue remains unattended[7]. Therefore, the urgency for a global attention to mitigate the issue require no further emphasis. Among the risk factors with the serious health issues, Air pollution ranks the highest annually accounting for majority of deaths. Air pollution has increased significantly after the industrialization and urbanization have taken place, and people are unaware of the fact that the impact it causes to our health. As urban areas have a high density of population, maintaining air quality is becoming more and more challenging[8]. The measurement of pollutants requires highly sophisticated, expensive, and power intensive equipment which can be placed only at very limited sites[23]

To address this epidemic issue, I believe, active participation from public on collecting and interpreting data, educating the behavior of individuals and industries, and helping to control and manage pollution sources effectively is crucial. Fortunately, this goal appears to be achievable due to the electronic and computing revolutions. It is possible that small, inexpensive, portable, and off-the-shelf pollution sensors along with low power processors and wireless communication modules can be bought at low cost. One of the important components in solving this issue is to increase the awareness among all stakeholders, particularly common people about the current situation and its impact so that they can act on it. The conventional method of monitoring the air quality with the help of a few heavyweight expensive stationary monitoring systems typically installed by the state may not be effective enough for this task. To achieve the goal effectively and without further delay, pollution monitoring must become part of daily activity for everyone. For that the devices to monitor pollution must be small, portable, inexpensive, and part of a global system.

With the technological advancement of low cost computing, communication, and sensing devices, and the revolution and the importance of open source software[1],

I believe it is possible to build pervasive air pollution monitoring system with commodity hardware and open source software. Now the question is how to design such pollution monitoring devices faster and make them accessible to as many as possible. Achieving the above stated goal requires a suitable system framework that can help to accelerate the process of the design and implementation of a air pollution monitoring system using the of-the-shelf commodity hardware and open source software. There are some recent attempts in this direction, but none is comprehensive and simple enough to follow and build a air pollution monitoring system with a little or moderate effort.

Chapter 2

Background and Related Work

This chapter shows the major research work done on this field, it can be seen that most of the work are done on indoor pollution, since it is easy for evaluation.

2.1 Development of Personal Integrated Environmental Monitoring System

Pollution in urban areas are increasing rapidly and due to which the number of people suffering chronic illness, permanent disability or even death are also increasing. The already existing station based environmental monitoring system are complex and costly hence there is a need to develop portable and low cost environmental monitoring system. The mobile environmental sensing system integrates different environmental detection sensors in one system and data from this system can further be used for processing and visualization. The system which the paper suggested is Integrated Environmental Monitoring System(IEMS). IEMS consist of 3 components.

1. Integrated Environmental Monitoring Device(IEMD)

2. Handheld Remote Control Panel(RCP)

3. Web Server.

IEMD is portable device which consists of MCU, sensors, wireless communication module. The device is powered using six AA batteries. Sensors used are temperature and humidity, UV, PM, Noise Sensor. The processor or MCU used in this is Arduino Nano board, and all the sensors are integrated into this MCU and the communication module used here is HC-06 blue tooth module. RCP is an android application which is an interface for the device control. This does the data exchange between IEMD and Web Server. RCP on receiving information from IEMD, then it will transfer whole data to webserver using Apache HTTP. Web Server provides a real time data visualization and data analysis. The paper has conducted a field test at several locations for evaluating the functionality of system. It showed that the system worked well. There were two main problems which cited:

1. GPS positioning accuracy was relatively low
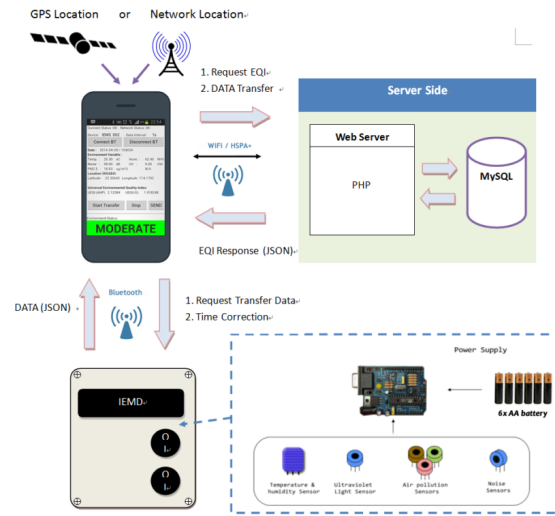
2. Low battery life

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Figure 2.1: System Architecture: IEMD

