

IoT Enabled Low-Cost Indoor Air Quality Monitoring System

*Thesis submitted in partial fulfillment of the requirements for the award
of degree of*

Master of Engineering
in
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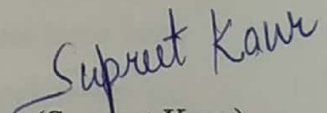
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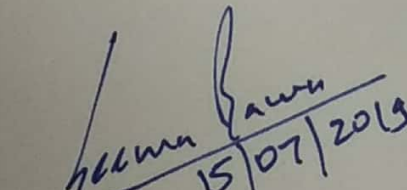
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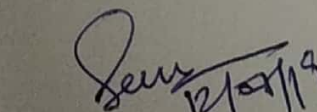
I hereby certify that the work which is being presented in the thesis entitled, "*IoT Enabled Low-Cost Indoor Air Quality Monitoring System*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar Institute of Engineering and Technology, Patiala, is an authentic record of my own work carried out under the supervision of *Dr. Seema Bawa, Dr. Seemu Sharma* and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.


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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.


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Abstract

Internet of Things (IoT) is considered as revolution in technology sector. It has ability to automate mundane tasks and simplify lives of people. IBM define IoT as “It is the concept of connecting any device to the internet and other connected devices”[1]. IoT can be seen in all areas of life such as homes, industries, healthcare, transport, environment monitoring etc. The present work has been done on one such application of IoT, i.e. Indoor Air Pollution Monitoring. Today, air is the most polluted resource around the globe. It is the essential element required for living and needs immediate attention of people from all professions. Even, indoor air is not safe. Infact, it is more polluted than outdoor air.

In this research, the prototype of indoor air quality monitoring device has been built. The two most dangerous and common indoor air pollutants have been addressed i.e. carbon dioxide (CO₂) and particulate matter (PM). Low-cost semiconductor sensors have been used for calculating abovementioned pollutant concentrations. An android application has been built for users to see their indoor air quality. The result shows poor air quality caused by different household and workplace activities and provides plant based solutions for controlling indoor air pollution.

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Chapter 1

Introduction

Internet of Things or IoT can be defined as “An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment”. In simpler words, we can say that IoT is connected objects through internet. IoT makes everyday objects smarter with the help of communication technologies, embedded systems and Artificial Intelligence (AI). The main goal of IoT is to connect everything with internet in order to simplify lives. It includes remote monitoring, real time monitoring and real-time analytics. The IBM report says 60% of data gathered by devices becomes obsolete within seconds. Thus, real-time analytics is of utmost important. Cisco predicts, “The number of connected devices by 2020 will exceed 50 billion”[2]. IoT is becoming ubiquitous technology. Fig.1 shows the growing number of devices connected with internet from the span of 2003 to 2020.

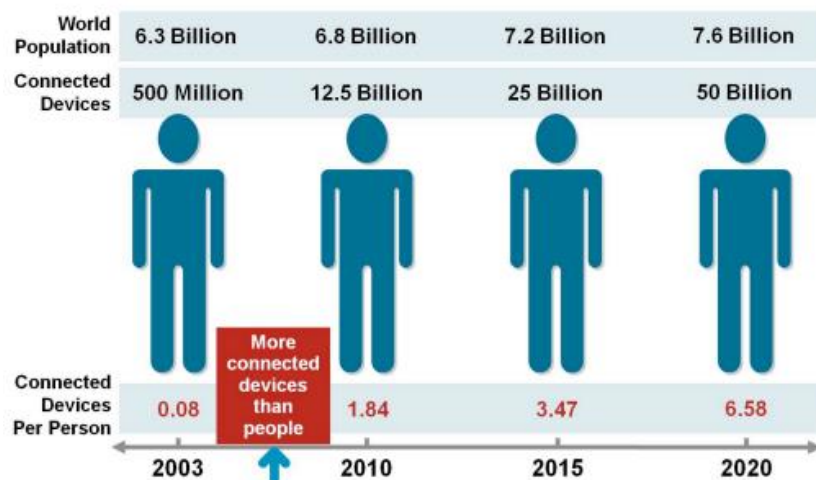


Figure 1.1 Growth of IoT [3]

Figure 1.2. shows the core elements of IoT. It includes identification, sensing, communication, computation, services and semantics.



Figure 1,1 Core Elements of IoT [4]

1.1 IoT Technology

Sensors

Sensors are input devices which detects and responds to electrical and optical signal. Sensors converts the physical parameters into a signal which can be measured electrically. Physical parameters include sound, light, temperature etc. They can be classified into active and passive sensors. LDR or Light Dependent Resistor, which detects absence or presence of light is one of the simplest example of sensor [5] [6].

Wireless Fidelity (Wi- Fi)

It is a networking technology through which computers and other devices communicate with each other over wireless signal. It uses radio waves to provide connectivity and works in the frequency of 2.4 GHz or 5Ghz depending upon the amount of data. Wi-Fi or 802.11 supports all types IEEE 802.11 technologies- 802.11a, 802.11b, 802.11g and 802.11n, Today, Wi-Fi is ubiquitous, providing connectivity to millions of homes, offices, institutes and public places such as airports, hotels, cafes, restaurants etc. [7] [8].

Bluetooth

It is an expensive, short range wireless technology. The range of Bluetooth is between 10 to 100 meters. It works on IEEE 802.15.1 standard. When set of Bluetooth devices (2-8) shares a common channel for communication, it is called piconet. The data shared through Bluetooth may include texts, videos, audios and pictures [8].

Radio Frequency Identification

Radio Frequency Identification or RFID is a technology which uses radio waves for transmitting the identity of an object or a person, wirelessly in the form of serial number. There are three categories of RFID: Active RFID, Passive RFID, Semi Passive RFID.

Actuators

An actuator is a device which causes moment in physical systems or converts energy into motion. The input to actuators can be electric current, hydraulic fluid etc. Actuators remains active all the time and consists of electroactive materials. These materials generate different types of outputs in response to current or electric field such as sound, temperature, light and moment The most commonly used actuators are electric actuators [8] [9].

Wireless Sensors Networks (WSN)

Wireless Sensor Networks can be defined as “network of devices that can communicate the information gathered from a monitored field through wireless links”[10]. WSN plays an important role in IoT. They are widely used in IoT applications such as healthcare, military, precision agriculture monitoring forest fire, environment monitoring etc. [8].

Artificial Intelligence

Artificial Intelligence can be defined as “electronic environments which are sensitive and responsive to the presence of people” [8]. AI is characterized by following terms- Embedded, Context Aware, Adaptive, Anticipatory, Personalized [8]. It is used to solves complex problems which are generally associated with high intellectual of humans.

1.2 Architecture of IoT

IoT has no standard architecture. However, IoT contains the same components- sensors, network devices, actuators and user interface. The most basic architecture is shown below. It is 3-layered architecture.

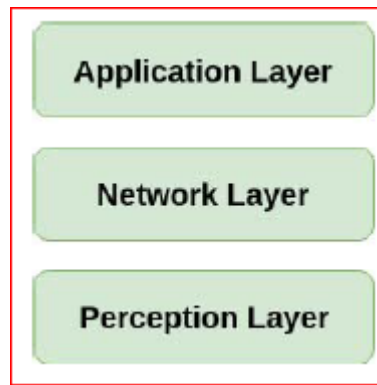


Figure 1.2 Architecture of IoT [4]

Perception Layer: This layer contains objects and sensors and is also termed as device layer. It is responsible for collecting data and information from sensors. It encompasses of technologies like RFID tags, sensor networks, GPS and terminals. In IoT, wireless sensor networks are considered more accurate for monitoring and controlling physical environments

Network Layer: This layer is used for transmission and processing of data received from perception layer. It encompasses technologies like Wi-Fi, ZigBee, Bluetooth etc. This layer acts as network and information center.

Application Layer: This layer focuses on social division of IoT and industry requirements. Various virtual market comes under application layer.

1.3 Applications of IoT

IoT, being pervasive, has applications in diverse fields such as healthcare, industries, environment, smart cities, connected roadways etc. Table 1 categorizes IoT applications, both existing and foreseen.

Table 1.1 Applications of IoT [11]

Areas	Applications
Society	Home Appliance Performance
	Health Care Monitoring
	Transport and Road Safety
	Border Security and Military Applications
Industrial	Supply Chain
	Agriculture and Rural Development
	Safety in Construction
	Food Security
Environment	Smart Environment IoT
	Climate Monitoring
	Water Monitoring and Control
	Natural Disasters

In this research work, one of the applications of IoT is addressed - Environment Monitoring. Environment Monitoring can be defined as “sampling and analyzing specific environmental media (such as soil, water, plants) for evidence of contaminants levels over time”[12].

1.3 Environmental Pollution

Environmental Pollution is defined as “the contamination of physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected [13]”. It has become one of the serious global challenge. It effects all kinds of living beings. Industrialization is one of the major causes of environmental pollution. There are various forms of pollution. Some of the common types are discussed below.

Air Pollution

Air pollution can be described as “the introduction of harmful substances in the air that results in detrimental impacts to the environmental and humanity”[14]. It is concentration of harmful particles in both outdoors and indoors. Smoke, CO₂, methane,

soot, pollen are some examples of common pollutants. Poor air quality is killing people worldwide [15].

Water Pollution

It is “the act of contaminating water bodies namely rivers, oceans, lakes, streams and groundwater”[14]. Water pollution can be categorized based on pollutants- chemical, biological and radiological pollutants. The most common sources of water pollution are disposal of chemicals coming from following sectors- industrial, medical, agriculture, household waste and oil spills [16].

Radioactive Pollution

Radioactive pollution is defined as “increase in natural radiation levels caused by human activities”[14]. It occurs during nuclear explosions, production and testing of nuclear weapons, by mining radioactive ores, disposal of radioactive waste and by accidents at nuclear power plants. It is of three types- Continuous, Occasional and Accidental. Above radioactive pollution sources are dangerous. But there are other low radiation emitting sources such as cell phones, ovens, computer/laptops, cell towers etc. which also effects our health and can cause reproductive, neurologic and cardiac dysfunction [19] [20].

Noise Pollution

It can be defined as “regular exposure to elevated sound levels that may lead to adverse effects in humans or other living organisms”. WHO says exposure to constant noise above 85 decibels for more than 8 hours a day is hazardous for humans. Despite, it is omnipresent it remains unnoticed. It can cause hypertension, sleep disturbances, hearing loss, impairment in child development, dementia and physiological dysfunctions in humans [19].

Thermal Pollution

Thermal pollution is “the harmful release of heated liquid into a body of water or heat released into the air as a waste product of a business” [14]. One of the most common cause of thermal pollution is the use of water as coolant in industries. Thermal pollution can cause lot of issues for aquatic life [20].

Land Pollution

Land pollution can be defined as “the destruction or decline in quality of the earth’s land surface in terms of its use, landscape and ability to support life forms” [14]. It is a serious problem for humans, animals and the earth. It is caused by soil erosion, industrialization, mining, agriculture chemicals, landfills and human sewage [21]

1.4 Health Impacts of Air Pollution

Air pollution has adverse effects on all living forms, especially humans. The effect on health is directly dependent on concentration of pollution, and exposure to pollution [22]. Moreover, people with lung infections or other ailments are more prone to this issue.

Major health hazards caused by air pollution are discussed below:

1. The most common effects of air pollution include irritation to eyes, nose and throat which is often negligible [23].
2. Poor Air can cause lung infections such as bronchial asthma or chronic obstructive pulmonary disease [23].
3. Prolonged exposure to air pollution may cause death. WHO says “4.2 million death occur due to ambient air pollution and 3.8 million deaths to household pollution per year” [23].
4. Worldwide 17% deaths are caused by acute low respiratory problems [23] .
5. 29% people die worldwide due to lung cancer caused by air pollution [23].
6. 24% people worldwide die from stroke caused by air pollution [23].
7. Air pollution effects pregnant women and their unborn child [23]
8. Due to air pollution, children develops diabetes and neurological disorders [23]
9. It effects cognition skills. Arithmetic and Communication skills are affected most [24].
10. According to a study, air pollution may aggravate semen quality in men [25].

