Smart Real-Time Indoor Air Quality Sensing System and Analytics

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***Abstract* - Indoor air quality monitoring and analytics is one of the important interdisciplinary research areas, which is attracting significant attention of various researchers from environment, mathematics, material science and electrical and computer engineering. According to a research study conducted by World Health Organization (WHO), pollution of indoor air is the most known hazardous case for respiratory diseases such as lung cancer, asthma and chronic diseases. Lack of information about the pollution sources and its serious impact on health leads to a huge number of people likely to be affected by various types of respiratory diseases. With the recent developments in sensing technology, machine learning and communication technology, IoT based Smart Real Time Indoor air quality sensing and analytics have been implemented to promote better awareness for users to alert them about indoor air quality to maintain the wellbeing in their indoor environments. The paper provides a proof of concept on IoT based Indoor air quality sensing system and analytics. The data is collected for analyzing indoor air quality in various indoor settings such as kitchen for oily based cooking, living room for insecticide spray, and smoking and flour mill for detecting flour dust during crop grinding. We used J48 and Naïve Bayes machine learning algorithm to model the air quality status. Result shows that the Naïve Bayes Algorithm detects 99.11% and J48 algorithm detects 99.30 % accurately**

Keywords - Air Quality, Air pollution,Internet of Things (IoT), Indoor-air quality (IAQ), Smart Home, Smart sensing, machine learning algorithm.

I. INTRODUCTION

According to a research study conducted by WHO, indoor air pollution is the eighth most known risk factor for respiratory diseases such as lung cancer, asthma and chronic diseases. Lack of information about the pollution sources and its serious impact on health leads to a huge number of people likely to be affected by various types of respiratory diseases. With the recent developments in sensing technology, machine learning and communication technology, IoT based Smart Real Time Indoor air quality sensing and analytics have been implemented to promote better awareness for users to alert them about indoor air quality in order to maintain the wellbeing of the indoor inhabitants. Indoor air quality (IAQ) plays a vital role in our daily lives. Approximately 90 percent of people spend their time indoor environment. Study shows that poor indoor air quality is the leading cause of respiratory infections, chronic lung diseases, and cancers might cause significant risks to people's health as reported by World Health Organization (WHO). According to Environmental Protection Agency (EPA), indoor air pollution may be two to five times worse than the air outdoors. The major cases of indoor air pollution is daily household activities. For example, oil-based cooking could generate a harmful airborne particulate matter (PM), tobacco smoking produces various chemicals with many of them identified as poisons in the form of tiny particles (PM) and gases including volatile organic compounds (VOCs). Cleaning and maintenance products such as pesticides and disinfectants contain and releases PM 2.5 and many VOCs that lead to long- term health risks such as child development and hormonal issues [4], [5], [28], [30]. Even though we are highly exposed to the various type of indoor air pollution, we focused on the two reasons.

Major motivation of Indoor Air Quality monitoring is based on the fact that most of the indoor air pollutants ate odorless and are not visible. Also, respiratory diseases have no simple symptoms until for long period of exposure [1]. Therefore, it is very important to determine and know whether the symptoms are due to exposure to indoor air pollutants or other related factors [2].

This paper presents an implementation of a IoT based system for the monitoring of indoor air pollution levels and their respective air quality indexes (AQI).In addition, the system could increase users' awareness towards IAQ, the information about the pollution detection, the AQI status or standard, the seriousness of the pollution, and the respective suggestions to help users how to reduce the pollution to its optimal level.

II. RELATED WORKS

Researchers have studied the problems related to air pollution using different technologies. Some of participatory sensing technique was developed for utilizing each person's mobile phone to create a collaborative sensor network to collect, share and analyze data.

In [7], [8] authors presented the concentration of carbon dioxide (CO_2) in indoor environment and analyzed the growth and decay rate of the pollutant. Brett J. et al. [9] shown that smoking is the most significant contributor to indoor air pollution in addition to a portion of the outdoor contribution.

Researchers also proposed a cloud-based approachcomprising of particulate matter sensors and air quality analytics engine in the cloud for measuring PM2.5 in real time basis [10],[12]. In [11] Jong-J.etal. presented the role of sensor networkfor sensing various indoor air pollutants and airborne particles. They also discussed several factors that contributes to poor air quality in past and current building structure, so that the latter buildings are more airtight and hence brings in less fresh air from the outside.

Sunyoung et al. [12], also developed a homebased PM 2.5 monitoring system to visualize and share the real time indoor air information with othersincreasing people' awareness towards IAQ. **Haryonoet al**. [13] emphasized on the pollutants emission from house hold activities and fuel based cooking especially liquid petroleum gas (LPG). They have shown that cooking ingredients and cooking methods strongly influences quality of indoor air. They have revealed that two typical cooking methods frying and boiling produces fine particles (PM2.5) and CO.

Another researchers presented the rise of sensing technology for the energy management and IAQ in urban environments, also identified the major challenges for their large-scale deployment, and shown the research gaps that should be covered by future investigations along with the introduction of low-cost sensors technology [14]. In another study researchers also used the air quality data for building a model, based on artificial neural network to estimate how much hours an HVAC system should be turned on ahead of its original schedule to reduce indoor PM2.5 to a best situation [15].

