WIRELESS SENSOR NETWORK FOR AIR QUALITY MONITORING

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***Abstract*—The continuous monitoring of air quality is important for the well-being of all species as it affects their health conditions. But, air quality is not thoroughly monitored in Sri Lanka. Air quality of both outdoor and indoor environments should be monitored to identify any unhealthy conditions. This research paper highlights the importance of establishing an air quality monitoring system using Internet of Things (IoT) and Wireless Sensor Network (WSN) concepts. A prototype system was developed and deployed in three selected indoor and outdoor locations to monitor air quality. The capabilities of this system include monitoring the temperature, humidity and the concentrations of Carbon Monoxide (CO), Carbon Dioxide (CO_2) and dust particles. This research paper summarizes the readings obtained from the prototype system and further improvements are also suggested.**

Keywords-air quality; Internet of Things; Wireless Sensor Network

I. INTRODUCTION

Air pollution can be identified as one of the biggest threats that the mankind is facing today. It occurs due to the availability of harmful substances in the air. Substances such as gases and particles cause the air to be polluted.
Air pollution was started with the usage of fossil fuels. The main cause for the air pollution is the harmful gases emitted by motor vehicles and the gases emitted from the industry. Some of the pollutant gases are Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO2) and Ozone (O3) [1].

These pollutant gases cause numerous health issues to the mankind and all other living species living on the planet. Lung diseases, lung cancers and cardiovascular problems can be caused because of polluted air. Furthermore, polluted air has a strong negative effect on the health of newborn babies and pregnant women [1].

Therefore, monitoring the quality of ambient air is crucial for assessing the level of pollution in relation to the ambient air quality standards and prevent extreme events by alerting people and initiating necessary actions.

The quality of the air in Sri Lanka is monitored by Central Environmental Authority (CEA) of Sri Lanka and World Air Quality Index Team - Beijing. The one and only monitoring station of CEA is situated in Colombo fort area [2]. The air quality index team is gathering data from the monitoring station situated in US Embassy, Colombo [3].

But, new studies reveal that other major cities are also having a higher concentration of pollutants in ambient air. A study was carried out recently in Kandy and it was identified as the 4th most polluted city in Sri Lanka, after Battaramulla, Colombo and Homagama. Also, Gampaha, Rathnapura, Dambulla and Digana are identified as other highly polluted areas in Sri Lanka [3].

Measuring the quality of air in the city of Colombo and suburbs will not determine the overall quality of air in the country. Therefore, an island wide Wireless Sensor Network (WSN) based on Internet of Things (IoT) should be deployed to overcome this problem.

Due to the current context, not only the outdoor air quality but also the indoor air quality plays a vital role in ensuring the wellbeing of people. The work force in the country is mainly located in urban areas. The office premises and housing schemes are situated close to one another in compact areas and most of the people spend about 90 percent of their time indoors.

Therefore, Indoor Air Quality (IAQ) is a growing concern and very less attention is given to continuously monitor IAQ. The quality of indoor air is important for occupants' comfort as well as for their health.

II. RESEARCH OBJECTIVES

A. *Importance of air quality monitoring*

In past few months, the quality of the air in Sri Lanka (Mainly in Colombo and suburbs) decreased drastically. A thick cloud of dust was present in the atmosphere for few weeks. Authorities have warned the public to wear face masks to prevent them from getting sick due to the polluted air.

Monitoring indoor air quality is as vital as monitoring outdoor air quality. The air quality inside crowded indoor environments can be decreased due to overcrowding and poor ventilation. Indoor air quality impacts the health of the people inside the buildings within a short period of time. Therefore, monitoring the air quality of indoor environments is also important.

This IoT based WSN can be implemented in selected outdoor and indoor locations. Then the authorities will be able to have a bird's eye view of the air quality in Sri Lanka at any given time. Therefore, they will be able to monitor and analyze the data and take necessary actions to reduce air pollution.

B. *Objectives*

The research objectives include:

- To identify the importance of outdoor and indoor air quality monitoring
- To design and deploy a prototype IoT based WSN in different environment conditions and measure air pollution.
- To design a web server-based architecture to store and monitor the data gathered from the WSN.
- To develop a web interface to monitor and analyze the data from the databases in real time

This research paper highlights the important of monitoring ambient air quality and IAQ. The tested IoT based WSN can be considered as an initial prototype to deploy an island wide outdoor and indoor air quality monitoring mechanism to ensure a healthy living condition in the country.