1.5 Indoor Air Pollution

Indoor air pollution can be defined as deterioration of indoor air quality with the presence of pollutants. Indoor air can be two-four times bad than outdoor [26]. Most of the times it is not visible to naked eyes but its hazardous to human health.

With the changing lifestyle, people tend to stay indoors more than outdoors. Maximum time is spent in educational institutes, offices and homes [27]. The common indoor air pollutants are carbon dioxide (CO₂), particulate matter (PM_{2.5}/PM₁₀), volatile organic compounds (VOC’s), formaldehyde, carbon monoxide (CO), Sulphur dioxide (SO₂).

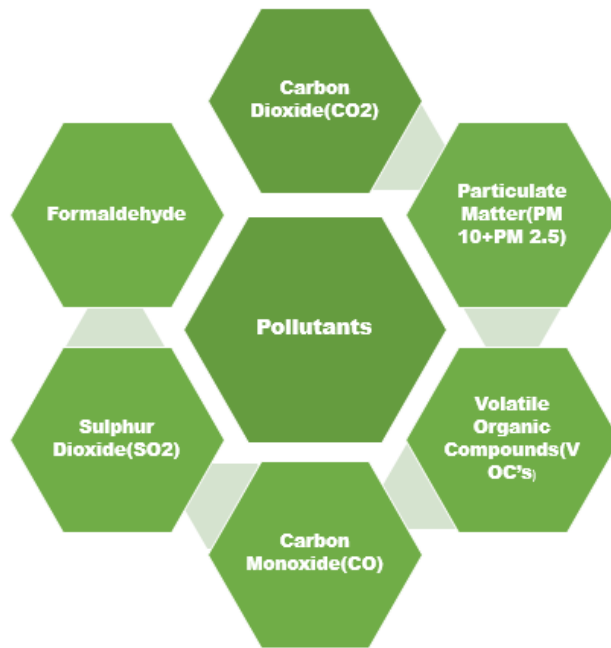


Figure 1.3 Indoor Air Pollutants [28]

Along with monitoring of indoor air quality, classification of pollutants is also essential. It is important for people to learn about various sources of household pollution. It will help in keeping environment safe and healthy. Figure 1.3 depicts sources of indoor pollution in homes. Classification of indoor air pollutant is present in Table 1.2.

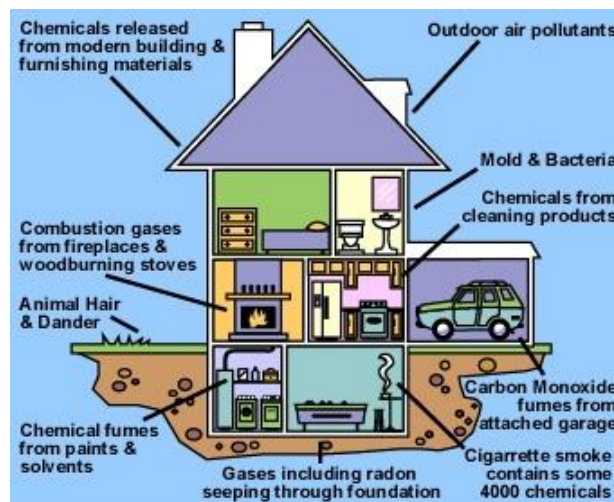


Figure 1.4 Sources of Household Pollution

Table 2.1 Classification of Indoor Air Pollutants

Classification of indoor air pollutants	Products causing air pollution	Home/Workplace	Pollutants present in air pollution
Human Activity	Cigarettes, Cooking	Home and Workplace	Carbon Monoxide, formaldehyde, ammonia, hydrogen cyanide, arsenic, vinyl chloride; Carbon Monoxide, nitrogen dioxide, formaldehyde, carbon dioxide, particulate matter
Fragrance Presence	Incense Sticks, Room Fresheners, Perfumes	Home and Workplace	VOC's, sulphur dioxide, formaldehyde, carbon monoxide, particulate matter, oxides of nitrogen; VOC's; VOC's, carbon dioxide
Chemicals Presence	Floor Cleaners, Glass Cleaners, Insect Repellent	Home and Workplace	VOC's

1.6 Organization of Thesis

The remaining thesis is structured as: Chapter 2 consists literature survey, discusses previous work done in the area of indoor pollution, Chapter 3 contains design and implementation details in depth. This chapter also discusses hardware and software components used for building the proposed IAQMS. Chapter 4 consists of test cases, followed by results. Lastly, in chapter 5 the work done is concluded and future scope is mentioned.

Chapter 2

Literature Survey

The advancements in technology, have made people to stay indoors more than the outdoors. The Environmental Protection Agency (EPA) says, indoor air quality can be two to five times worse than the air outdoor [29]. It is perilous to human health, thus monitoring of indoor air quality becomes essential.

In this section, various IoT based Indoor Air Quality (IAQ) monitoring systems are presented. The technologies, features and pollutants addressed in the existing systems are discussed.

CO₂ is most common and prevalent pollutant which can be found both indoors and outdoors [30]. The negative impact of CO₂ in educational institutions and workplaces has been presented in [31] [32] [33]. According to the study in [30], CO₂ impairs cognition. Even in moderate amount, it can damage human decision making skills. In another study [32], CO₂ has been monitored in two different classrooms, for analyzing the time for which indoor environment remains healthy, depending upon number of occupants. In this work, CO₂ has been used as tracer gas to detect inadequate air quality. Similarly, in another research [34], cognitive wireless sensors have been used for measuring CO₂ in different rooms of university. This is done to reduce interference with existing wireless technologies. The resulting IAQ monitoring system provides accurate results with minimal outliers.

Volatile Organic Compounds (VOC's) is another pollutant which can be easily found indoors. It can be found in household products such as paints, cleaning agents, varnishes, insect repellents, air fresheners, lighter fuel, door mats etc. [14] [35] . A low cost and easy to use IAQ monitoring system has been built in [36] for measuring TVOC's. Research says VOC's are toxic, even if present in small amount [36].

Apart from above pollutants, there are various pollutants which are deteriorating indoor air quality. IAQ monitoring systems have been designed for measuring pollutants such as carbon dioxide (CO₂), carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), particulate matter (PM_{10/2.5}), ozone (O₃) and other environmental parameters- temperature, humidity, luminosity [33] [37] [31] [38] [39] [40]. The IAQ

monitoring application presented in [40] has been developed using CoAP protocol. CoAP stands for Constrained Application Protocol. It is web- based IoT protocol [41]. An IAQ monitoring application [38] which can be deployed in buildings has been developed, using wireless sensors networks. In [39], Bolt- an IoT platform has been used for building IAQ monitoring application. Ozone (O₃) at ground level is considered harmful. An IoT enabled IAQ monitoring application has been built for measuring ozone concentrations near photocopy machines in [42]. The concept of health classrooms, for which clean air is essential has been presented in [31]. IAQ monitoring system for measuring particulate matter (PM_{2.5}) concentrations, in context of smart buildings has been presented in [43].

The researchers have also worked on autonomous and portable indoor air quality monitoring systems. The technology used for making IAQ systems portable, is the use of Unmanned Ariel Vehicle (UAV) and Near Field Communication (NFC) in smart phones [44] [45]. IAQ monitoring systems for accessing the health of employees, for better productivity has been presented in [46].

IAQ monitoring systems are also becoming an essential part of “Ambient Assistant Living”. One such low cost IAQ monitoring system has been developed in [47]. The data related to health of occupants is continuously collected and is accessed by doctors. Instant medical aid can be given if needed. The proposed system is very useful for elder people, living independent of their families.

Over the years, IAQ monitoring systems has been developed, which also classifies sources of pollutants, along with pollutant concentrations in indoor environments [48] [31] [33]. It has become important for people to learn about sources of indoor air pollution. The products causing pollution in homes or educational institutions in presented in [35] [49].

2.1 CO₂ based IAQ monitoring applications

There are various IAQ Monitoring applications which are focused on CO₂. The health hazards caused by CO₂ and its wide presence in indoor environment leads to the necessity of developing such applications.

IAQ monitoring application for measuring CO₂ has been designed and developed in [50]. The effect of CO₂ on human decision making skills has been presented. Results shows that CO₂ effects cognition or decision making skills, even if it is present small or moderate amount. In this system CO₂ sensor is integrated with wireless local area

network through which data is collected and stored on server. The networking protocol used in the system is UDP. In this experiment, number of sensors are used for measuring CO₂ concentrations in a room. The sensors communicate to remote server through wireless access point. Raspberry pi is acting as wireless access point in the system. Remote server consists of web server for representing resultant concentration of CO₂ and a local database which stores data coming from each sensor through access point. An application on server processes data gathered by sensors, analysis it and draw conclusions. Average is calculated of all the values of CO₂ captured by different sensors and further it is compared with threshold and accordingly user is informed. Apart from this, the program on server also draws graphs, analysis report and records number of times notification system was activated.

In another study [34], CO₂ has been measured in different rooms of “University of Toronto”. There is one control room, where all monitored data is collected and resultant values are calculated. CO₂ sensors are integrated with radio modules and thus wireless sensor nodes are formed. In the next step, data from sensor goes to the radio module which consists of two antennas and a microcontroller. Here packets are formed and transmitted to the control room. Relay, is responsible for transmitting packets. CO₂ has been measured using iAQ 2000 sensor. The system uses opportunistic routing algorithm and cognitive networking technique to minimize interference with existing systems. Calibration is done and data smoothing is also performed. Results shows that as number of people increases, CO₂ concentration also increases. Graphical User Interface has been developed for displaying CO₂ concentrations.

An IAQ Monitoring Application for measuring CO₂ and other pollutants-NO₂, CO, particulate matter (PM₁₀/ PM_{2.5}/ PM₁) along with two meteorological parameters-temperature and humidity has been presented in [33]. Low cost sensors with high precision have been used for designing the system. Calibration of sensors has been done using machine learning algorithms, for obtaining accurate results. Arduino is used as microcontroller and for communication Wi-Fi and Bluetooth are used. In this research, relationship between number of students and pollutant concentration is analyzed, so as to formulate ventilation effect. Also, the relationship between pollutant concentration and time spent by occupants in classroom has been evaluated. Results shows that after two hours CO₂ and particulate matter levels crosses permissible limits.

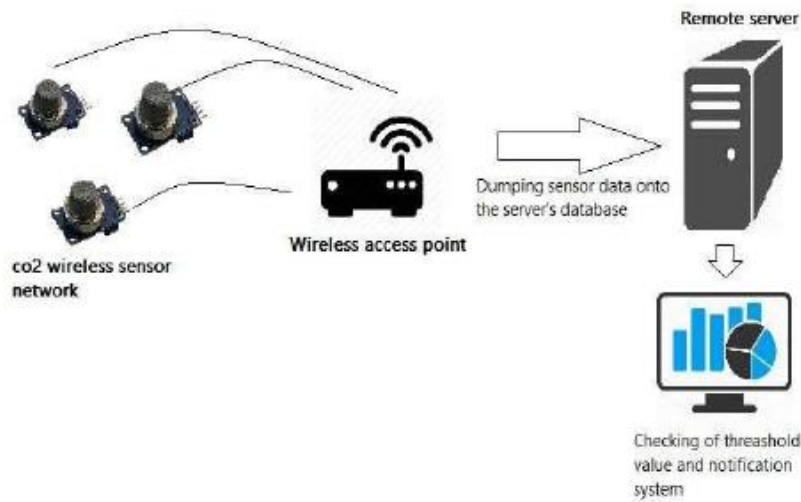


Figure 2.1 Architecture of IAQ monitoring system [30]

Table 2.1 shows comparison between various IAQ monitoring systems have been made.