Goncalo M. and Rui P. [16] developed an indoor air quality system based on an IoT paradigm for ambient assisted living to know a variety of environmental parameters such as air temperature, relative humidity, luminosity and concentration of carbon monoxide (CO), carbon dioxide (CO2) gases.

Authorsalso developed air quality prediction model using neural network for environmental engineering problems [17] - [18]. Various parameters such assulfur dioxide (SO2), carbon monoxide (CO), nitrogen dioxide (NO2), nitric oxide (NO), temperature, relative humidity and air velocity were used for modeling to minimize the increasing effects of air pollution. The concentration and composition of particles in indoor air are affected by both indoor and outdoor pollution sources.

Furthermore, in another machine learning approach**, KingsyGrace. R et al**. in [21] presented analysis of air pollution using k-means clustering algorithm and compared the result with Possibility based Fuzzy C-Means clustering algorithm. The research work highlights that traditional methods are too complex to process and analyze the bulky data, and therefore heterogeneous data is converted into meaningful information by using data mining approaches for decision making.

Luis P. and Sanchez F. [24], presented models for assessment and prediction of air quality. Firstly, they developed an air quality assessment by using computational model for evaluating toxic compounds that affect sensitive people. They also proposed the model that predicts the concentrations of air quality by using an autoregressive technique to provide air quality index based on the fuzzy inference system previously developed.Another study in [25] found that smoking, candle, frying, grilling, stove use, toasting, cooking pizza, vaporizing oil and fan heater use could raise the indoor micrometer particleconcentration levels.

Asmaa A. et al. also shown that the rise in concentration of CO2 at a work place leads to a rise in the amount of volatile organic compounds (VOCs), hence decreases the performance of the workers in office [28].

III. METHODOLOGY

This section describes the methodology used in the study, the hardware and software components, threshold based algorithm, ML algorithm, andanalysis of data generated by sensors, android app usedfor visualizing the sensor data. The air quality sensors, microcontroller and other important devices used for the study are explained in detail.**Architectural design:** The crucial components used in the system development are described in the following section.

A. Sensing components

The IAQ Sensing layer consists of the air quality sensors, those are PM 2.5 and VOCs, CO, Temperature and humidity sensors.

Table 1. Sensing platform

Air Quality Sensor	Standard name
Particulate Matter (PM 2.5)	Sharp GP2Y1010AU0F
Carbon monoxide (CO)	MQ-7
Volatile Organic Compounds (VOCs)	MQ-135
Humidity	DHT22
Temperature	DHT22

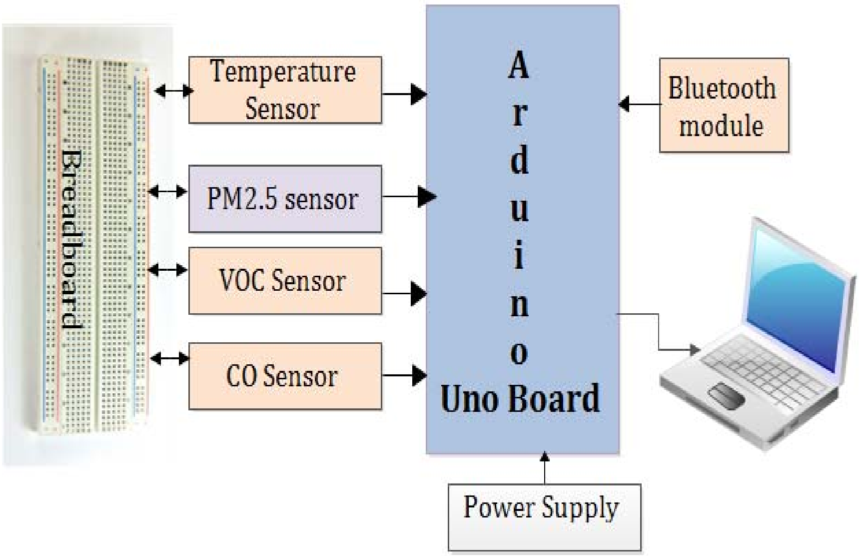


Fig.1 Block diagram for hard ware interfacing.