III. LITERATURE REVIEW

A. *Similar research*

Modular Sensor System (MSS) for urban air pollution monitoring is a similar research carried out in 2016 [4]. The system could measure NO_2, CO_2 and SO_2 levels. They've used a GSM module for their project. GSM modules are difficult to work with and cause regular errors. When compared with the proposed project, features such as in-built gas level indicator and a mobile application to measure the pollution levels in real time are some of the lacking features. Those are the main drawbacks of MSS for an urban air pollution monitoring project.

The paper with the title "Proficient modus operandi for scrutinize air pollution using wireless sensor network" is also a similar research [5]. This project was done to measure the air quality of the surrounding areas. The system could measure NO_2, CO_2, SO_2 levels as well as Methane (CH_4), and Hydrogen Sulphate (H2SO4).

When compared with this proposed network, the main difference is the type of sensors used. Furthermore, researchers of this project have used a GSM module to communicate with the database. Instead of a GSM Module, a Wi-Fi module can provide a stable connectivity. The features such as in-built gas level indicator and a mobile application to measure the pollution levels in real time are not included in this project.

B. *Quality of air*

"Quality of air" refers to the condition of air in the surrounding. Quality of air is considered as good, when the air is clean and free from harmful substances (pollutants). Air quality is determined by considering the concentrations of pollutants, the temperature and relative humidity.

Several factors need to be considered when determining the quality of air of indoor and outdoor environments [6]. They are:

- Air Quality Index (AQI)
- PM standards
- Carbon Monoxide Level

Carbon Dioxide Level

- Level of other toxic gases
- Temperature
- Relative Humidity

1) *Carbon Monoxide (CO) Level:*

Carbon monoxide is colorless, odorless, nonflammable poisonous gas. CO levels of indoor environments and the potential health problems are listed in the table below.

CO LEVELS AND THE POTENTIAL HEALTH PROBLEMS

Concentration (ppm)	CO Level	Health problems occurred
0 - 1	Normal Level	-
9	Maximum level allowed	-
9 - 35	Maximum exposure for 8 hours	Sick building syndrome
35 - 50	Harmful / Unhealthy	Poor concentration Loss of attention Sleepiness nausea
50 - 100	Hazardous	Evacuation needed to prevent fatal diseases

2) *Carbon Dioxide (CO_2) Level*

Carbon Dioxide level is another factor which is considered to determine the air quality. It is a colorless, odorless, nonflammable gas. Unlike Carbon Monoxide, the level of Carbon Dioxide affects the air quality of both indoor and outdoor environments.

Carbon Dioxide is produced from incomplete burning of fossil fuels as well as from metabolic process in living organisms. Levels of Carbon Dioxide and the potential health risks are listed in the table below.

TEMPERATURE AND HUMIDITY.

Concentration (ppm)	CO_2 Level	Health problems occurred
350 - 500	Normal	-
500 -1000	Acceptable (Poor air circulation)	Discomfort in breathing
1000 – 2000	Poor	Headache and drowsiness
2000 – 5000	Harmful	Poor concentration Loss of attention Sleepiness nausea
Above 5000	Hazardous	Fatal diseases

Temperature and humidity play a major role in air and outdoor and indoor environments. Environmental Protection Agency (EPA) of United States recommends maintaining the humidity between 30% - 60% and the temperature between 20 ^{0}C - 23 ^{0}C in indoor environments. These levels are identified as ideal conditions for indoor environments [8].

3) *Humidex:*

Humidex formula calculates the equitant temperature that human body would feel, according to the current temperature and relative humidity of air [9].