Table 2.1 Comparative Analysis of IoT Enabled Air IAQ Monitoring Systems

Year	Pollutants Addressed	Type of Sensors Used	Benefits
2013	TVOC's	Semiconductor Sensor	A serious health hazard indoor air pollutant is addressed with less complexity. Proposed IAQ monitoring system has low cost [36]
2013	Carbon Monoxide (CO)	Not Specified	Uses near field communication thus making the proposed IAQ monitoring portable [44]
2015	Particulate Matter (PM 10), Carbon Dioxide (CO ₂), Nitrogen Dioxide (NO ₂), Carbon Monoxide (CO), Ozone(O ₃), Oxygen, Volatile Organic Compounds(VOC's), Temperature and Humidity	Semiconductor Sensors, Optical Sensors, Electrochemical and Thermal Sensors	Classification of pollutants is presented along with indoor air quality monitoring [37]
2016	Carbon Dioxide (CO ₂), Carbon Monoxide (CO), and physical parameters-moistness, temperature , glow	Infrared Sensors(T6615), Semiconductor Sensor(MQ7), SHT10 and LDR	IAQ monitoring system is proposed with in Ambient Assistant Living [47]
2016	Carbon Dioxide (CO ₂)	Semiconductor sensor (iAQ-2000)	Proposed IAQ monitoring application uses cognitive networking technique and

			opportunistic routing algorithm for minimum interference with existing network, thus making it more efficient [34]
2017	Nitrogen Dioxide(NO ₂), Carbon Monoxide(CO) and Sulphur Dioxide (SO ₂), Ozone (O ₃) and Particulate Matter (PM 2.5/PM 10)	Laser Dust Sensor, Electrochemistry Sensor	A moving and portable IAQ monitoring system through un-manned aerial vehicle (UAV) [45]
2017	Carbon Dioxide (CO ₂), Nitrogen Dioxide(NO ₂), Carbon Monoxide(CO) and Sulphur Dioxide (SO ₂)	Semiconductor Sensor	Low-cost, small in size and efficient IAQM system in all aspects [51]
2018	Carbon Dioxide (CO ₂), Nitrogen Dioxide(NO ₂), Carbon Monoxide(CO), Particulate Matter (PM 2.5+PM 10+PM 1) and meteorological parameters-temperature, relative humidity	Low-Cost Sensors	Low-Cost IAQ monitoring system, A ventilation effect is formulated by considering number of occupants and pollutant concentration [33]
2019	Carbon Monoxide (CO), Particulate Matter, Temperature, Humidity , VOC's	Dust Sensor (GP2Y1010AU0F), Semiconductor Sensors(MQ7, MQ135) and DHT22	Low-cost, Real-time IAQ monitoring system, Modelling of air quality status has been done using Machine Learning Algorithms [28]

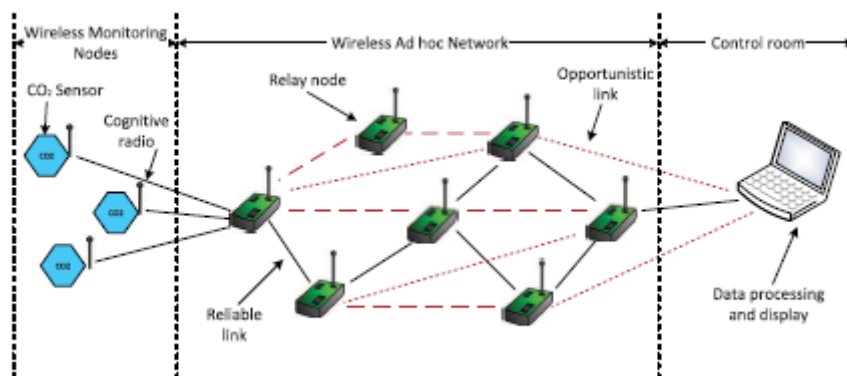


Figure 2.2 Architecture of IAQ monitoring system [34]

2.2 Portable IAQ Monitoring Applications

The indoor air pollution is rising with change in our lifestyle and urbanization. Thus, to combat increasing indoor air pollution, portable IAQ monitoring applications are required. Portable IAQ monitoring provides more accurate results.

In one study [44], near field communication (NFC), a feature of smartphone has been used for making IAQ monitoring system portable. In this system, the pollutant addressed is CO. Sensor data is collected and evaluated based on zones. For conducting this research, Samsung Galaxy S3 has been used. An android application runs on this smartphone which captures CO measurements, from sensors through Bluetooth and data is transferred to remote server for storage and processing. For identifying phone location tags are used based on sensor proximity. And accordingly data is clustered as per tags.

In another study [27], Unmanned Aerial Vehicle (UAV) has been used for making the portable. Pollutants which has been addressed in this study are PM_{2.5} and CO₂. The author has mentioned the harmful effects of both PM_{2.5} and CO₂ and thus developed an autonomous and portable IAQ monitoring system. The system also provides the status of air quality around the building. Fuzzy method is used for controlling actuators of air cleaner and ventilators. Whenever, pollutant concentration rises above permissible levels as directed by WHO, ventilators are opened or air cleaners starts working.



Figure 2.3 Architecture of IAQ monitoring system [27]

2.3 IAQ monitoring systems with classification of pollutants

In IAQ monitoring systems, identification and categorization of air pollution sources makes the monitoring system more advanced. This enables better solutions for reducing

indoor air pollution. In recent years, study on classifying pollutants in IAQ monitoring systems has been done.

The IAQ monitoring system which has been presented in [37], classifies pollutant sources into five different environments- ambient air, fragrance presence, chemical presence, human activity and lastly foods and beverages. Indoor air pollutants addressed in this study are Nitrogen Dioxide (NO_2), Ozone (O_3), Carbon Dioxide (CO_2), Volatile Organic Compounds (VOC's), Carbon Monoxide (CO), Particulate Matter (PM_{10}) along with humidity and temperature. In the system built, the classification of sources of indoor air pollutants has been done using Principal Component Analysis (PCA) and Artificial Neural Network. The results show that classification rate is 99.1%.

Home-based smart IAQ monitoring system entitled 'AirSense' in [48], identifies pollution sources, detects pollution events, forecast pollution levels for avoiding serious threats and also provides suggestions. Pollutants addressed in this study are $\text{PM}_{2.5}$ and VOC's and two environment parameters- humidity and ambient temperature. The results show that in controlled experiment, this system can accurately identify three pollution events- cooking, spraying pesticides, smoking and combination of these events. This system also provides a weekly report on indoor air quality, which helps users to learn about their activities causing indoor air pollution.

IAQ monitoring system in [35], monitors and classifies the sources of Volatile Organic Compounds (VOC's) in controlled experiment. Principal Component Analysis (PCA) has been used for identifying and classifying pollutant sources. Household products such as, Air Freshener, Paint, Paint Stripper, Insect Repellent, Ant control and Lighter fuel was used in this study. This system aims to help users by imparting knowledge to them, about household products containing harmful VOC's.

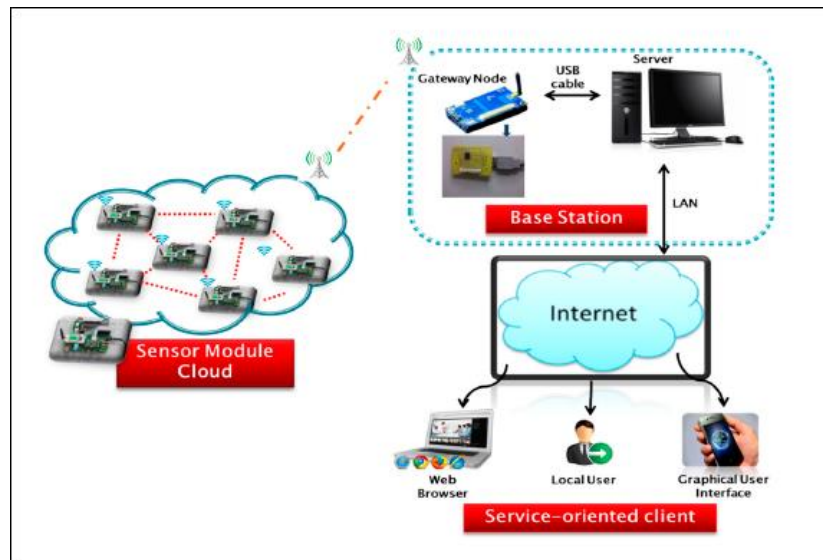


Figure 2.4 Architecture of IAQ monitoring system [37]

2.4 Research Gaps

This section tells about the gaps encountered during literature survey in the area of Indoor Air Quality Monitoring Devices.

1. The work which has been done is CO₂ is measured using wireless sensor networks and notifications are sent on server application. Further, it can be extended or improved by designing mobile application and IoT based ventilation systems [30].
2. The existing system measures ozone concentrations using low cost semiconductor sensor. This work can be enhanced by adding more sensors for measuring other pollutants.
3. In the present work [45] [43], an indoor air quality monitoring system is designed for measuring PM 2.5. Further, it can be extended to other pollutants.
4. The work which needs to be done in existing indoor quality monitoring system is to build IoT based ventilations systems. Further, botanical air purifiers can be integrated [33].
5. Indoor Air Quality Monitoring System in context with Ambient Assistant Living is presented in [47]. Further, work can be done on energy efficiency of the proposed system.

2.5 Problem Formulation

Quality of life (QOL) is an important aspect of living. WHO defines it as “A state of complete physical, mental and social well-being and not merely the absence of disease” [52]. Indoor Air Quality is essential for quality of life. Our surrounding needs to be healthy and pollutant free. Thus, smart indoor quality monitoring systems becomes essential. Literature review in the area of indoor air quality, indoor air pollutants and indoor area quality devices has been done. Further, research gaps are found. Based on research gaps problem is formulated [33] [30]. The resultant solution will include a prototype for measuring three indoor air quality pollutants- CO₂, CO and particulate matter with botanical air purifier.

2.5 Objectives

1. To review work done in the area of Indoor Air Pollution Monitoring using IoT.
2. To propose an IoT based system for monitoring of Indoor Air pollution.
3. To design, implement and test the proposed IoT based Indoor Air pollution monitoring system.

2.6 Research Methodology

1. In first phase of research, IoT is studied- introduction, challenges, technologies and applications.
2. Among different applications of IoT, environment monitoring is chosen. Then in environment monitoring- Air pollution monitoring is selected and further in Air pollution monitoring- Indoor Air Pollution Monitoring is selected.
3. In the second phase, study is done on different indoor air pollutants, sources of indoor air pollutants. Among different pollutants CO₂ and particulate matter is selected as they are commonly present in indoor environment and are hazardous to human health.
4. After this hardware technology for implementing the project is selected. MQ 135 sensor was selected for CO₂ and dust sensor (Sharp GP2Y1014AUA) for particulate matter.
5. In the third phase, indoor air quality monitoring system is implemented and tested.
6. Solutions are also provided for controlling indoor air pollution.

This section describes the design and the detail implementation procedure of the propose Smart Indoor Air Quality Monitoring System. It discusses hardware and software components of proposed system and includes architecture, use case and sequence diagram of the system developed.

3.1 Hardware and Software Used

Table 3.1 Hardware and Software Used

Components	Name of Components
Microcontroller	Arduino Uno
Sensor for measuring CO ₂	MQ 135
Sensor for measuring PM	Dust Sensor ((Sharp GP2Y1014)
Sensor for measuring CO	MQ 7
Cloud Platform	Blynk Cloud
Platform	Blynk
Software	Arduino IDE (Version: 1.8.7)
Gateway	ESP8266

Arduino Uno

Arduino is an open source platform for building IoT projects. It includes both hardware components as well software components in the form of Arduino Boards and Arduino IDE respectively. Arduino Uno Board is one type of Arduino board. It is beginner board for working in IoT or electronics. It is affordable, easy to use and robust board [53]. Technical specifications of Arduino Board are shown in table 3.2.

Table 3.2 Arduino Uno Specifications

Components	Specifications
Microcontroller	ATmega328P
Operating Voltage	5V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM I/O Pins	6
Analog Input Pins	6
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

MQ-135

MQ 135 is low cost semiconductor sensor. It can detect and measure gases such as alcohol, smoke, ammonia (NH₃), benzene, carbon dioxide (CO₂) and nitrogen oxides (NO_x). The SNO₂ is sensitive material for this sensor with low conductivity in clean air and high conductivity in presence of some gas. Conductivity is directly proportional to concentration of gas [54] [55]. Table 4.3 depicts pin configuration of MQ 135 sensor.