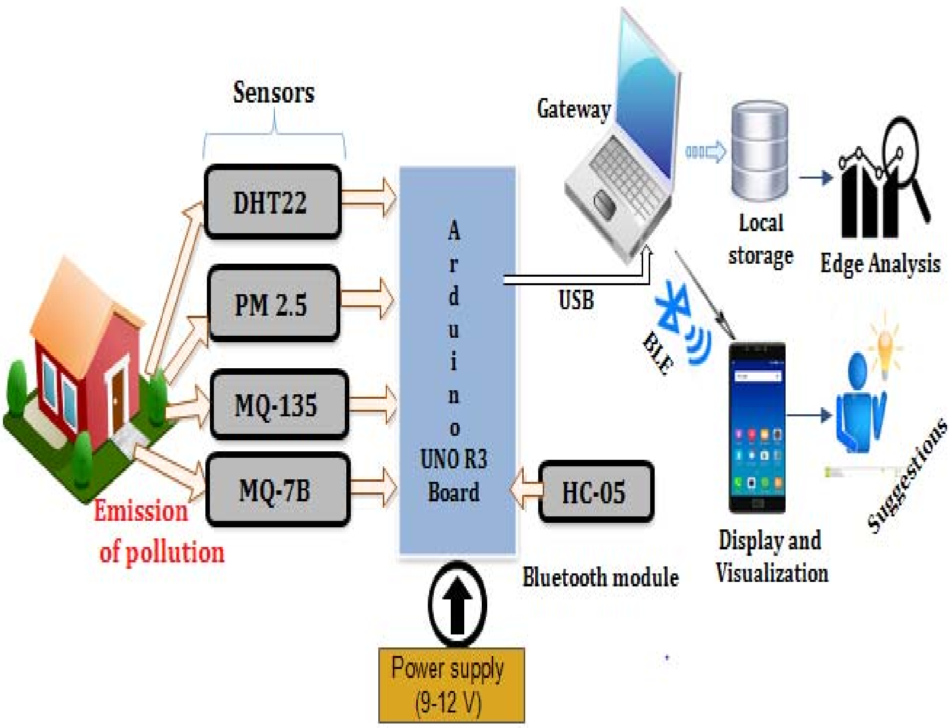


Fig.2Proposed system architecture

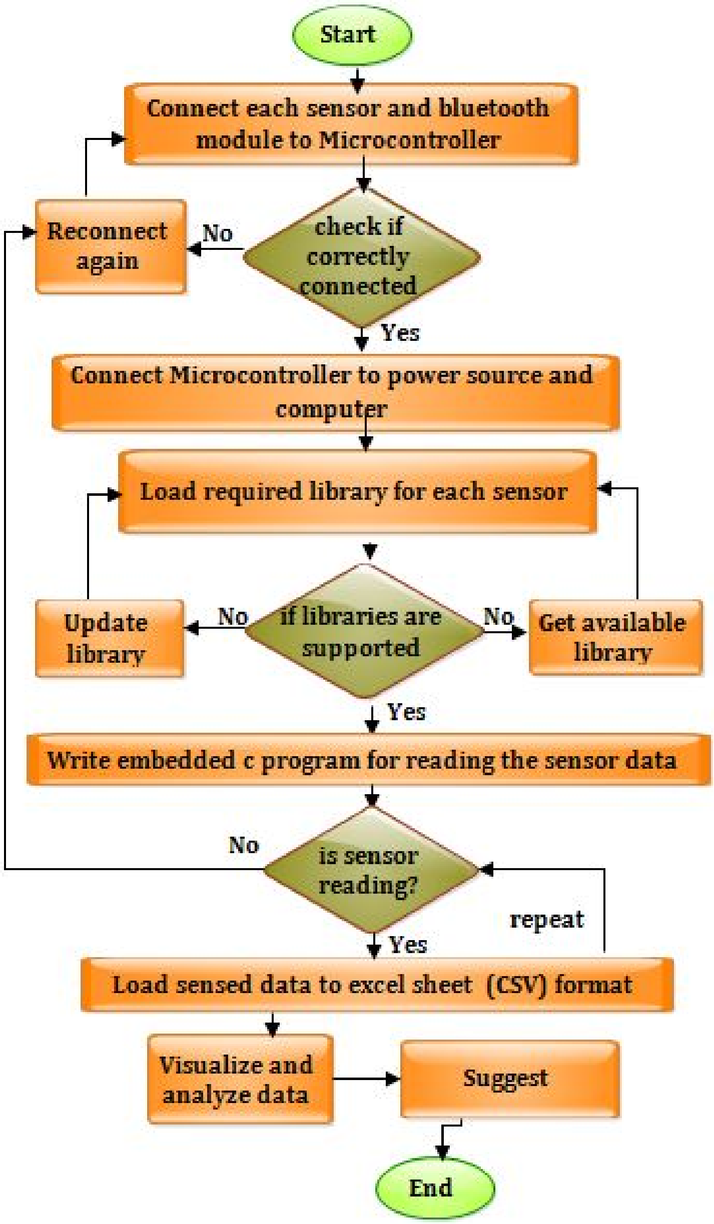


Fig.3 flow chart of the system

The air quality sensorsare described in the following sections.

*1) MQ-135 Air quality sensor***:** thismeasures general air quality because it is sensitive to many gazes and VOCs (Volatile Organic Compounds) including formaldehyde, benzene, ammonia (NH3), nitrogen oxides (NOx), alcohol, smoke and carbon dioxide (CO2). We used this sensor for sensing VOC pollutions.

*2)MQ-7 Carbon monoxide (CO) sensor:*used for detection of CO concentration. The detection Range is 0-500ppm (part per million). The Application area is domestic CO gas leakage alarm. The MQ-7 gas sensor is SnO2, which with lower conductivity in clean air. It detects CO at low temperature (heated by 1.5V). The sensor's conductivity gets higher along with the CO gas concentration is rising. Figures shown below are the hardware components used for implementation of the Smart Real Time Indoor Air Sense

(a) (b) (c)

Fig. 4 (a) Arduino Uno R 3 microcontroller board (b) MQ-135 sensor (c) MQ- 7 CO sensor

3) DHT22 Temperature and humidity sensor:DHT22 is a digital, temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and generate a digital signal on the data pin (no analog input pins used).It is shown in fig. 5(a)

- Cost effective having 4 pins
- Uses 3 to 5V power
- Good for -40 to 125°C temperature readings
- Good for 0-100% humidity readings

*4) Sharp GP2Y1010AU0F:*This is an optical air quality sensor, designed to sense dust particles with small size.