2.2 Air Sense: An intelligent home-based sensing system for indoor air quality analytics

Air sense is an excellent approach to assess the quality of indoor air. The paper tries to introduce the idea of Indoor Air Quality to the society by proposing a system which measures indoor pollution as the current society is miss-informed or ignorant about it. The system works through electronic sensors which are coupled to a Arduino (processing unit). The system not only extracts the data, but also provides its customers with very effective visualization and analysis of the data. This system has made use of some machine algorithms for the data analysis so as to provide intelligence to the system. The researchers of the paper have done an excellent work on developing this robust system that would sense the pollution and provide education and awareness among the users.
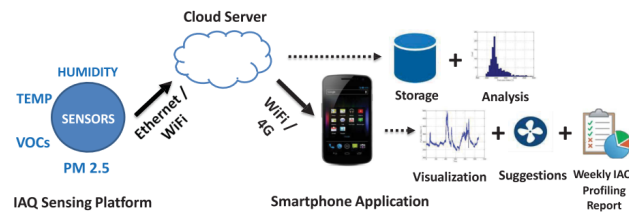
Figure 2.2: System Architecture: Air sense

The main challenge in the system was to present the extracted data in such a way that, anyone irrespective of their backgrounds could understand the data and importance of Indoor Air Quality. This posed the system three sub challenges which included Pollution Event Detection, Source Identification and IAQ Forecast. All these were to be found from three sensor readings. This paper was able to successfully

use some state of the art machine learning algorithms to accurately predict the pollution sources and forecast their behavior. The system has also got a smart phone application which gives the users a very effective interface for visualizations and understanding the data. The main weakness of the paper is that the pollution sources have been limited to very few. The second weakness is that the prediction has been carried out on historical data rather than the data related to pollution in a particular area or state.

2.3 IOT Enabled Proactive Indoor Air Quality Monitoring System for Sustainable Health Management.

This system measures the indoor air quality. All though the paper discussed about a variety of pollutants and pollution events, the author's interest in office environment wherein the pollution to the gases from electronic devices and machines are high. Hence the system considers Ozone gas to be the primary pollutant. The author has put forward an idea of transmitting data through a Bluetooth channel and process the data in a Wi-Fi Network. The paper also discusses about the new construction design wherein the ventilation is very less which might lead into the presence of numerous sources of synthetic chemicals which has resulted in elevated concentrations of volatile organic compound inside the rooms. One such machine is the photocopiers, which is known to emit poisonous gases like ozone. The system consists of 4 nodes. Sensing node which is a Arduino which acquires the data from the sensors Ozone sensor which measures the level of ozone and sent it to the sensing node. Gateway node which used to transmit the acquired data through Bluetooth and finally a processing node which process the data. Overall, the paper only discusses ozone as pollutant in the system neglecting all the other pollutants.

2.4 Toward On-Demand Urban Air Quality Monitoring using Public Vehicles.

The paper discusses an effective method to acquire air quality data in an urban area. In the earlier systems the sensing module was fixed at different stations and therefore will only measure the air quality in the vicinity.

The system proposed has the sensing unit kept on a public vehicle which keeps on moving in and around the city. The system has made use of garbage trucks and garbage patrol vehicles due to above mentioned reasons. The paper's main focus is in pollutants like PM, CO and SO. The system is also aided with GPS system so that the sensors values could be mapped onto the locations. To remotely monitor the sensing conditions and to check for maintenance, a control center tool has also been developed. It consists of a map, graph which tracks the route of the vehicles and the sensor data acquired by each vehicle. The next part of the paper is a monitor which was developed along with the system to send the users the collected data. It estimates the amount of pollution inhaled by the user, by the acquiring the user's location from the mobile application and mapping it to the location-sensors value which has been already computed. It also considers the respiratory volume of the user to estimate the pollution inhalation.
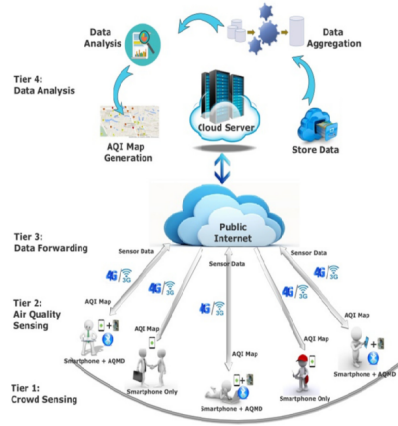
Figure 2.3: System Overview

The paper proposes an effective and low cost system to understand the air quality in an urban area.