Table 3.3 Pin Configuration of MQ 135 sensor

Pin No.	Pin Name	Function of Pins
1	Vcc	Used to power the sensor, Generally the operating voltage is +5V
2	Ground	Used to connect the module to system ground
3	Digital Out	By setting a threshold value using the potentiometer. A digital output from this pin can be obtained.
4	Analog Out	This pin outputs 0-5V analog voltage based on the intensity of the gas

Dust Sensor (Sharp GP2Y1014AUF)

It is an optical sensor used for measuring particulate matter. It gives output in analog form. This sensor is also used in commercial air purifiers. Light scattering is the working principle of this sensor [56]. Pin Configuration of this sensor is shown in table 3.4 and specifications are shown in table 3.5

Table 3.4 Pin Configuration of Dust Sensor (Sharp GP2Y1014AUF)

Pin No.	Pin Name
1	V-LED
2	LED-GND
3	LED
4	S-GND
5	V _o
6	V _{cc}

Table 3.5 Specifications of Dust Sensor (Sharp GP2Y1014AUF)

Light emitting element	LED
Minimum detectable dust size	0.5 μm
Dust density sensing range	Upto $\sim 580 \text{ ug/m}^3$
Sensing time	<1 sec
Output interface	Analog
Sensitivity	0.5 + - 0.15V per 100 ug/m^3 change
Output under zero dust conditions	0 to 1.5V

Arduino IDE (Version: 1.8.7)

It is an open source platform for writing codes. The codes written on Arduino IDE can be easily uploaded to any Arduino Board through USB cable. It can run on Windows, Linux and Mac OS X. The latest version of Arduino IDE is 1.8.9. The codes written on Arduino are C/C++ based [53].

ESP8266

It is a system on chip (SOC) which includes antenna switches, 32-bit Tensilica microcontroller, power amplifier, low noise receive amplifier, standard digital peripheral interface and power management modules. It is highly-integrated and low power module which can provide Wi-Fi services to any microcontroller [58].

Key features of ESP8266 are:

1. High Durability
2. Compactness
3. Power Saving Architecture
4. 32-bit Tensilica Processor

Blynk

It is an affordable IoT platform which makes easier to build android applications, provides private cloud, analytics and device management. It consists of widgets for designing applications and supports both android and iOS. The advantage of blynk platform is it can be connected to any hardware over Wi-Fi or 2G, 3G, LTE, Ethernet etc. [59].

Key features of Blynk:

1. Time-Effective
2. Cost-Effective
3. Customizable
4. Fast and reliable

3.2 Architecture of the Proposed System

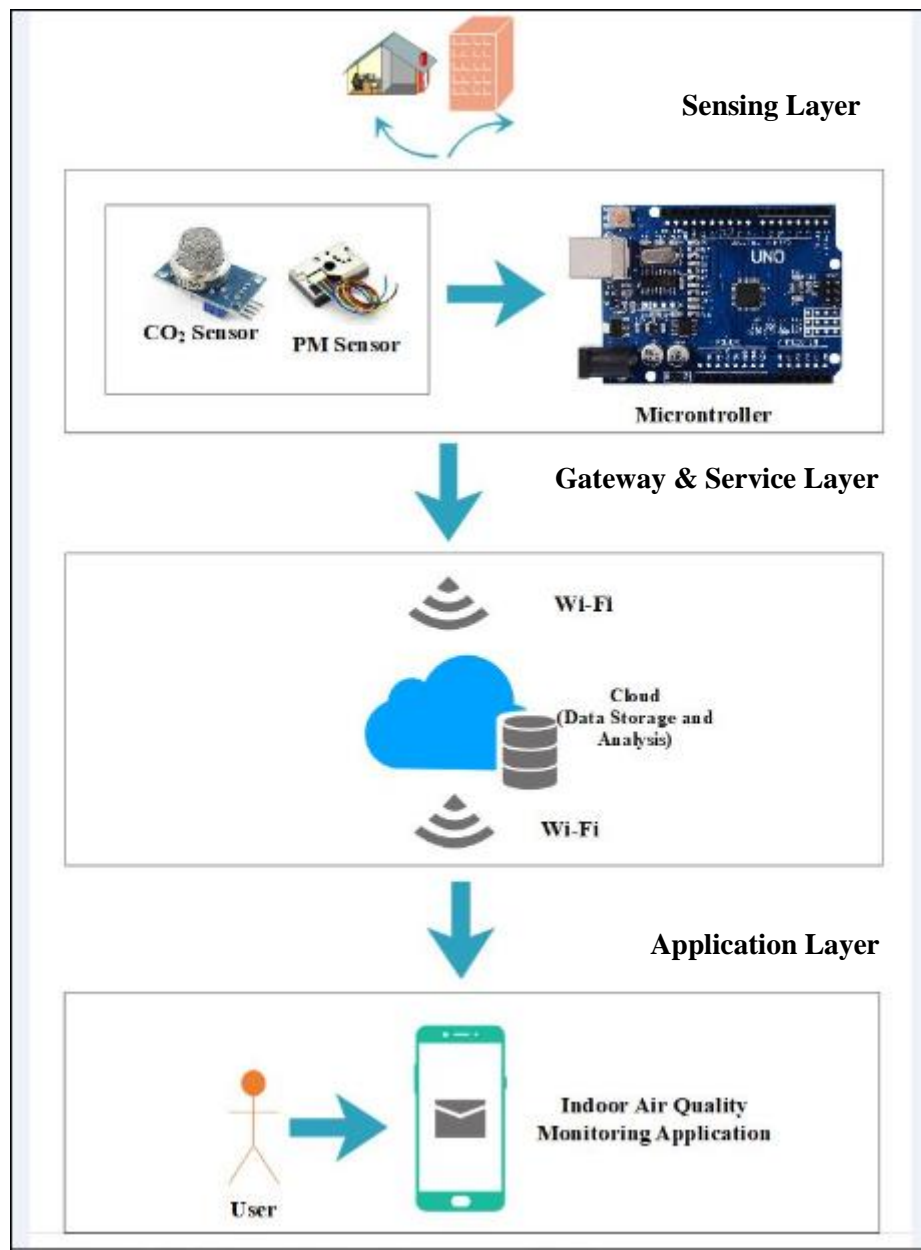


Figure 3.1 Proposed Architecture

The architecture proposed for this system is depicted in Figure 3.1. It consists of three sensors MQ- 135 for measuring CO₂ in PPM, MQ-7 for measuring CO in ppm and Dust Sensor (Sharp GP2Y1014AUA) for measuring PM in ug/m³. The environment for measuring these pollutants includes cigarettes, incense sticks, mosquito coil, cooking and indoor construction. Arduino Uno is used as microcontroller, which can be powered

up by laptop or computer. The data collected by the sensors goes to Arduino Uno for processing and further it is sent to cloud for storage. In the prototype built, Blynk cloud is used. Lastly, android application is designed for notifying the user and for providing him plant based solutions. Blynk- an IoT platform is used for this purpose.

3.3 Implementation Steps:

1. The first step towards implementation includes, extensive study on sensors, microcontrollers, gateway and various IoT platforms. From different sensors, aforementioned low cost sensors are selected. Arduino Uno is used as microcontroller board, due to its efficiency, low cost and easy to use feature.
2. In the second step all the three sensors are connected with Arduino Uno according to their respective datasheets.
3. After connecting sensors with Arduino Uno, ESP8266 which acts as gateway in this application is connected. Figure 3.2 shows the all the connections between the hardware components.

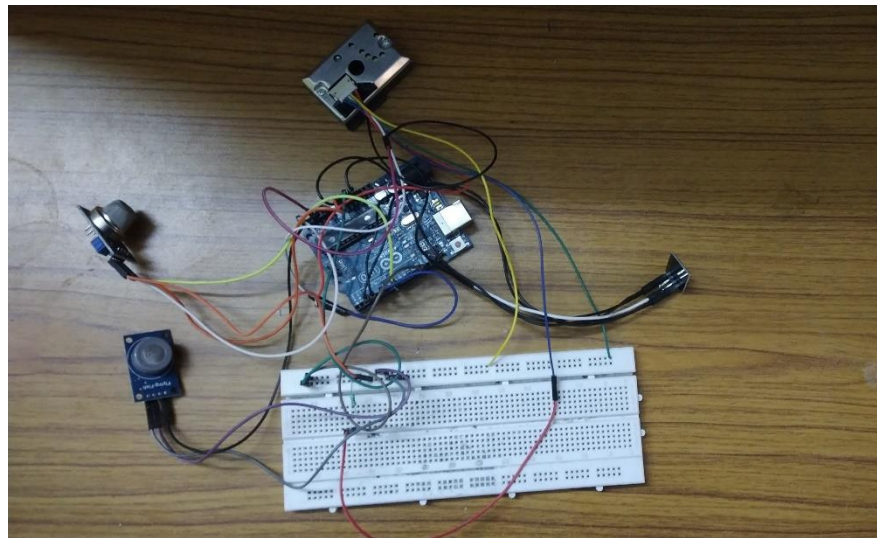


Figure 3.2 Hardware Setup of proposed IAQMS

4. After making connections testing of ESP8266 is done through writing AT command on serial monitor of Arduino IDE. Connection between ESP8266 and Arduino Uno are considered successful, if OK is displayed on screen.
5. In the next step, ESP8266 is connected with available Wi-Fi network as shown in Figure 3.3.

```
AT+CWJAP="Dolls","arrow1012"  
WIFI CONNECTED  
WIFI GOT IP  
17:51:22.131 -> OK
```

Figure 3.3 ESP8266 connected with available Wi-Fi network

6. Both sensors, MQ-35 and MQ-7 are pre-heated for 24 hours before using. MQ 135 is calibrated against outdoor ppm concentration of CO₂ i.e. 400.
7. In this application Blynk is used as an IoT platform as it has low cost and easy to use. Moreover, it provides all the features required for this proposed monitoring system.
8. In the next step code is written on Arduino IDE for measuring CO₂ and CO values in ppm respectively and PM in ug/m³. In the proposed system, CO values are measured at constant 5V.
9. The measured values of above pollutants are shown on serial monitor of Arduino IDE and an android application is designed for this purpose using Blynk.
10. Blynk uses unique authorization token for every device on Blynk platform.
11. Two different widgets Gauge meter and Super Chart are used for data representation on android application. Figure 3.4 shows all the widget on Blynk screen.
12. After designing application, code is written on Arduino IDE for sending data collected from sensors to Arduino IDE and android application respectively.
13. Users are notified before pollutants concentration reaches their harmful level. In case of CO₂ users are warned, when CO₂ levels goes above 800, for PM users are notified when it reaches 100 and for CO is set as threshold value. Notification widget is used for this purpose and code is written on Arduino IDE

3.4 Use case of the proposed system

Figure 3.4 represents use case diagram of the proposed system. It is used to show how users connects with the system.