Formula of Humidex:

$$\text{Humidex} = \text{Temperature} + \frac{5}{9}(e - 10)$$

Where;

e = (6.112 x 10 [7.5* T / (237.5 + T) * H * 100])

H= Relative humidity

T=Temperature [9]

HUMIDEX CHART [10]

Humidex	Effect
>29	Little or no discomfort
30 - 34	Noticeable discomfort
40 – 45	Intense discomfort
Above 45	Dangerous discomfort
Above 50	Heat stroke

IV. METHODOLOGY

C. Overall IoT based WSN system

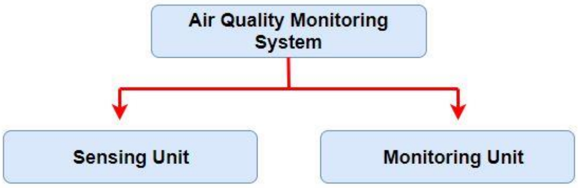

Figure 1: IoT System

This IoT based WSN consists of two main components. They are sensing unit and monitoring unit. Sensing unit gathers data using the sensors and sends the data to the database via internet using a Wi-Fi module. Monitoring unit stores the data and displays the data in real time. Several sensor units are placed in selected locations and all the data gathered is stored in a central database for monitoring purposes.

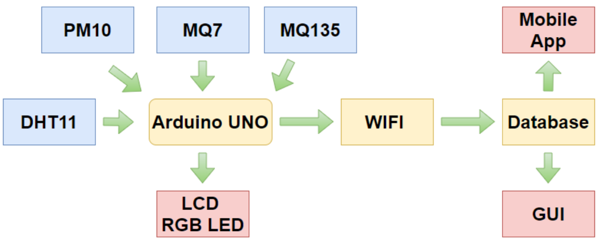

Figure 2: Overall IoT system with WSN

Four sensors are used to measure the quality of air and an Arduino microcontroller is used to process the data. LCD display and RGB LED is used to display the information on the sensing unit. A Wi-Fi module is used to access internet, to send the collected data to the central database. After storing the data in the database, the web user interface or the mobile application can be used to monitor the air quality around the nodes in real time.

D. Sensing unit

Sensing unit measures the concentrations of pollutants of the surrounding air. 4 Sensors are used in the sensing unit to measure the pollutants. The Sensing unit consists of the components as depicted in the Fig. 3.

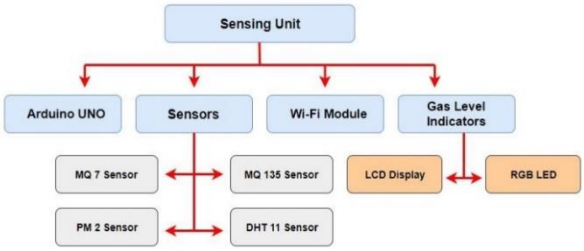

Figure 3: Components of the sensing unit Sensors

1) DHT11 sensor

DHT 11 sensor can measure the temperature and relative humidity of the surrounding air. This sensor, consists of a resistive element for measuring relative humidity and a Negative Temperature Coefficient (NTC) measuring component to measure the temperature.

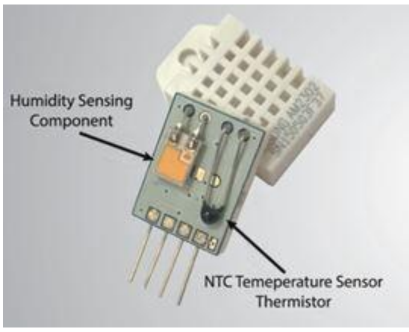

Figure 4: DHT11 Sensor

Operating conditions of DHT 11 Sensor are mentioned below.

- Temperature Range: 0 – 50 ºC
- Humidity Range: 20% – 100%.
- Operating Voltage is 3 -5 V [11]

2) Sharp GP2Y1014AU0F Sensor (PM 10 Sensor)

Sharp GP2Y1014AU0F Sensor measures the density of the dust particles present in air. It is capable of measuring PM 10 (particles which are 10 micro meters or lesser in diameter) density.

Figure 5: Sharp GP2Y1014AU0F Sensor

Operating conditions of Sharp GP2Y1014AU0F sensor are mentioned below.

- Light emitting element: LED
- Minimum particle size detectable: 0.5µm
- Sensing range: up to 580 µg/m^3
- Operating Voltage: 5V [12]

3) MQ7 Sensor:

MQ7 sensor measures the Carbon Monoxide (CO) level in the air. It measures the ppm (parts per million) value of CO concentrations.
MQ7 is a Metal Oxide Semiconductor (MOS) type gas sensor. Tin Oxide (SnO_2) is used as the sensing element which changes the resistivity as per the carbon monoxide concentrations [13].