An infrared emitting diode and a phototransistor are diagonally arranged into this device, to allow it to detect the reflected light of dust in air. It is effective in detecting very fine particles like cigarette smoke, and also commonly used in air purifier systems. It is shown in fig. 5(b)

5) HC-05 Bluetooth module: It is IEEE 802.15.1 standardized protocol, through which one can build wireless Personal Area NetworkHC-05 Bluetooth module is designed for wireless communication. It uses serialport to communicate with microcontroller devices. It is used for many applications like wireless headset, game controllers, wireless mouse, wireless keyboard etc. It has range up to <100m. It is shown in fig. 5(c)

B. Connecting and interfacing equipment's

1) Abreadboard: is a device used as a construction base in developing an electronic circuit.It is a good unit for making temporary circuits and prototyping.It is made of plastic having strips of metal underneath with a numerous holes and it is solder less, which allows them to be reusable.

2) Jumper wires are an electrical wire with a connector or pin at each end. Used to interconnect the components of a breadboard with other equipment or components, without soldering.

*3)Resistors***:** are usedto **r**educe current flow, adjust signal levels, divide voltages, and terminate transmission lines.

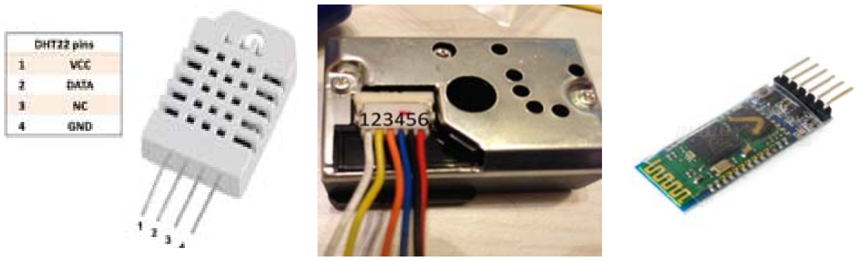
*4) Capacitor*are used for storing energy electrostatically in an electric field. It also used for power conditioning. We used capacitor 220µF (microfarad) with PM2.5 sensor.

C. Processing and communication components

1) Arduino Uno R3 microcontroller: an arduino is a microcontroller used for building and interfacing various sensors and devices required for a given project. It allows uploading sketches/programs into the microcontroller memory. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a software, or IDE. . It is shown in fig. 4(a).

*2) Gateway device:*we used the personal computer as a gate way.

3) Bluetooth technology: It is IEEE 802.15.1 standardized protocol, through which one can build wireless Personal Area Network. HC-05 Bluetooth module is designed for wireless communication.It uses serial port to communicate with microcontroller devices. It is used for many applications like wireless headset, game controllers, wireless mouse, wireless keyboard etc.It has range up to <100m.



(a) (b) (c)

Fig. 5shows the hardware components used for implementation of the SmartRealTimeIndoorAirSense (a) DHT22 temperature and Humidity sensor (b) Sharp GP2Y1010AU0F PM 2.5 sensor (c) HC-05 Bluetooth module

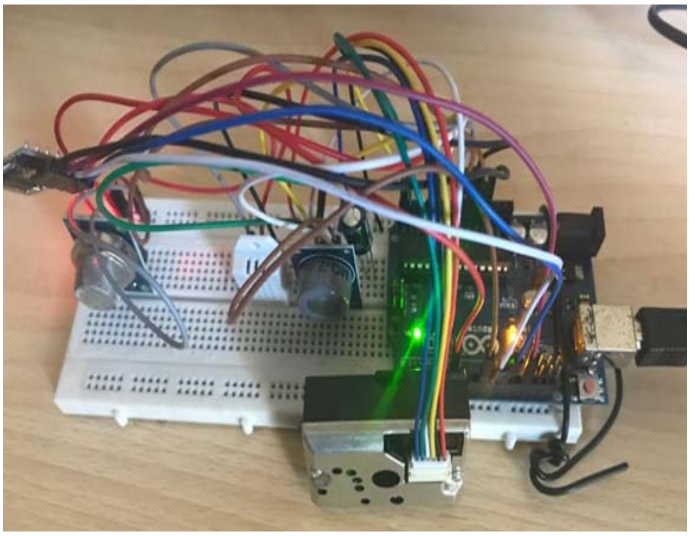


Fig 6 a proof of concept of SmartRealTimeIndoorAirSense

IV. ANALYSIS AND VISUALIZATION

The **EPA** (Environment Protection Agency) uses the Air Quality Index (AQI) to measure five major pollutants for which it has established National Ambient Air Quality Standards under the Clean Air. AQI is a numerical scale developed by EPA. It is used by government agencies to communicate how polluted or clear the air is in our surrounding for reporting day to day air quality with regard to human health. An increase in air quality index indicates increased air pollution and severe threats to human health [5], [40].

There are six distinct AQI categories: Good, Moderate, unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous. The threshold value for each category were developed based on established national air quality standards [32]. AQI calculations focus on major air pollutants including particulate matter, carbon monoxide (CO), sulfur dioxide (SO2), ground-level ozone, and nitrogen dioxide (NO2). The sub-index value is calculated for each of these pollutants. The highest sub-index reflects overall AQI. The general formula used to calculate air quality index [33] is given by equation (1).