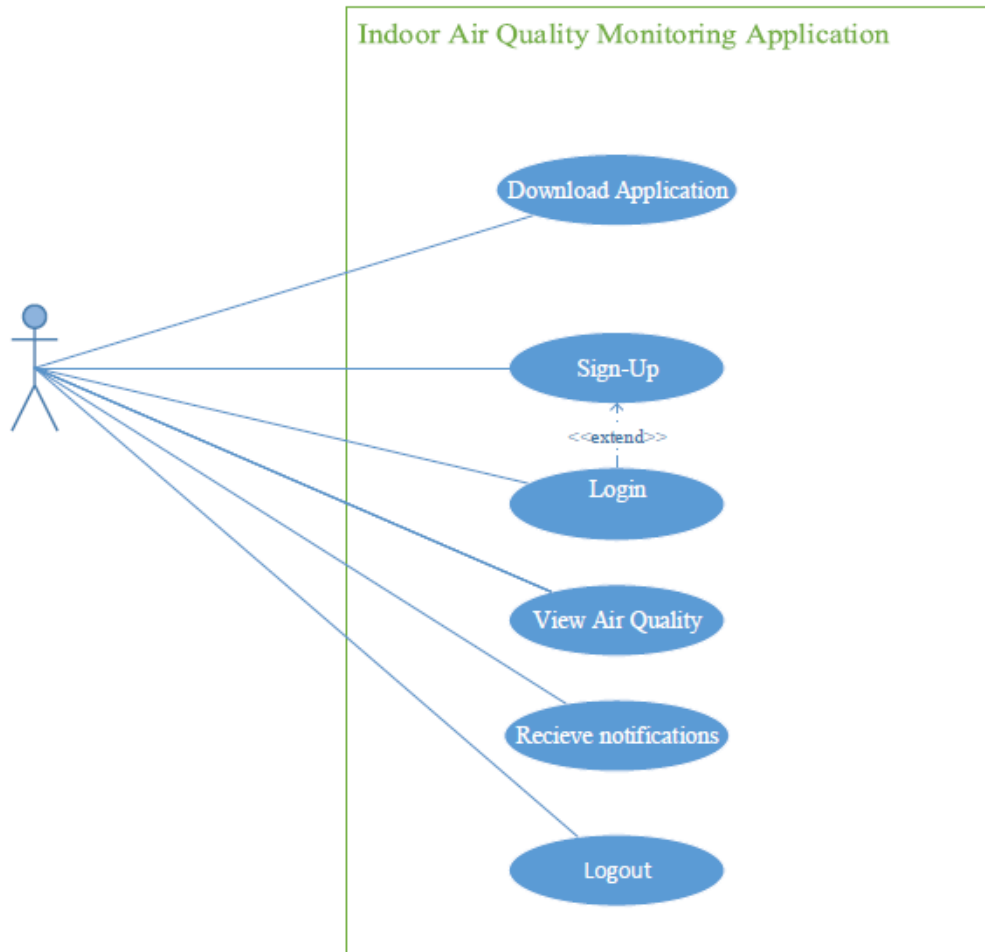


Figure 3.4 Use Case of the Proposed System

3.5 Sequence Diagram

Figure 3.5 represents sequence diagram of the proposed system. It shows the sequence of operations performed in underlying IAQ monitoring system.

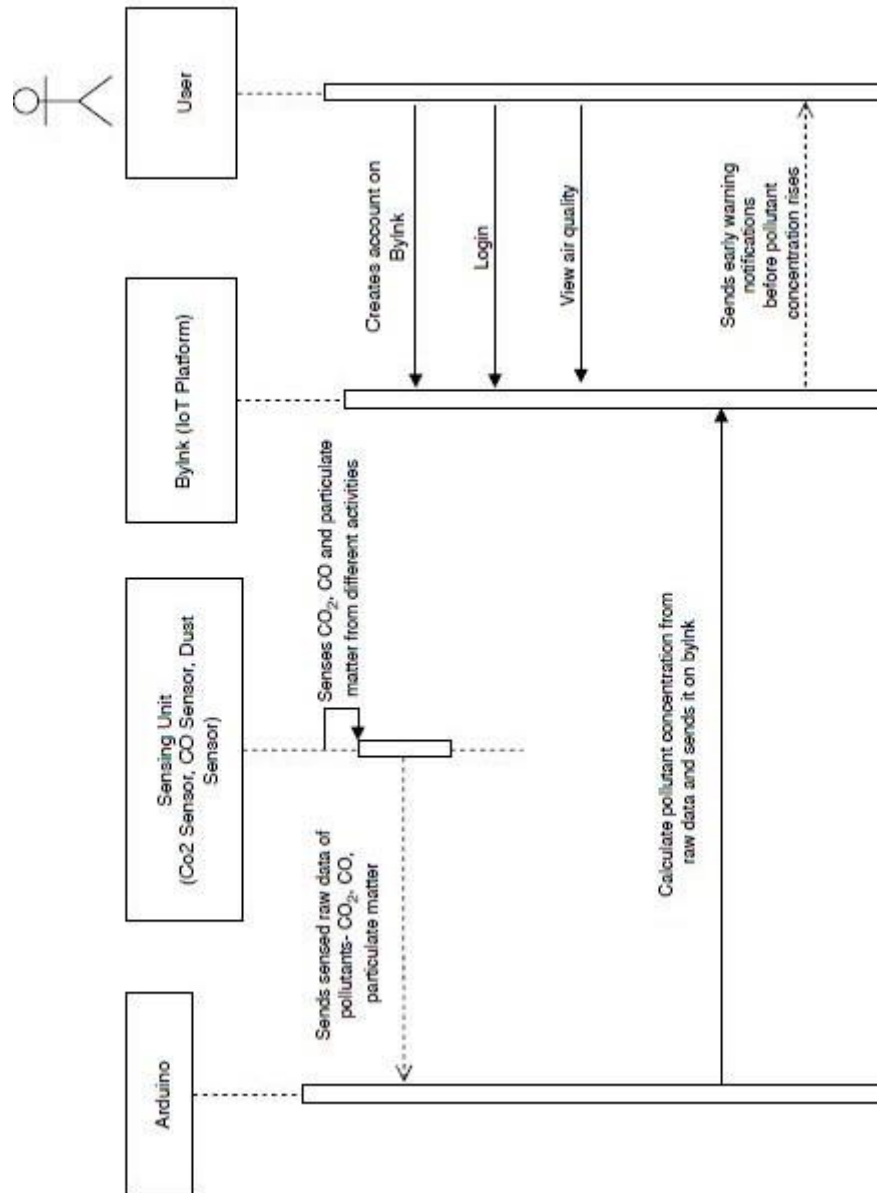


Figure 3.5 Sequence Diagram of Proposed System

Chapter 4

Testing and Results

This chapter describes the testing and results of proposed IAQ monitoring system. Testing includes the activities which are used for evaluating results. CO₂ and particulate matter are measured in the proposed IAQ monitoring system.

4.1 CO₂ Test Cases

Testing Environment: Testing is done in an experimental setup in a closed environment. A medium sized box () is taken for this purpose. The hardware setup of IoT is placed inside the box and results are obtained.

Activities Addressed:

- Cooking
- Smoking (Cigarette Burning)
- Incense Stick Burning
- Mosquito Coil Burning

Table 4.1 CO₂ Test Case 1

Sensor used	MQ-135
Activity	Cooking
Duration of testing	2 hours
Ventilation	Minimum required
Testing Area	Hostel Mess

Table 4.2 CO₂ Test Case 2

Sensor used	MQ-135
Activity	Smoking (Cigarette Burning)
Duration of testing	2 hours
Ventilation	Minimum required
Testing Area	A medium sized box placed in a closed small room

Table 4.3 CO₂ Test Case 3

Sensor used	MQ 135
Activity	Incense sticks Burning
Duration of testing	2 hours
Ventilation	None
Testing Area	A medium sized box placed in a closed small room

Table 4.4 CO₂ Test Case 4

Sensor used	MQ 135
Activity	Mosquito Coil Burning
Duration of testing	2 hours
Ventilation	None
Testing Area	A medium sized box A medium sized box placed in a closed small room

4.2 Particulate Matter Test Cases

Testing Environment: Testing is done in an experimental setup in a closed environment. A medium sized box () is taken for this purpose. The hardware setup of IoT is placed inside the box and results are obtained.

Activities Addressed:

- Smoking (Cigarette Burning)
- Incense Stick Burning
- Construction Work

Table 4.5 Particulate Matter Test Case 1

Sensor used	Dust Sensor ((Sharp GP2Y1014)
Activity	Cigarettes and Incense Sticks Burning
Duration of testing	2 hours
Ventilation	Minimum required
Testing Area	A medium sized box placed in a closed small room

Table 1 Particulate Matter Test Case 2

Sensor used	Dust Sensor (Sharp GP2Y1014)
Activity	Construction
Duration of testing	1 hour
Ventilation	Yes
Testing Area	College construction

4.3 Results and Discussions

This section contains results after running above test cases. Results obtained are further discussed and summarized. Results are shown on user friendly android application.

4.3.2 Observations

Figure 4.1 shows that CO₂ levels rises while cooking. MQ-135 has low proximity, thus resultant values obtained of CO₂ (in ppm) while cooking are closer to actual values. But despite that, we can conclude that cooking increases CO₂. Figure 4.2 shows the effect of cigarette burning in indoor spaces. With improper implementation, cigarettes can release CO₂ at higher level. Here, we can see that how cigarettes can pollute environment at such larger scale. In Figure 4.3, CO₂ levels in the presence incense sticks are shown. Results are taken while burning one incense stick. From the results, it can be concluded that incense sticks can increase CO₂ considerably high. Figure 4.4 shows the results when mosquito coil is burnt. In this case a moderate level of CO₂ is released. Figure 4.5 shows the amount of PM levels while burning of cigarettes and incense sticks together. In this experiment 1 cigarette and 2 incense sticks are taken. PM during construction activity is shown in Figure 4.6.

In this experiment, dust sensor (Sharp GP2Y1014AUAF) is used which detects particular matter but cannot tell the difference between PM_{2.5}, PM₁₀ or dust particles of bigger sizes. Thus, on the basis of experiment results, 150 ug/m³ is considered unhealthy. It can be concluded that cigarette smoking and burning of incense sticks releases high amount of PM.

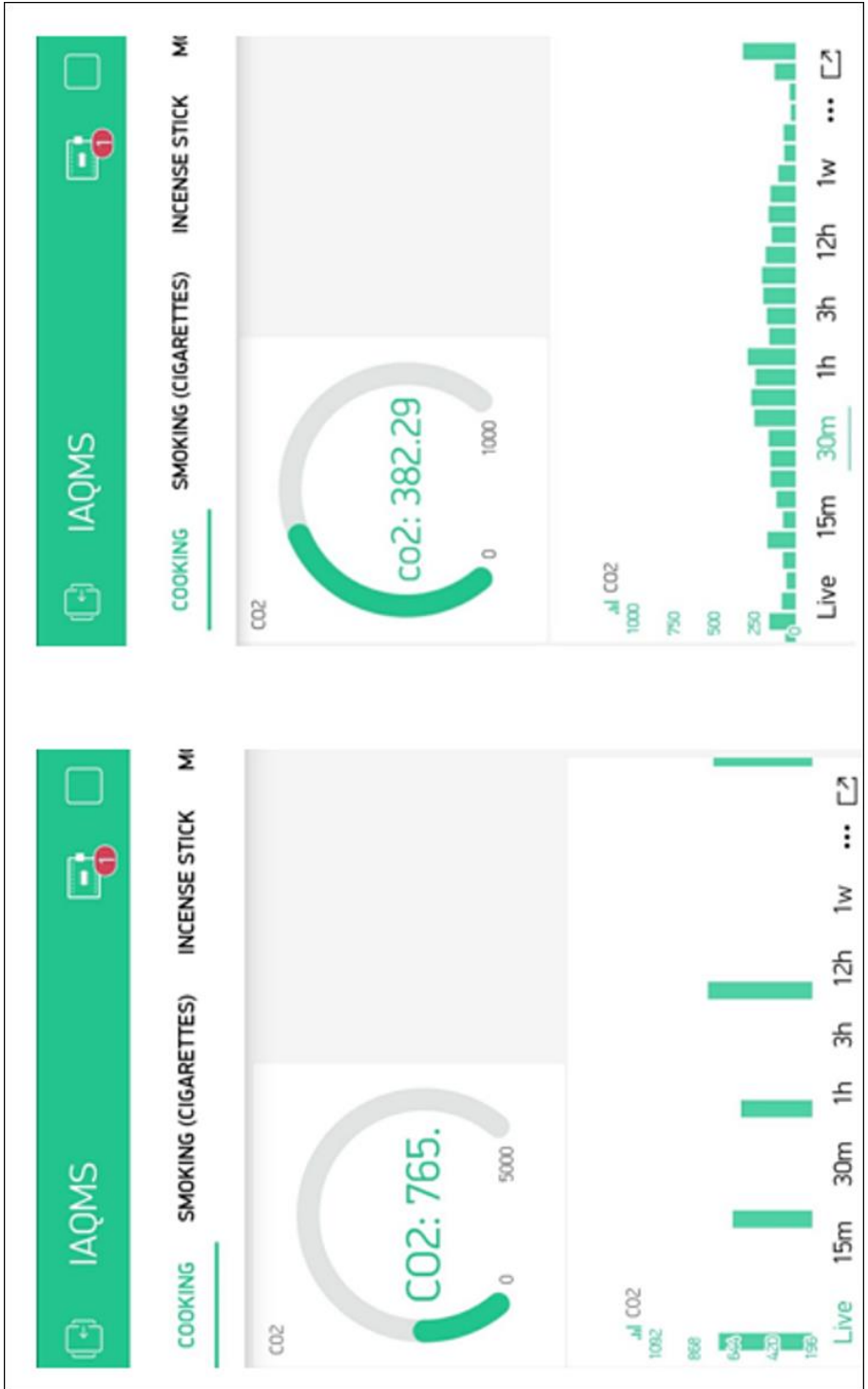


Figure 4.1 CO₂ in PPM during cooking (oil based)