Figure 6: MQ 7 Gas Sensor

4) MQ 135 Sensor:
MQ 135 sensor measures the CO_2 level in the air. It measures the ppm (parts per million) value of CO_2 concentrations. [13].

Figure 7: MQ 135 Gas Sensor

During the research, three types of environments were chosen to set up the sensor network. Those environments are,

1. Indoor environment of a house
2. Indoor environment of an office building
3. Outdoor environment of an urban area

E. *Final IoT based WSN setup*

Sensing units were set up in above mentioned locations to build the sensor network. Data was collected for 7 days. Before collecting data from the sensor network, a suitable time interval was needed to be determined in between two readings. Therefore, a sensing unit was placed on an indoor environment with average ventilation and data was gathered for 3 hours, with a 5-minute interval between two readings. After analyzing the sensor data, it was identified that there were no sudden changes recorded in the air quality during short periods of time. Hence, the time interval between 2 sets of data were chosen as 1 hour.

A house with a good ventilation and with large open areas were chosen for this research. Sensing unit was placed in the middle of the house and gathered data of the air quality for 7 days.

V. RESULTS

F. *Daily variation of Carbon Monoxide (CO)*

The daily variation in Carbon Monoxide (CO) concentration of three locations are illustrated in the figure below.

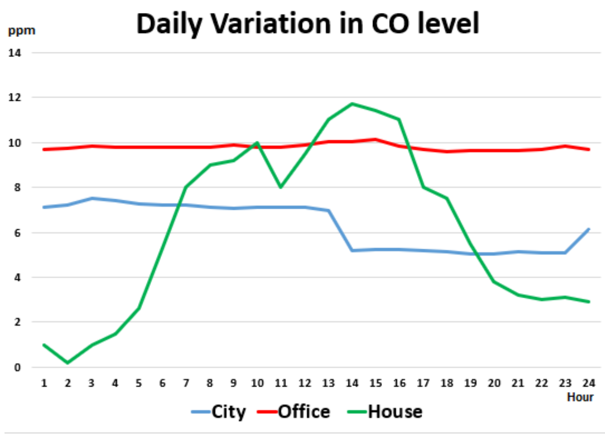

Fig. 28. Daily variation of CO level

G. *Daily variation of Carbon Dioxide (CO_2)*

The daily variation in Carbon Dioxide (CO_2) concentration of three locations are illustrated in the figure below.

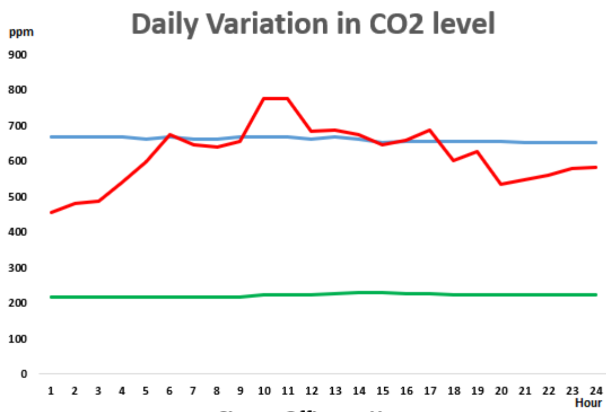

Fig. 29. Daily variation of CO_2

H. *Daily variation of Dust Particles*

The daily variation in dust particle concentration of three locations are illustrated in the figure below.

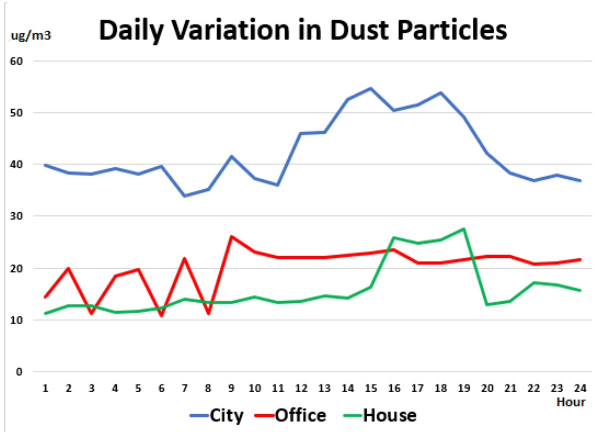

Fig. 30. Daily variation of dust particles

I. *Daily variation of Temperature*

The daily variation in temperature of three locations are illustrated in the figure below.

