Sensor Network For Air Pollution Monitoring

Master's Thesis Proposal

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Contents

1 Introduction

Air pollution is a matter of serious concern and society is unaware of the impact that it the causes to human health as well as environment. As reported by WHO, more than 92 percentage of people living in cities do not breathe clean air. Lung cancer which is caused by breathing polluted air, contributes to 36 percentage of total death rate as of 2017. Air pollution can be defined as 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]. 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 cause to human health. As urban areas have a high density of population, maintaining air quality is becoming more and more challenging [8]. Measurement of pollutants required sophisticated, expensive, and power intensive equipment which can be placed only at very limited sites [23]. The monitoring stations usually consist of instruments for each individual pollutants and the collected data from these stations will be send over to some data centers where it is analyzed and displayed for the public. These stations can be permanent stations comprising of instruments like Tempered Element Oscillating Microbalance(TEOM) for measurement of particulate matter, UV photometry for ozone, chemiluminiscence for nitrogen dioxide [24]. These devices are expensive, bulky and high maintenance required on a regular basis.

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.

2 Background and Related Work

Air pollution monitoring is a hot research topic due to the increasing concern on the adverse effects of pollution [10]. The adverse effect of air pollution has turned many researchers to study and research about the main pollutants and the health issues raised by them. The rate of pollution is incresing rapidly and society is unaware of the fact that majority of health issues are related directly to the air we breathe. Stationary monitoring systems are used for the identification of pollutants, wherein there will be around 150 stations throughout a region which will be continuosly monitoring the air and the raw parameters are then used for calculating the indexes which will tell the seriousness of pollution [24]. Later the development of wireless sensors encouraged many research to work using these sensor network for the data collection since it was much more easy and collected data can be analayzed and uploaded to any IoT platform for visualization. In [10] proposed a monitoring system which could be mount on a public transport system so that there will be a wide coverage in data collection with limited number of sensor. Firdhous has proposed a proactive IoT-enabled indoor air quality monitoring system focusing on concentration of ozone near photocopy machine [13].Another work done by Man Sing Wong which came up with a personal monitoring system which is portable device focussing on low cost sensors such as UV, temperature and other air quality sensors integrated on a processor and could work on few batteries[14]. Biyi Fang proposed a system called Airsense which primarily focussed on indoor air quality which was aided by machine learning aspects for prediction and a software to visualize data [15]. Joy Dutta talks about a portable system which senses concentration of pollutants, which could be used by individuals to gather and aggregate data through crowd-sensing. The system also supports a software for visualization [8].

Out of all the papers there are only few papers that discuss the outdoor air quality. Most of the papers are on the indoor air quality due to the fact that it's easy to anticipate all the pollutants and their ranges that would be present indoor. As far as the outdoor air quality is concerned, the number of the pollutants and their range would vary from places to places. Although the above-discussed systems are the effective system, those can only be used for specific conditions and gases and are complex. This is the scenario where the proposed system can be of use. The idea is to create a simple visualization system wherein all possible gases which contribute to outdoor air quality is included. Also instead of just visualizing the concentration of pollutant, using the metrics which is already issued by the government would make it much more easier to understand the collected data. Another drawback of the above-cited papers are, they do not discuss the calibration of sensors or tend to neglect the importance of calibration of a sensor. Usually calibration is done by technicians who visits to the stations and reports to the authority [24]. Since calibration takes a lot of effort and there is no well defined method for each sensor's calibration, there is not much work done in this area.

3 Problem Statement

The aim is to propose, design and develop an air pollution monitoring system using off the shelf hardware and open source software, with the following objectives in mind.

1. To educate the common people on adverse effect of air pollution by showing how polluted the vicinity is.
2. To influence the behavior of people by representing the concentration of pollutant as well as AQHI(Air Quality Health Index) which provides the seriousness that pollutants cause to health.
3. To give an idea of how to integrate all the hardware components to a processor and also make an independent software, which can be accessed anywhere in the world.
4. To encourage and help citizen science to solve the issue of air pollution and give more understanding to the impact it cause to human health and environment.

3.1 Research Question

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

1. What all factors should be considered while selecting sensors for measurement of pollutants?
2. Which processor to be used for processing the data collected from sensors?
3. How should the hardware component i.e the sensors and the processor, should be packaged?
4. What kind pollutants affect the human health most? How to measure them?
5. As the pollution is in the atmosphere, should it not be measured everywhere all the time? If so, what kind of infrastructure is needed to facilitate such a ubiquitous measurement?
6. What is the difference between different metrics which is used to show the effect of pollution?
7. How can the seriousness of pollution be made aware?
8. How can the representation of Air quality health index be done?

3.2 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. Packaging of hardware component.
5. Transferring the data to a platform or a database using the WiFi module.
6. Checking whether the collected data is accurate.

4 Methodology

The proposed architecture contains three major components i.e, the hardware architecture which is the sensor system and the processor, the communication middle ware for transferring of the collected data and the software architecture which does the analysis and display.