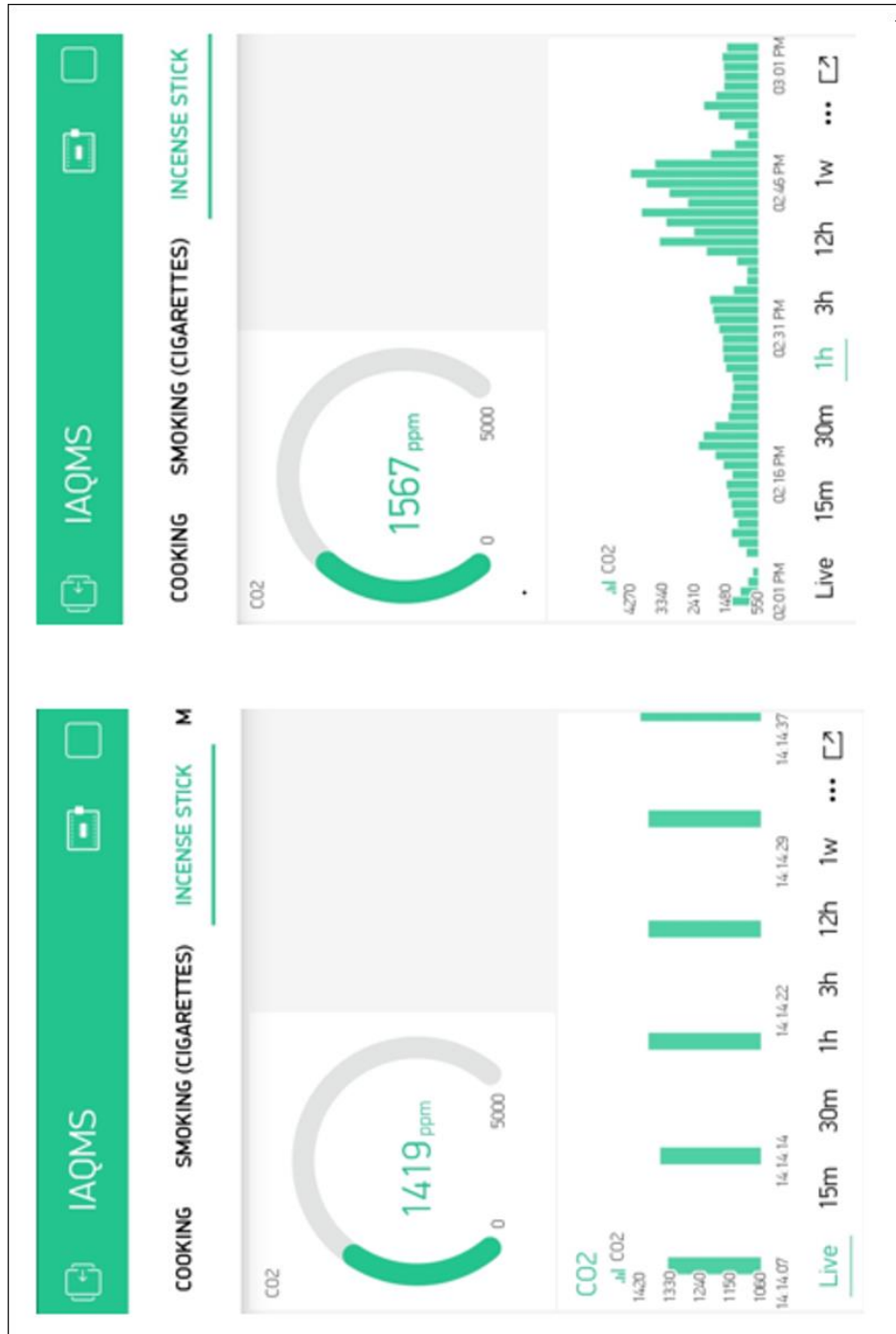


Figure 4.2 CO₂ in PPM while burning of incense sticks

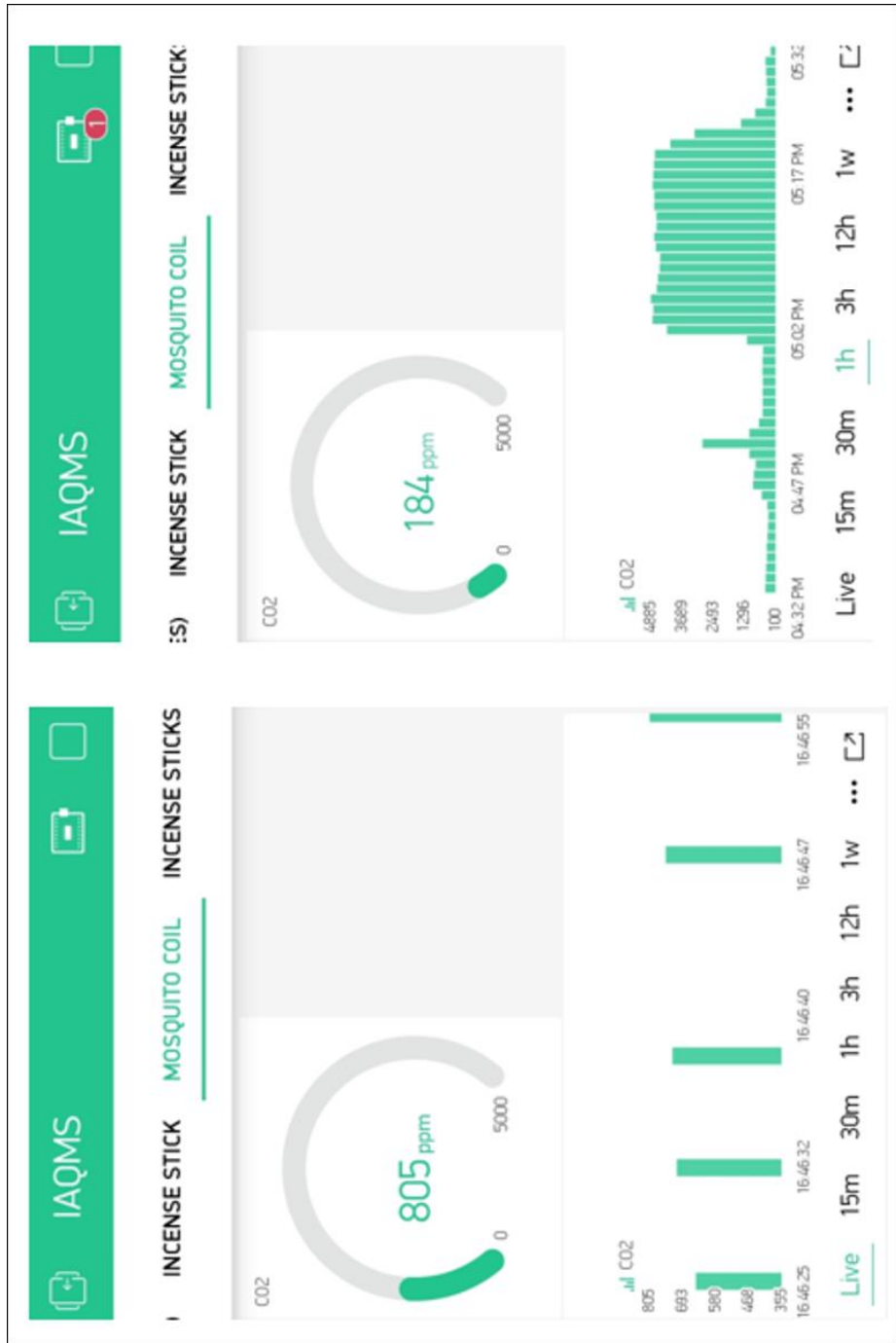


Figure 4.3 CO₂ in PPM while burning of mosquito coil

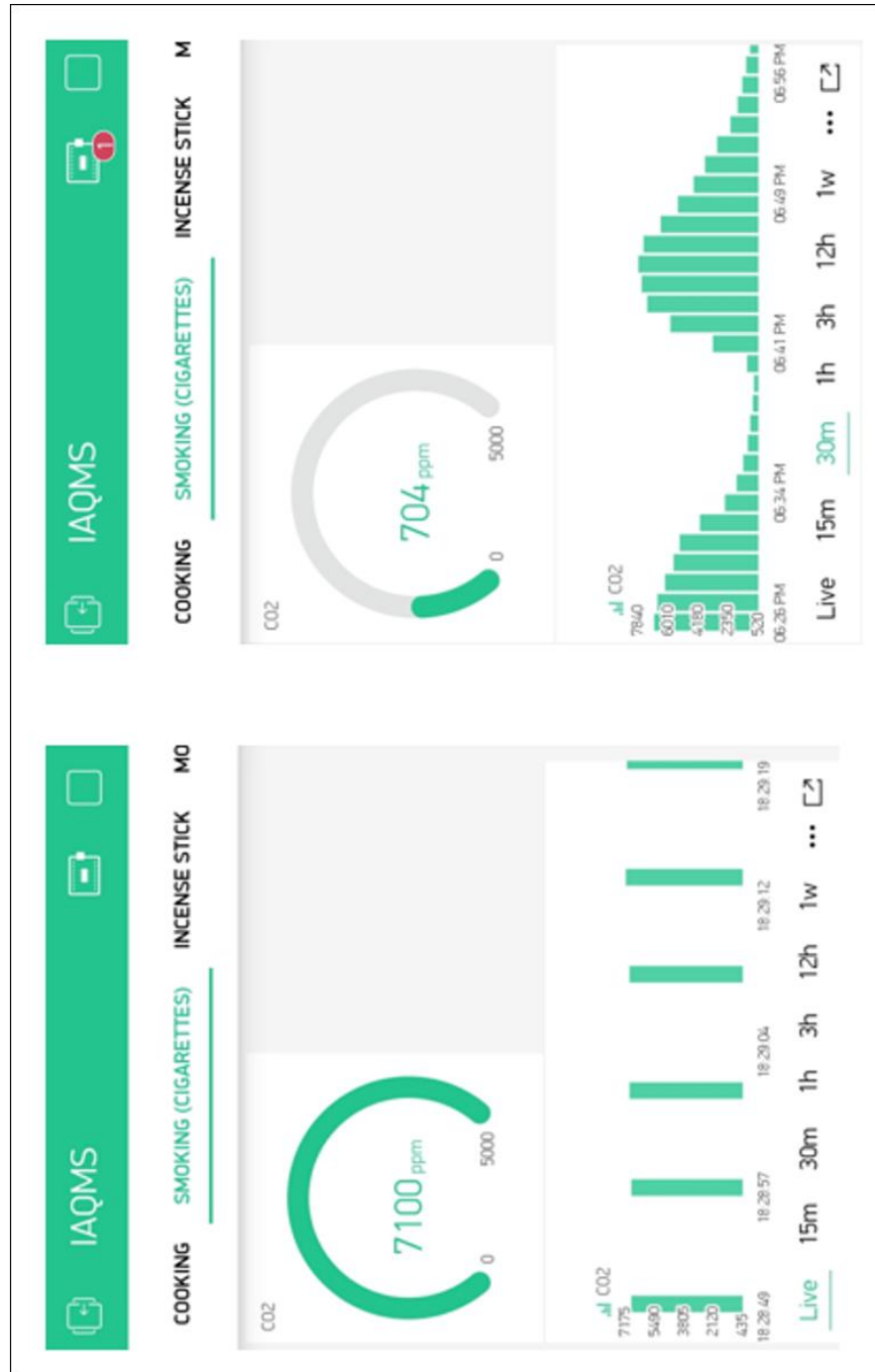


Figure 4.4 CO₂ in PPM during smoking (cigarettes)