AQI = $((I_{H}i-I_{lo}) / (BP_{Hi}-BP_{Lo}))*(C_{p}-BP_{Lo}) + I_{Lo}$……..… (1)

Where

AQI = the AQI for each pollutant

$I_{H}i$ = the AQI value corresponding to BPHI

I_{lo} = the AQI value corresponding to BPLo

Cp = the rounded concentration of the pollutant

BP_{Hi}= the breakpoint that is greater or equal to Cp

BP_{Lo}= the breakpoint that is less than or equal to Cp

A. Experimental Setup

Data Collection:the data collection hasbeen completed in two weeks in three various environments to obtain the sufficient amount of data. We deployed our sensor module during home based activities especially cooking in the kitchen, smoking and spraying of insecticide in the living room and grinding flour mill. The sensor module was kept around two to five meter (2-5m) near to the cooking, smoking, spraying and grinding activities to detect the emission of pollution. The generateddata was stored to comma delimited value (CSV) file format for further analysis. The features on the CSV file are temperature, humidity, PM2.5, VOC, CO, AQI and Air quality status.

B. ML algorithm for classification of the air quality

WEKAis a suit of machine learning software tool having various standard data mining tasks such as data preprocessing, regression, clustering, association rules, classification, prediction, feature selection and visualization. After gathering air quality data, we performed the preprocessing such filling or cleaning missing data values, removing inconsistent data points.

*1) Naive Bayes Machine Learning Algorithm:*This algorithm is a classification algorithm used for binary (two-class) and multi-class classification problems. The technique is easiest to understand when described using binary or categorical input values.We applied the naïve Bayes algorithms to our data set, the algorithm detects **99.11**% instances correctly as healthy and **0.89%** as unhealthy.

*2)J48 Machine Learning Algorithm:*This is one of best predictive and classification ML algorithm. We used this ML algorithm for accurately classifying the AQI category either healthy or unhealthy depending on the available features of the data set. We followed the EPA AQI standard to group the AQI categories of good and moderate as healthy and group the remaining four AQI categories as unhealthy [32]. The total data set contains 3043 instances. The algorithm detects **99.31**% instances correctly as healthy and **0.69%** asunhealthy.

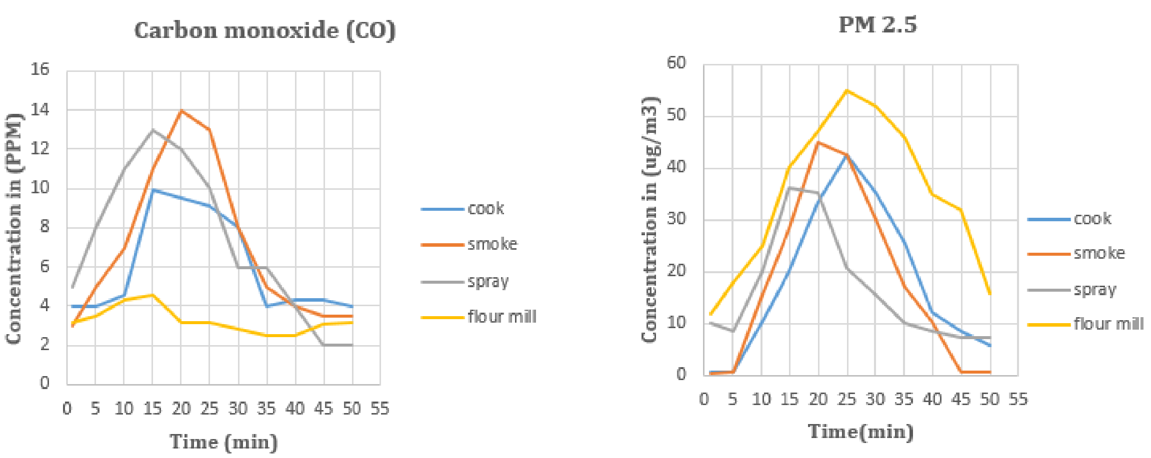
Result of Naïve Bayes Algorithm

```
Time taken to build model: 0.44 seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances        3022               99.3099 %
Incorrectly Classified Instances        21                0.6901 %
Kappa statistic                          0.861
Mean absolute error                      0.0109
Root mean squared error                  0.0813
Relative absolute error                 20.0995 %
Root relative squared error             49.6363 %
Total Number of Instances              3043

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
                 0.999    0.202    0.994      0.999    0.996      0.864    0.887     0.993     healthy
                 0.798    0.001    0.944      0.798    0.865      0.864    0.887     0.818     unhealthy
Weighted Avg.    0.993    0.197    0.993      0.993    0.993      0.864    0.887     0.988

=== Confusion Matrix ===

    a    b   <-- classified as
 2955    4 |    a = healthy
   17   67 |    b = unhealthy
```