2.5 Towards smart city: Sensing Air quality in city based on opportunistic crowd sensing.

A crowd sensing based air quality monitoring system is designed which aims at collecting and aggregating sensor data for air pollution monitoring in city. An air quality monitoring system(AQMD) was made and connected with smart phones and the information was gathered and shared to cloud. Air sense developed here is a 4 tier architecture consist of crowd which provides data, the dealing with data which means air quality sensing, transferring of data (data forwarding from smart phone to cloud) and finally the data analysis which is storage, aggregation and analysis. Finally, the result computed in tier 4 is sent back to tier 1 through tier 3. The AQMD consists of sensors, a Bluetooth module, Arduino and a power supply. Arduino interfaces between sensor and Bluetooth module. whenever there is a change in air quality Arduino communicates with Bluetooth module and then data are transmitted to smart-phones via Bluetooth. In smart-phone the data from Arduino is collected, transferred to cloud and provide AQI map.

2.6 MyPart: Personal, portable, accurate airborne particle counting

The primary air pollutant for major health issues is small airborne particles of size less than 10 microns and due to which a particle sensor named My-Part was developed which is of low cost. My-part sensor differs from the other sensor available in market in the following features accessibility, flexibility, portability and accuracy. The paper compares My-part to the existing sensor system such as thermal based gas sensors and states that either some system consists of low cost gas sensors which does a poor job of accurately measuring the actual gas concentration due to sensor

response selectivity and gas interaction problems with sensor. Next comparison is done with low cost led and photo diode based sensors and states that these sensors give unreliable readings especially at lower concentration. Another comparison is done with laser and photo diode based sensors and points that these system performs poor in outdoor and there is ambient light leakage. The design of My-Part is based on traditional laser based photo diode system with improvement in airflow to remove light leakage, integration of structural design and circuitry for ambient visualization, BLE transceiver for low power networking and also mobile application for visualization. Two main issues tackled by is accuracy and calibration of sensor which no existing consumer sensor has addressed. A mobile application was also developed in addition to the hardware.

Chapter 3

Problem Statement

Aim is to create a simple pollution monitoring system which would educate the common lay men on the adverse effect of air pollution by showing them how polluted is their vicinity. This can be done by including all the possible pollutants that degrades the air quality. The pollutants changes from place to place since it depends on the human activities and the type of industries located in a particular surrounding. Identifying the pollutants and with the help of visualization tool, I aim to display the concentration of each pollutant and a combined measure which would define the quality of the air. This can be taken as the first step towards making a software which can exclusively display the values of pollutants.

Just by measuring and displaying individual pollutants may not be useful. There should be some metrics such as Air Quality Health Index (AQHI) or Air quality Index (AQI) which represents the seriousness of pollution to health or environment. These metrics must educate the public, rather than confuse, to avoid breathing polluted air and also influence the authorities to act to mitigate. The ultimate aim is to create a software which can take the values from the hardware system and represent these values along with AQHI with respect to time. The quality of the air we breathe not only impacts individual's health but also has a significant cumulative effect on public health, global environment, and worldwide economy [18]. Air pollution can cause heart disease, chronic obstructive pulmonary disease (COPD), stroke, and lung cancer, etc. On a daily basis, people could suffer from difficulty in breathing, coughing, wheezing, and asthma [18]. I believe this research can contributes towards encouraging and helping citizen science to solve the issue of air pollution and can give more understanding to the effect that causes to health.

3.1   Research Question

Some important research questions to be addressed related to the issue of air quality are:

1. What kind pollutants affect the human health most? How to measure them?

2. As the pollution is in the atmosphere, should it not be measured everywhere all the time?

3. What is the difference between different metrics which is used to show the effect of pollution?

4. How can the seriousness of pollution be made aware?

5. How can the representation of Air quality health index be done?

6. What kind of infrastructure is needed to facilitate such a ubiquitous measurement?

Chapter 4

Solution Strategy

The proposed architecture contains five essential elements: Sensors, processing unit, mining repository, animation and analytics modules, and communication middleware as shown
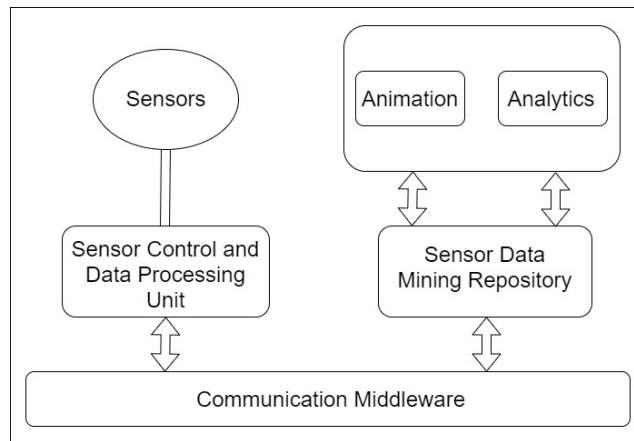