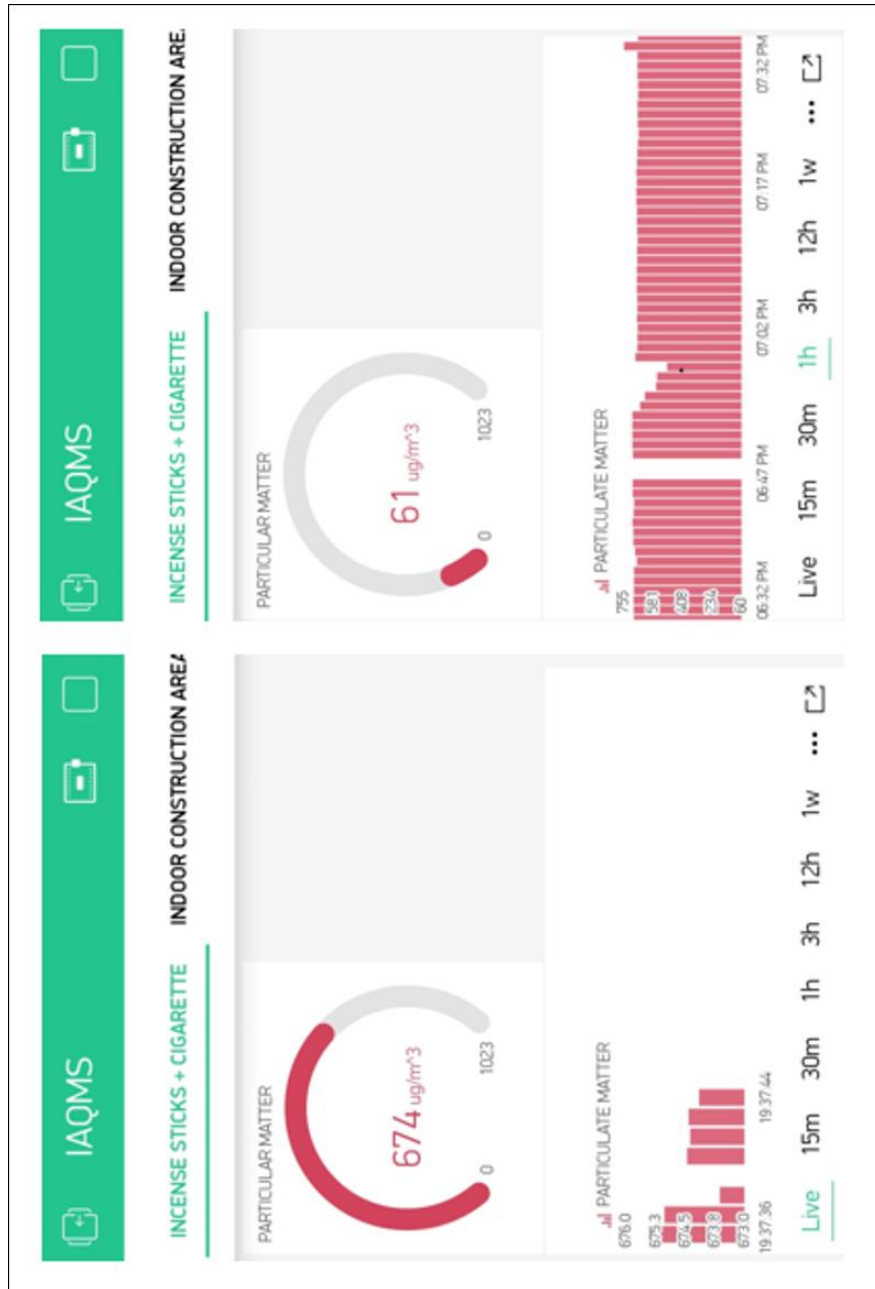


Figure 4.5 PM amount while burning of cigarette and incense sticks

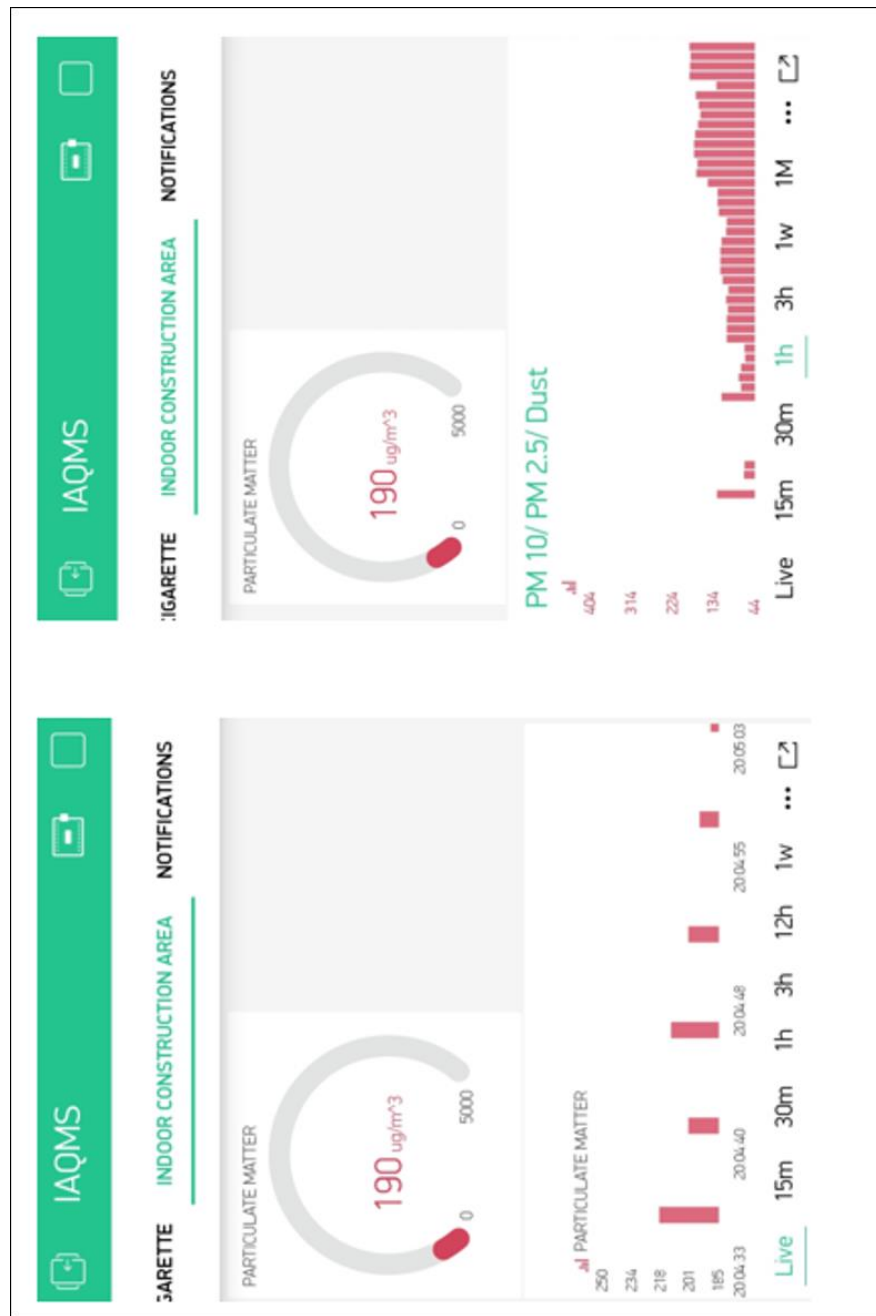


Figure 4.6 PM amount while indoor construction

Figure 4.7 shows early warning message for Co2 i.e. when Co2 level increases 800 ppm, user is notified through Bylnk. The notification says, CO2 is rising, detoxify your environment by planting any of these plants- money plant, spider pant, aloe vera, areca palm and snake plant. Similarly, in case of particulate matter user is notified when pm level reaches 100 ug/m³. Plants are organic, affordable and long term solutions for maintaining healthy and pollutant free environment. This research concludes plants can be used along with IoT ventilation and purification systems for reducing or controlling indoor air pollution.

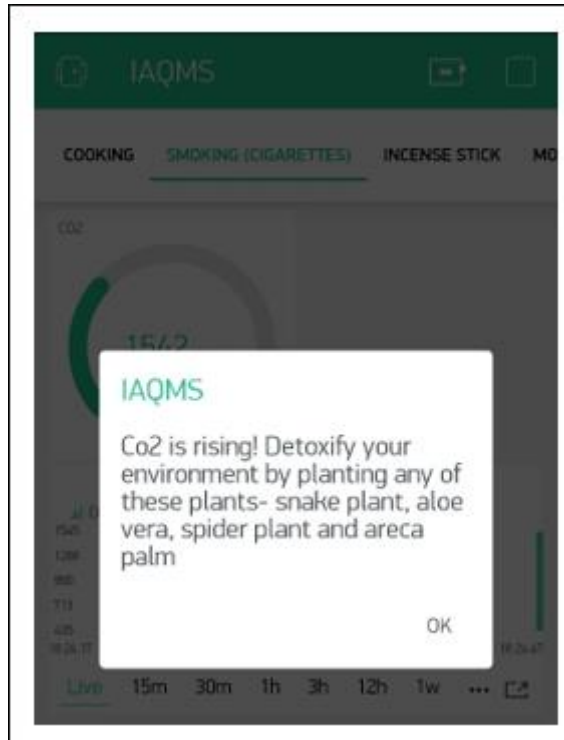


Figure 4.7 Notification

4.3.3 Discussions

In this research, it can be seen that activities such as cooking, cigarette smoking and burning of incense sticks and mosquito coil can increase CO₂ and particulate matter in indoor spaces. It also tells, how different activities impacts environment. High levels of both CO₂ and particulate matter are considered dangerous for human health.

Botanical solutions are suggested for improving indoor environment. Botanical solutions include plants such as money plant, spider pant, aloe vera, areca palm and snake plant for reducing above mentioned pollutants. Money plant, Spider plant and snake plant releases oxygen at nigh time also [60]. The study says, spider plant can reduce particulate matter from indoor spaces[61]. Thus, they are chosen for reducing indoor air pollution. Plants provides an added advantage of humidifying air.[62].

Lastly, an android application is designed for displaying results and for notifying users. The application is informative and helps users in learning about indoor air pollution and its common causes.

Chapter 5

Conclusion and Future Scope

The IAQMS, proposed in this research is useful for monitoring indoor quality. The application covers two hazardous indoor air pollutants- carbon dioxide (CO₂) and particulate matter (PM). The environmental activities for measuring above mentioned pollutants includes cooking, smoking (cigarettes), incense sticks, mosquito coil and indoor construction. Early warning messages are sent to users through android application. Also, valuable suggestions are provided for reducing indoor air pollution in the form of botanical solutions, as indoor plants. Android, being a popular platform among users, enhances usability of system.

The proposed application has stressed on household and workplace pollution. In future, it can be enhanced by covering other indoor environments. For measuring other pollutants, more sensor nodes can be added. The environmental activities, peculiar to other indoor environments can be addressed.