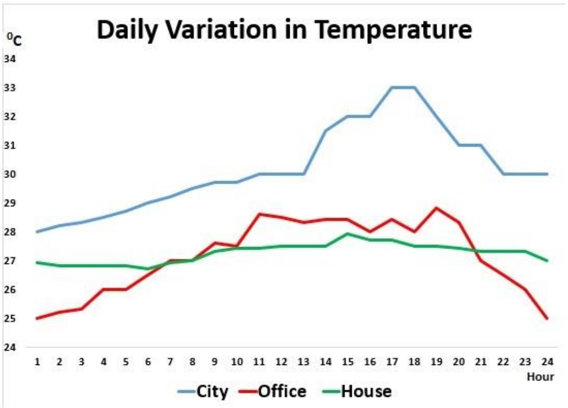

Fig. 31. Daily variation of Temperature

J. Daily variation of Relative Humidity

The daily variation in relative humidity of three locations are illustrated in the figure below.

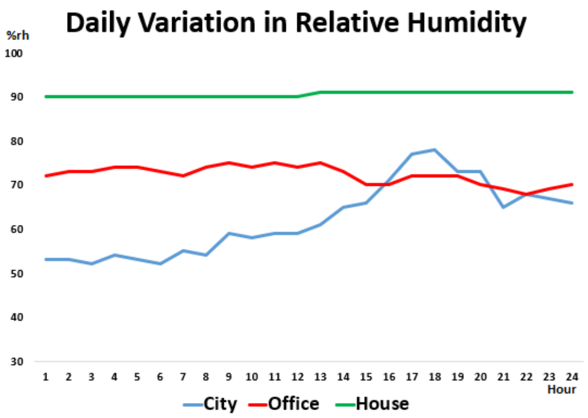

Fig. 32. Daily variation of relative humidity

Fig. 1 shows the daily variation of CO levels in ambient air in the 3 selected locations. While the CO level in city stayed in the acceptable range, two indoor environments showed a significant increase of CO levels during the day time.

Fig. 2 shows the daily variation of CO_2 levels in ambient air during the study. While the CO_2 level inside the house stayed in the acceptable range, the CO_2 levels in office area and in the city reached almost the 'poor' level during the day time.

Fig. 3 shows the daily variation of the concentration of dust particles (PM10) in ambient air during the study. PM10 level in city reached the unhealthy level during day time.

Fig. 4 shows the daily variation of the temperature in ambient air during the study. While the temperatures inside the office and the house remained stable, the temperature in the city increased during day time.

Fig. 5 shows the daily variation of the humidity in ambient air during the study. Higher levels of humidity was identified inside the house during the period due to the poor ventilations.

VI. CONCLUSIONS

The literature review conducted during this research, shows that both the outdoor and indoor air quality should be monitored closely to ensure a healthy living environment. The deployed IoT based WSN was used to determine the quality of the air in various environments. Three tests were carried out in three different locations as a prototype testing.

From the results obtained in section V above, it was determined that the highly occupied building areas with poor ventilation has higher concentrations of pollutants (CO, CO_2). Also, the temperature and the relative humidity is higher inside the office building. Hence, the ventilation must be increased to normalize the air quality and to ensure the well-being of the workers.

Furthermore, it was determined that the urban areas are mostly polluted during the day time. Carbon Dioxide and dust particles were the main pollutants in the urban area selected. It is due to the higher number of motor vehicles, industrial buildings and construction sites in the vicinity.

This sensor network can be further developed by using more accurate sensors and can be implemented in all major cities in Sri Lanka. So, the authorities can monitor the level of air pollution in both outdoor and indoor environments in real time.

It can be concluded that Sri Lanka should implement a similar IoT based WSN to monitor outdoor environment condition in urban areas and a similar WSN systems should be implemented inside buildings to monitor indoor environments also to provide good living condition for the people.

Further, this sensor network can be further developed by,

- Using more sensors to gather data such as smoke, flammable gases and other pollutants.
- Calibrating the sensors to get more accurate readings.
- Using sensors with more accuracy.
- Developing the mobile application software and the graphical user interface to get daily, weekly or monthly reports and emergency alerts.
- Integrating this sensor network with home automation and home security systems.

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