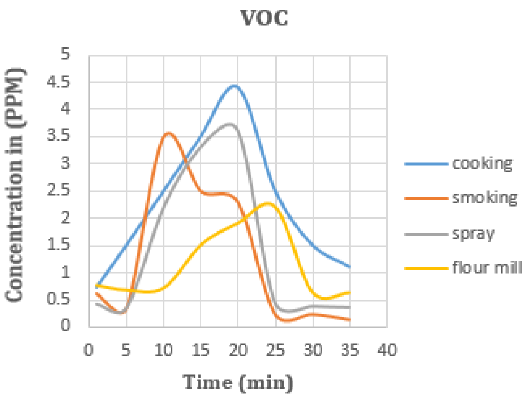
Results of J48 Algorithm

```
Time taken to build model: 0.09 seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances        3016               99.1127 %
Incorrectly Classified Instances        27                0.8873 %
Kappa statistic                          0.8375
Mean absolute error                      0.0088
Root mean squared error                  0.0939
Relative absolute error                 16.3829 %
Root relative squared error             57.3409 %
Total Number of Instances             3043

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
                 0.995    0.143    0.996      0.995    0.995      0.838    0.918     0.996     healthy
                 0.857    0.005    0.828      0.857    0.842      0.838    0.917     0.769     unhealthy
Weighted Avg.    0.991    0.139    0.991      0.991    0.991      0.838    0.918     0.989

=== Confusion Matrix ===

    a    b   <-- classified as
 2944   15 |    a = healthy
   12   72 |    b = unhealthy
```

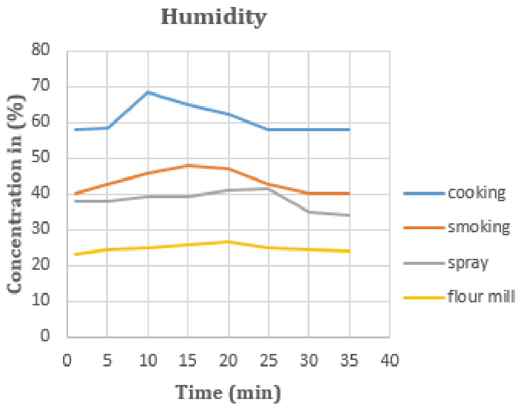
The pollution event due to various indoor activities cooking, smoking, and insecticide spray are visualized by the graphs in fig. 7



(a) (b)



(c)



(d)

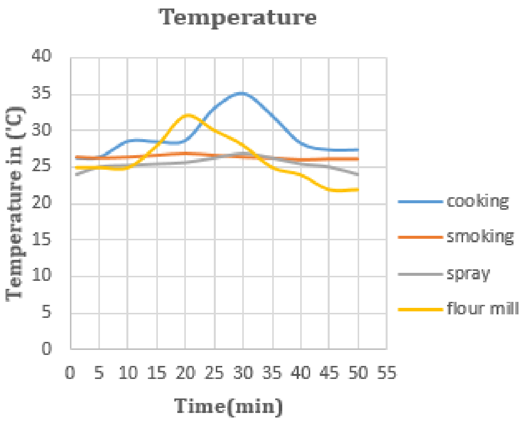
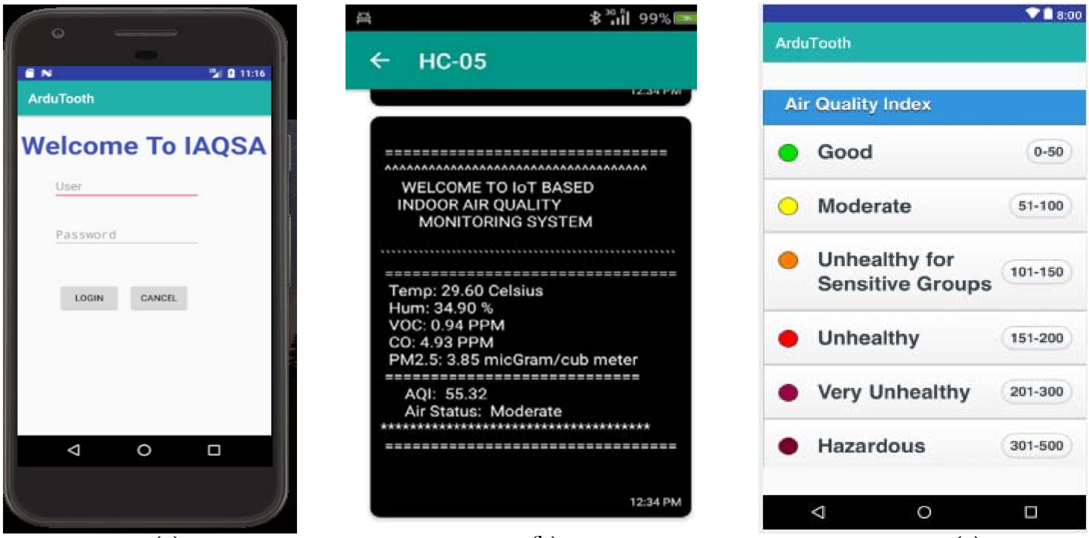


Fig. 7. The above graph shows (a) CO, (b) PM 2.5, (c)VOCs, (d) humidity sensor and (e) Temperature measurements of indoor air pollution generated by cooking, smoking, insecticide spray and flour dust.