Figure 4.1: System Architecture

4.1 Sensors and Communication

Sensor networks are new instruments useful to detect the conditions in remote places in the physical world [20] in environmental monitoring applications such as pollution monitoring, transportation management, intrusion detection and many more [22]. With the help of sensors, it is possible to collect data remotely and collected data can be transferred to the required platform. There are different sensors available in market which can measure the pollutants and display the value, but the idea here is to select the one which is of low cost and also gives the most accurate values. Sensors will collect data from the environment as per their schedule. Communication module essentially sends the sensor data to mining repository. It can occasionally receive data from other nodes and servers. These two modules are controlled by sensor control and processing unit.

4.2 Sensor Control and Processing Unit

This module has two primary purposes: first is to control the sensors in collecting data, which means how much data is to be collected and what is the time interval for transferring the data from each sensors. It is not necessary to measure the data in every minute since the value of sensor data wont change rapidly. There should be certain interval set for the data collection and transfer. Second purpose is to filter and process the collected data and then forward, if necessary, to the mining repository through the communication module. The collected data should be applied to certain formula in order to get the the most accurate value.

4.3 Mining Repository

This module stores and maintains the sensor data that will be used by the search analytic service to generate graphs and other meaningful results. For IoT application such as this, a near real time search engine with standardized API to enable easy access to data must be integrated with the repository. As it has to store large volumes of data, it also requires capabilities such as sorting and filtering to segregate and organize data so that it can be accessed efficiently all the time.

4.4 Animation and Analytics

These components are to provide statistical data analysis and visualization through intuitive graphics services to help users to make decisions. Particularly, analytics component is needed to performs statistical and machine learning functionality and animation component is to display the necessary data to users. Since the system is aimed to be used by various stakeholders including common people, we would like to emphasize the importance of accurate and intuitive graphic display if it is intended to used effectively.

4.5 Messaging Middleware

This is a software layer that connects various heterogeneous components for seamless communication between them. Such a system allows the system designer and the programmers to focus on building standard, adaptable, and effective solutions rather than worrying about the finer details of the underlying communication issues [11].

Chapter 5

Research Challenges

The major challenges expected on creating a complete system are:

1. The integration of different sensors with the processor.

2. Integration of communication module which is WiFi with processor as this module alone requires a different voltage level to drive.

3. Calibration of each sensors based on the data sheet.

4. Transferring the data to a platform or a database using the WiFi module.

5. Checking whether the collected data is accurate.

Chapter 6

Time-Line

This chapter gives an overview of the total time required in building a sensor network for pollution monitoring system. It gives an idea of dividing the whole process into different tasks and shows the rough time required to complete each task. The estimated time line for the completion is given below figure 6.1
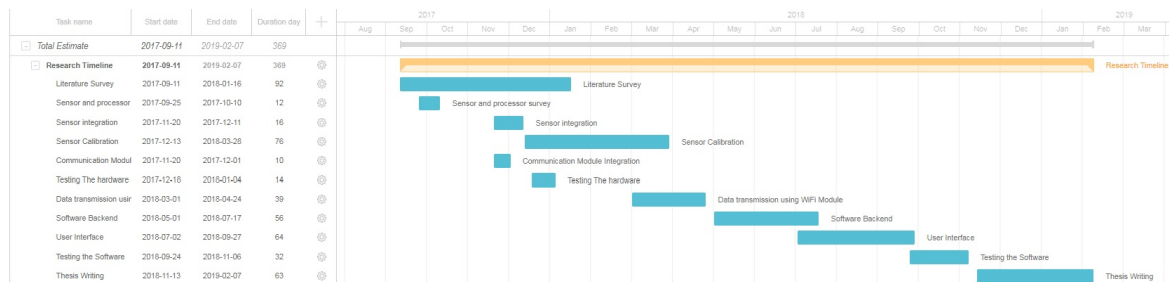

Figure 6.1: Thesis Time-line

Chapter 7

Progress

The hardware part of the system was implemented and the values were collected and represented in an open source platform, Thingspeak, which plotted the value of each pollutant concentration corresponding to a particular time.