4.1 Hardware Architecture

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. Communication module

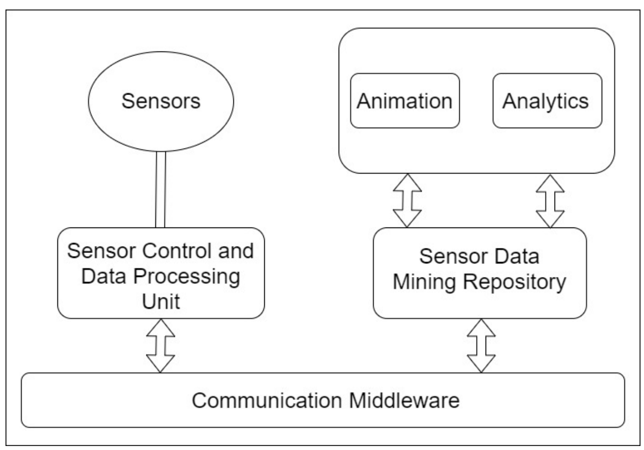

Figure 1: System Architecture

1. Sensors

   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.

   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].

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.

In addition to temperature and humidity sensors, the proposaed system integrates four other sensors into the system to measure major pollutants such as PM, O3, NO2, and CO. In case of additional sensors, it can be easily integrated into the setup. The PM sensor Shinyei PPD42 that is integrated in the system can measure both PM2.5 and PM10. The MQ series sensors MQ-131 and MQ-2, respectively, 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.

Sensors will collect data from the environment as per their schedule. Communication module essentially sends the sensor data to mining repository.

2. 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.

3. Communication Module

   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.

4.2 Communication 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]. The collected data from the hardware platform should be stored in a server, so this transferring part is done here. The thingsspeak server can be used for storing the values of pollutant and data from the server can be retrieved using a python programming to the back end of the software.

1. 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.

4.3 Software Architecture

These components are to provide statistical data analysis and visualization through intuitive graphics services to help users to make decisions. Particularly, analytic component is needed to performs statistical 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, I would like to emphasize the importance of accurate and intuitive graphic display if it is intended to used effectively.

5 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.

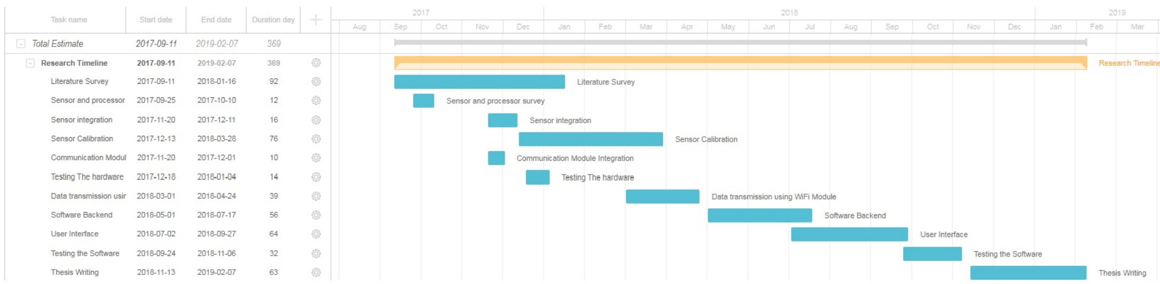

Figure 2: Thesis Time-line

6 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. The implemented system is as shown in figure 3, in which all the sensors are attached to processor. All the sensors were selected carefully based on performance, cost and size so that the system remains compact and portable. For the initial testing of the system the data collected from the hardware was represented in Thingspeak visualization environment itself to understand how the collected data from sensors looks like. Along with the representation of the concentration of pollutant there was also an attempt done in calculating the Air Quality Health Index(AQHI), which was successfully shown along with other graphs.

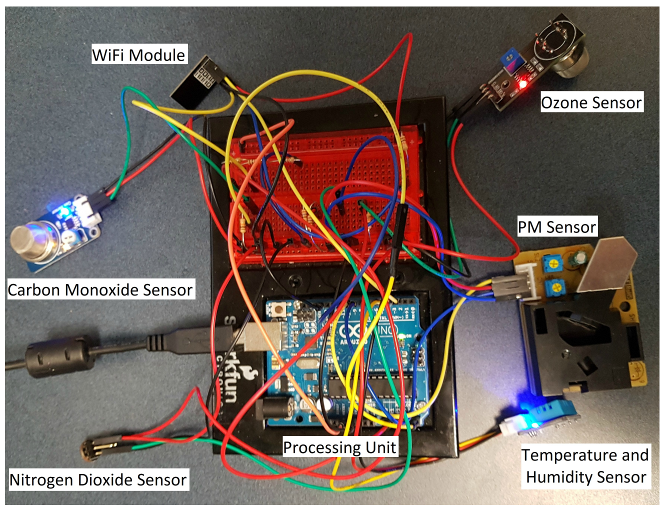

Figure 3: Hardware System

The graphs for different pollutants and the index for understanding the effect of pollution is explained in the paper [25]. The paper clearly gives an idea about the Thingspeak platform and also about the hardware architecture. There was not much changes made from proposed architecture.

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