C. Smart phone application

The goal of developingan android application is for increasing user awareness of IAQ, visualizing the lively streaming indoor air quality datawithina specified interval of time. After installing and launching the application, thelogin window will be displayed. The user must fill the required credentials to login to the application. If the user want to exit, it is possible to use the Cancel button. After logging in the main layout will be displayedThen establishing the Bluetooth connection, hence the data from the sensor will be transferred to smart phone throughserial port by Bluetooth communication protocol. Depending on the amount of the pollution, AQI and each pollutant concentration, suggestion to users will be displayed accordingly.



(a) (b) (c)

Figure 8. The **SmartRealTimeIndoorAirSense an** android applicationscreenshot of (a) login window, (b)visualizing the lively streaming indoor air quality information and suggestion (c) the EPA based AQI standard with color code.

V. CONCLUSION

In this work, we designed a prototype of SmartRealTimeIndoorAirSense, an intelligent real time indoor air quality sensing, monitoring and analytics system that detects indoor air pollution events, visualizing pollution levels of each pollutant to estimate the AQI, and providing actionable suggestions to help user in order to improve IAQ in a timely manner. Specifically, SmartRealTimeIndoorAirSense is developed using cost effective air quality sensors for continuously monitoring the concentrations of CO, PM 2.5 and VOCs, which are three of the most common air pollutants in the indoor environment and the ambient temperature and humidity sensors for sensing temperature and humidity level at home. SmartRealTimeIndoorAirSense is currently designed for indoor home uses, but it can be extended to be used in public buildings such as office rooms, class rooms, shopping malls and subway stations. Therefore, we believe SmartRealTimeIndoorAirSense has incredible chance to be adopted widely in a real world.

The study further highlights the strong link between indoor air quality and possible health risk in the form of various respiratory diseases.Despite suitable measures and guidelines defined by agencies including WHO, we believe that the air pollution is the serious ongoing issue which requires further attention.

VI. FUTUREDIRECTIONS

We suggest that the responsible authority and Environment protection agency should work with researchers, Information Technology companies, government's authorities, to minimize air pollution and its severe causes. The research work on indoor air quality can be extended in several directions:

With the ongoing focus on Smart City challenges including air pollution in India, **further research work is required to improve participatory sensing** techniques usedto create a map of air quality information.

Future research is needed to develop cost-effective sensors capable of measuring low concentrations of gaseous pollutants and distribution of nanoparticles. This could of interest to various researchers and industry professionals active in nanotechnology and nanoparticles.

The problem of finding a correlation between the air quality and possible health risks in terms of respiratory diseases, has been studied widely. But there is no single correlation measure which is better to the other. Also, Indoor Air Quality is relatively new as compared to outdoor air pollution.

Therefore**, further researchcan be conducted to develop new correlation** measuresto improve the correlation of indoor air pollutants with diseases. This could attract an attention of a mathematician working with environment researcher.

For professionals in computer science and IT domain, an IoT platform can be developed using fog computing and cloud computing to do the device level analytics and analytics at the air pollution control room respectively.