7.1 Architecture of Hardware

As proposed, a higher level generic framework to guide building a air pollution monitoring system using low cost commodity hardware and open source software. As the choices for these hardware and software components are enormous and is keep changing as the technologies advance, suggesting one specific combination is hard and also not helpful if the hardware is not available globally at low cost. Therefore, I decided to experiment with a few options of using most commonly available hardware components which are low cost. To start with, I designed a functional air pollution monitoring hardware system. The system shown in has three main hardware components:

1. Sensors

2. Microcontroller board

3. WiFi communication module

7.2 Sensors

Based on the severity of health impact, different countries measure different set of pollutants. For example, India measures 8 major pollutants such as particulate matters (PM), ozone (O3), nitrogen dioxide (NO2), carbon monoxide (CO), sulfur dioxide (SO2), ammonia (NH3), and benzene (C6H6) (in some places lead (Pb) instead). Most other countries measure a subset of these pollutants and, for example, Canada measures PM,O3,NO2,SO2 and CO [19]. In addition to temperature and humidity sensors, we integrated four sensors into our system to measure four major pollutants such as PM,O3,NO2, and CO. Additional sensors can be easily integrated into our setup. The PM sensor Shinyei PPD42 that we integrated in our system can measure both PM2.5 and PM10. The MQ series sensors MQ-131 and MQ-2, respectively,
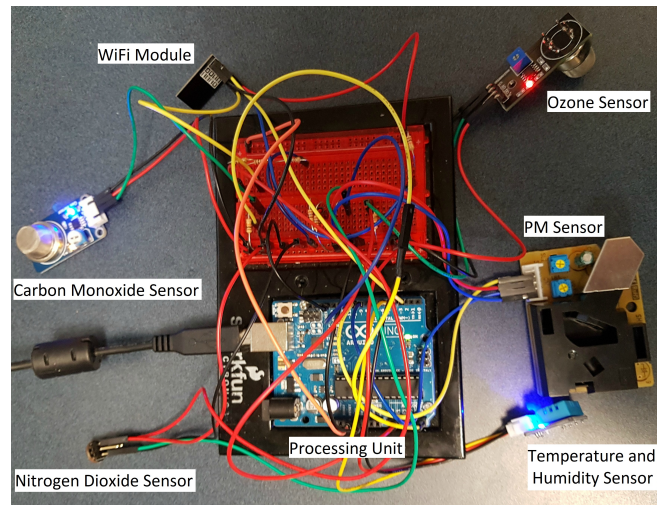
Figure 7.1: Hardware System

are used to measure the concentration of O3 and CO in the air. The MICS-2714 sensor is used to measure the concentration of NO2 in the air.

7.3 Microcontroller Board

For simplicity and ease of programming, I have use Arduino Uno which internally has ATmega328 microcontroller board. Since it is open-source based platform with rich software support, it is a widely used platform for various applications. Arduino supports both digital and analog inputs. It has 14 digital pins and 6 analog pins, and has shield to connect with both Ethernet and WiFi. As edge computing is preferred in this context, most of the calculation such as measuring gas concentration and computing air quality and air quality health indices are done in Arduino.

7.4 Communication Link

For the sensor device to communicate with the IoT software platform for data analytic and visualization services, we use ESP8266 WiFi module that has a networkable microcontroller. This module is very compact and has high durability and power saving features. Once the module is connected to the network it can transfer the data from Arduino to the specified IoT platform by using simple write commands.

7.5 Software Platform

I have used an open source IoT platform called Thingspeak [21]. It is integrated with the system to aggregate, analyze, visualize, and store the sensor data that we collect[21]. Thinkspeak can allow many users to integrate their system with other systems for collective and cooperative analysis of sensor data and promote citizen science in solving important global problems. It also offer a 'hub' model for data

repository and a set of APIs for accessing and using the sensor data for their analysis and interpretations. Thinkspeak provides an intuitive user interface that is easy to understand. It also provides a mobile application called Thingview which can be installed on phone and the same data from the system can be visualized simultaneously. For this purpose, I have used Thinkspeak to display the results. As soon as the value is transferred to Thingspeak, it can immediately draw graph showing online visualization.In total eight channels of Thingspeak for the graph representation of all the pollutants measured by the sensors and Air Quality Health Index(AQHI).

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