References

- [1] “What is Internet of Things?,” *IBM*, 2016. [Online]. Available: <https://www.ibm.com/blogs/internet-of-things/what-is-the-iot/>. [Accessed: 10-Jul-2019].
- [2] V. Afshar, “Cisco: Enterprises Are Leading The Internet of Things Innovation,” *HUFFPOST*, 2018. [Online]. Available: https://www.huffpost.com/entry/cisco-enterprises-are-leading-the-internet-of-things_b_59a41fcee4b0a62d0987b0c6. [Accessed: 22-Jun-2019].
- [3] D. Evans, “The Internet of Things How the Next Evolution of the Internet The Internet of Things How the Next Evolution of the Internet Is Changing Everything,” no. April, 2011.
- [4] D. Navani, “The Internet of Things (IoT): A Study of Architectural Elements,” 2017.
- [5] “Different Types of Sensors,” *Electronics Hub*, 2019. [Online]. Available: <https://www.electronicshub.org/different-types-sensors/>. [Accessed: 16-Jun-2019].
- [6] “Sensors: Different Types of Sensors,” *ENGINEERS GARAGE (An EE World Online Source)*. [Online]. Available: <https://www.engineersgarage.com/articles/sensors>. [Accessed: 16-Jun-2019].
- [7] “What is WiFi and How Does it Work?,” *CCM Forum*, 2016. [Online]. Available: <https://ccm.net/faq/298-what-is-wifi-and-how-does-it-work>. [Accessed: 16-Jun-2019].
- [8] S. Madakam, R. Ramaswamy, and S. Tripathi, “Jcc_2015052516013923,” *J. Comput. Commun.*, no. May, pp. 164–173, 2015.
- [9] R. . Bonaldi, “12b - Electronics used in high-performance apparel—Part 2/2,” in *High Performance Apparel Materials, Development and Applications*, Textiles: Woodhead Publishing Series, 2018, pp. 285–306.
- [10] “Wireless Sensor Networks and their Applications.” [Online]. Available: <https://www.elprocus.com/introduction-to-wireless-sensor-networks-types-and-applications/>. [Accessed: 16-Jun-2019].
- [11] K. Abdulla, A. Rabaiei, and S. Harous, “Internet of Things : Applications and Challenges College of Information Technology , UAE University Opportunities of IoT :,” *2016 12th Int. Conf. Innov. Inf. Technol.*, pp. 1–6, 2020.
- [12] A. W. W. J.F. ARTIOLA, “Sampling and Data Quality Objectives for Environment Monitoring,” *Sci. Direct*, pp. 11–27, 2004.
- [13] I. V Muralikrishna, V. Manickam, and E. Management, “Learn more about Environmental Pollution Introduction Societal Responsibility and Economic Viability Particulate Matter and Its Size Fraction- ation,” 2017.
- [14] S. B. Supreet Kaur, Seemu Sharma, “Smart Indoor Air Quality Monitoring

- System,” *Int. J. Recent Technol. Eng.*, p. 5, 2019.
- [15] C. Nunez, “Air pollution, facts and information,” *National Geographic*, 2019. [Online]. Available: <https://www.nationalgeographic.com/environment/global-warming/pollution/>. [Accessed: 17-Jun-2019].
- [16] “Water Pollution,” *Environmental Pollution Centers*. [Online]. Available: <https://www.environmentalpollutioncenters.org/water/>. [Accessed: 17-Jun-2019].
- [17] “Radioactive Pollution,” *Environmental Pollution Centers*. [Online]. Available: <https://www.environmentalpollutioncenters.org/radiation/>. [Accessed: 17-Jun-2019].
- [18] Y. Posudin, “Radioactive Pollution,” Wiley Online Library, 2014.
- [19] “Noise Pollution,” *Environmental Pollution Centers*. [Online]. Available: <https://www.environmentalpollutioncenters.org/noise-pollution/>. [Accessed: 17-Jun-2019].
- [20] M. R. W. Dodds, Walter K., “Responses to Stress, Toxic Chemicals, and Other Pollutants in Aquatic Ecosystems,” in *Freshwater Ecology*, 2nd ed., Elsevier, 2010, pp. 399–436.
- [21] J. O. Donnel, “Land Pollution: Causes, Effects and Solutions for the Future,” *conservation INSTITUTE*, 2018. [Online]. Available: <https://www.conservationinstitute.org/land-pollution/>.
- [22] D. Y. C. Leung, “Outdoor-indoor air pollution in urban environment : challenges and opportunity INDOOR AIR POLLUTANTS,” vol. 2, no. January, pp. 1–7, 2015.
- [23] “WHO Global Ambient Air Quality Database,” *World Health Organization*, 2019. [Online]. Available: <https://www.who.int/airpollution/data/cities/en/>. [Accessed: 27-Apr-2019].
- [24] X. Zhang, X. Chen, and X. Zhang, “The impact of exposure to air pollution on cognitive performance,” no. August, 2018.
- [25] “Air pollution and sperm quality: Breathing in toxic air may worsen semen quality,” *Times Now Digital*, 2019. [Online]. Available: <https://www.timesnownews.com/amp/health/article/air-pollution-and-sperm-quality-breathing-in-toxic-air-may-worsen-the-semen-quality/389219>. [Accessed: 30-Apr-2019].
- [26] A. Kankaria, B. Nongkynrih, and S. K. Gupta, “Indoor Air Pollution in India : Implications on Health and its Control,” no. July 2015, 2014.
- [27] P. Liu *et al.*, “A Low-Cost Intelligent Mobile Indoor Environment Monitoring System,” no. Icmemtc, pp. 226–230, 2016.
- [28] D. U. Urku and H. Agrawal, “Smart Real-Time Indoor Air Quality Sensing System and Analytics,” vol. 10, no. 6, pp. 1484–1495, 2019.
- [29] “Indoor Air Quality|EPA’s Report on the Environment (ROE),” *US EPA*. [Online]. Available: <https://www.epa.gov/report-environment/indoor-air->

- quality. [Accessed: 01-Jul-2019].
- [30] P. Srivatsa and A. Pandhare, "Indoor Air Quality : IoT Solution," no. March, pp. 218–220, 2016.
 - [31] W. Zhang, S. Qin, and Z. Chen, "Analysis on the Construction and Application of Health Classrooms in Information Environment," pp. 131–135.
 - [32] N. Marchetti, A. Cavazzini, L. Pasti, and M. Catani, "A Campus Sustainability Initiative : Indoor Air Quality Monitoring in Classrooms," *2015 XVIII AISEM Annu. Conf.*, pp. 1–4, 2015.
 - [33] P. K. Sharma, T. De, and S. Saha, "IoT based indoor environment data modelling and prediction," *2018 10th Int. Conf. Commun. Syst. Networks, COMSNETS 2018*, vol. 2018–Janua, pp. 537–539, 2018.
 - [34] P. Spachos and D. Hatzinakos, "Real-Time Indoor Carbon Dioxide Monitoring," *IEEE Sens. J.*, vol. 16, no. 2, pp. 506–514, 2016.
 - [35] Y. Chen and S. Shrestha, "Source Classification of Indoor Air Pollutants using Principal Component Analysis for Smart Home Monitoring Applications," *2018 IEEE Int. Conf. Electro/Information Technol.*, pp. 129–133, 2018.
 - [36] I. Peng, "Implementation of Indoor VOC Air Pollution Monitoring System with Sensor Network," *2013 Seventh Int. Conf. Complex, Intelligent, Softw. Intensive Syst.*, pp. 639–643, 2013.
 - [37] S. M. Saad *et al.*, "Classifying Sources Influencing Indoor Air Quality (IAQ) Using Artificial Neural Network (ANN)," pp. 11665–11684, 2015.
 - [38] R. Plessis, A. Kumar, G. P. Hancke, and B. J. Silva, "A wireless system for indoor air quality monitoring," *IECON 2016 - 42nd Annu. Conf. IEEE Ind. Electron. Soc.*, pp. 5409–5414, 2016.
 - [39] P. Asthana, "IoT Enabled Real Time Bolt based Indoor Air Quality Monitoring System," *2018 Int. Conf. Comput. Charact. Tech. Eng. Sci.*, pp. 36–39, 2018.
 - [40] S. M. Saad, A. Rahman, M. Saad, A. Muhamad, Y. Kamarudin, and A. Zakaria, "Indoor Air Quality Monitoring System using Wireless Sensor Network (WSN) with Web Interface," *2013 Int. Conf. Electr. Electron. Syst. Eng.*, pp. 60–64, 2013.
 - [41] "CoAP." [Online]. Available: <https://coap.technology/>. [Accessed: 14-Jun-2019].
 - [42] B. H. Sudantha and P. M. Karunaratne, "IoT Enabled Proactive Indoor Air Quality Monitoring System for Sustainable Health Management," pp. 216–221, 2017.
 - [43] X. Yang, L. Yang, and J. Zhang, "A WiFi-enabled Indoor Air Quality Monitoring and Control System : the Design and Control Experiments," *2017 13th IEEE Int. Conf. Control Autom.*, pp. 927–932, 2017.
 - [44] U. Engagement, "Zone Based Indoor Mobile Air Pollution Monitoring," pp. 749–752, 2013.
 - [45] S. Zhi, "Intelligent Controlling of Indoor Air Quality based on Remote

- Monitoring Platform by Considering Building Environment,” no. Icsai, pp. 627–631, 2017.
- [46] R. Pitarma, F. Caetano, and A. Monitoring, “Monitoring Indoor Air Quality to Improve Occupational Health,” no. January, 2016.
- [47] G. Marques and R. Pitarma, “An Indoor Monitoring System for Ambient Assisted Living Based on Internet of Things Architecture,” 2016.
- [48] B. Fang, Q. Xu, T. Park, and M. Zhang, “AirSense : An Intelligent Home-based Sensing System for Indoor Air Quality Analytics,” pp. 109–119, 2016.
- [49] X. Li and N. Zhu, “Indoor Air Pollution Control and Cognition Situation Investigation in University,” pp. 1307–1309, 2011.
- [50] A. K. Patel and P. Biren, “Internet of Things (IoT): A Literature Review,” vol. 4, no. 05, pp. 1001–1003, 2016.
- [51] G. Parmar, S. Lakhani, and M. K. Chattopadhyay, “An IoT based low cost air pollution monitoring system,” *2017 Int. Conf. Recent Innov. Signal Process. Embed. Syst.*, pp. 524–528, 2017.
- [52] “Health statistics and information systems,” *World Health Organization*. [Online]. Available: <https://www.who.int/healthinfo/survey/whoqol-qualityoflife/en/>. [Accessed: 15-Jun-2019].
- [53] “Arduino.” [Online]. Available: <https://www.arduino.cc/en/Main/Software>. [Accessed: 15-Jun-2019].
- [54] “MQ 135 Gas Sensor Pinout, Features, Alternatives, Datasheets and User Guides.” [Online]. Available: <https://components101.com/sensors/mq135-gas-sensor-for-air-quality>. [Accessed: 11-Jun-2019].
- [55] “MQ135 Semiconductor Sensor for Air Quality Control.” [Online]. Available: <http://www.china-total.com/Product/meter/gas-sensor/MQ135.pdf>. [Accessed: 11-Jun-2019].
- [56] “Application Guide for Sharp GP2Y1014AU0F Dust Sensor,” 2018. [Online]. Available: <https://github.com/sharpsensoruser/sharp-sensor-demos/wiki/Application-Guide-for-Sharp-GP2Y1014AU0F-Dust-Sensor>. [Accessed: 11-Jun-2019].
- [57] “Technical Data MQ 7 Sensor.” [Online]. Available: <https://www.sparkfun.com/datasheets/Sensors/Biometric/MQ-7.pdf>. [Accessed: 11-Jun-2019].
- [58] “ESP8266EX Resources|Espressif Systems.” [Online]. Available: <https://www.espressif.com/en/products/hardware/esp8266ex/resources>. [Accessed: 16-Jun-2019].
- [59] “Blynk IoT platform,” *Blynk Inc.*, 2019. [Online]. Available: <https://blynk.io/>. [Accessed: 16-Jun-2019].
- [60] M. Ljubojevic and M. Zoric, “Quality of Life Context Influence Factors Improvement Using Houseplants and Internet of Things,” 2016.
- [61] H. Gawro and B. Bakera, “Phytoremediation of particulate matter from indoor

air by Chlorophytum comosum L . plants,” pp. 265–272, 2015.

- [62] “NASA Plant Research Offers a Breath of Fresh Air,” *NASA*. [Online]. Available: https://spinoff.nasa.gov/Spinoff2019/cg_7.html. [Accessed: 10-Jun-2019].

List of Publications

[1] Supreet Kaur, Seema Bawa and Seemu Sharma, “**Smart Indoor Air Quality Monitoring System**”, International Journal of Recent Technology and Engineering (IJRTE-2019, Scopus Indexed).

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[2] Supreet Kaur, Seema Bawa and Seemu Sharma, “**IoT Enabled Low-Cost Indoor Air Quality Monitoring System with Botanical Solutions**”, Wireless Personal Communications (Springer, Journal no. 11277)

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