REFERENCES

[1] Biyi F., Qiumin X., Taiwoo P., and Mi Z.; AirSense: an intelligent homebased sensing system for indoor air quality analytics. ACM, 2016.
[2] Charith Perera, Chi Harld Liu, Srimal Jayawardena, and Min Chen "A Survey on Internet of Things from Industrial Market Perspective,"IEEE publication, VOLUME 2, 2014.
[3] Madhvaraj M. Shetty and D.H. Manjaiah, "Challenges, Issues and Applications of Internet of Things,"Springer International Publishing AG, pp.231-243, 2017.
[4] Luigi Atzori, Antonio Iera, Giacomo Morabito, "The Internet of Things: A survey" Published by Elsevier B.V, 2010.
[5] The WHO European Centre for Environment and Health, Bonn Office,2010," WHO guidelines for indoor air quality book", Available at:[http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf, accessed, 20 August 2017.
[6] Ovidiu V. and Peter F.,"Internet of Things from Research and Innovation to market Deployment", River Publishers (EBook), 2014.
[7] Divya Lohani and Debopam Acharya, "A Context Aware IoT System to Measure Indoor Air Quality and Ventilation Rate," IEEE 17th IEEE International Conference on Mobile Data Management, 2016.
[8] Petros Spachos, and Dimitrios Hantzinakos," Real-Time Indoor Carbon Dioxide Monitoring through Cognitive Wireless Sensor Networks," IEEE Sensors Journal, 2015.
[9] Brett J., Kyra N., Leah C., Sheila T., Fernando H., Paul L., Jane E., "Indoor air sampling for fine particulate matter and black carbon in industrial communities in Pittsburgh", Elsevier 108–115, 2015.
[10] Yuan Cheng, Xiucheng Li, Zhijun Li, Shouxu Jiang, Yilong Li, Ji Jia, and Xiaofan Jiang," Air Cloud: a cloud-based air-quality monitoring system for everyone," In Proceedings of the 12th ACM Conference on Embedded Networked Sensor Systems, ACM, pp. 251–265, 2014.
[11] Jong-Jin Kima et. al., "Wireless Monitoring of Indoor Air Quality by a Sensor Network," SAGE publication pp145–150, 2010.
[12] Sunyoung Kim and Eric Paulos. "InAir: sharing indoor air quality measurements and visualizations," In Proceedings of the 28th international conference on Human factors in computing systems (CHI). Atlanta, Georgia, USA, pp1861–1870, 2010.
[13] Haryono S. Huboyo, Susumu T., and Renqiu C.," Indoor PM 2.5 Characteristics and CO Concentration Related to Water-based and Oil-based Cooking Emissions Using a Gas Stove," Aerosol and Air Quality Research, pp. 401–411, 2011.
[14] Prashant K., Claudio M. et al., "Indoor air quality and energy management through real-time sensing in commercial buildings." UBICOMP, SEATTLE, WA, USA 2014.
[15] Xuxu C., Yu Zheng., Yubiao C. et al. "Indoor Air Quality Monitoring System for Smart Buildings", ACM 2014.
[16] Gonçalo Marques and Rui Pitarma,"An Indoor Monitoring System for Ambient Assisted Living Based on Internet of Things Architecture" International Journal of Environment Research and Public Health, 2016.
[17] Suraya Ghazali and Lokman Hakim Ismail, "Air Quality Prediction Using Artificial Neural Network" IEEE International conference, 2014.
[18] Azman Azid, Hafizan Juahir, et al., "Prediction of the Level of Air Pollution Using Principal Component Analysis and Artificial Neural Network Techniques", Springer International Publishing Switzerland 225:2063, 2014.
[19] Online resource Available at:https://www.ibm.com/internet-of-things/?lnk=mpr_iot&lnk2=learn accessed Monday 07/08/2017 4:20 PM
[20] David Hasenfratz, Olga Saukh, Silvan Sturzenegger, and Lothar Thiele "Participatory Air Pollution Monitoring Using Smartphones",ACM, 2012.
[21] Kingsy Grace. R, Manimegalai. R, Geetha Devasena. M.S., Rajathi. Si, Usha. K., Raabiathul Baseria. N, "Air Pollution Analysis Using Enhanced K-Means Clustering Algorithm for Real Time Sensor Data", IEEE Region 10 Conference (TENCON) Proceedings of the International Conference, 2016.
[22] Randall V. Martin, "Satellite remote sensing of surface air quality, Atmospheric Environment", Elsevier 2008
[23] Changhai Peng, Kun Qian, Chenyang Wang, "Design and Application of a VOC Monitoring System Based on a ZigBee Wireless Sensor Network", IEEE Sensors Journal, pp. 1-14, 2013
[24] Jose Juan Carbajal-Hernándezet al., "Assessment and Prediction of Air Quality using Fuzzy Logic and Autoregressive Models Atmospheric Environment", Elsevier, pp. 37-50, 2012.
[25] He, Congrong, Lidia Morawska, Jane Hitchins, and Dale Gilbert. "Contribution from indoor sources to particle number and mass concentrations in residential houses." Atmospheric environment 38(2), pp.3405-3415, 2004.
[26] Brienza, Simone, Andrea Galli, Giuseppe Anastasi, and Paolo Bruschi. "A low-cost sensing system for cooperative air quality monitoring in urban areas." Sensors 15(6), pp. 12242-12259, 2015.
[27] Namdeo, A., Yadav, J. and Deshpande, A., 2015, Harvard. "Belief and Plausibility of UK Pulmonologists' on Health Effects Due to Air Pollution: Revisited", International Journal of Health Sciences and Research (IJHSR), 5(12), pp.346-354.
[28] Asmaa Ali. Mansour, Samer, Nidal Nasser, and Lutful Karim, "Wireless Sensor Network-based air quality monitoring system." In Computing, Networking and Communications (ICNC), 2014 International Conference, pp. 545-550. IEEE, 2014.
[29] Abed, Ali Ahmed. "Internet of Things (IoT): Architecture and design." Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA), Al-Sadeq International Conference on. IEEE, 2016.
[30] Xiang, Y., Piedrahita, R., Dick, R. P., Hannigan, M., Lv, Q., & Shang, L." A hybrid sensor system for indoor air quality monitoring", In Distributed Computing in Sensor Systems (DCOSS), IEEE International Conference on (pp. 96-104), 2013.
[31] Internet of Things and Data Analytics Handbook (2017)
[32] National Air Quality Index report Central Pollution Control Board (Ministry of Environment, Forests & Climate Change) CPCB, Delhi-110032, October, 2014
[33] Central pollution control board ministry of environment & forests, govt. Of India east Arjun Nagar, Delhi June 2014
[34] Online resource Available athttps://www.arduino.cc/accessed Tuesday 14/09/2017 8:10
[35] Online resource Available athttp://forefront.io/a/beginners-guide-to-arduino/accessed Tuesday 24/09/2017 5:10
[36] Online resource Available athttp://howtomechatronics.com/tutorials/arduino/dht11-dht22-sensors-temperature-and-humidity-tutorial-using-arduino/accessed Tuesday 04/10/2017 8:10
[37] Online resource Available athttp://microcontrollerslab.com/interfacing-mq-135-gas-sensor-arduino/accessed Thursday 8/11/2017 8:10
[38] Online resource Available athttps://www.instructables.com/id/Arduino-CO-Monitor-Using-MQ-7-Sensor/accessed Wednesday 4/09/2017 7:20
[39] https://programmingelectronics.com/using-the-print-function-with-arduino-part-1/ accessed Friday 14/10/2017 3:30
[40] Online resource Available athttps://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-qualityaccessed Monday 14/08/20176:30

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