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A Framework for Air Pollution Monitoring in Smart Cities by Using IoT and Smart Sensors

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In the last half century, the world population migrated from villages to cities due to lack of facilities, education institutes, medical services, and job opportunities in the remote areas. Due to this migration the big cities are under pressure to remain live-able and healthier because population increasing quickly as compared to the services infrastructure. As the city's population increasing very rapidly and demand for the civic facilities remains very high. One of the major additions is the road traffic which become the big contributor in air pollution and make the environment very unhealthy. In modern era, it is important to persistently monitor the environmental pollution of city to make it healthier and live-able. Internet of Things (IoT) with smart sensor system is the solution which can be used to monitor the city for various purposes and one of them is the pollution monitoring in big cities. Sensor system can be installed and managed by integrating with IoT and be monitored by sitting in city central office. In this research work, a framework for air quality monitoring is proposed to monitor environmental pollution for the smart cities by using IoT and smart sensors. The proposed system is capable to measure the humidity, carbon emission, temperature, smoke, sound and other hazardous particulate in the atmosphere and send the measurements to city central office where it is analyzed for further actions for the betterment of city environment. Collected data is banked in a data bank for future use and can be shared with other research institute and environmental agencies.

Povzetek: Razvit je sistem pametnega mesta za nadzor kvalitete ozračja z uporabo pametnih senzorjev in sistema IoT.

1 Introduction

Sound, industrial waste, traffic noise and noise pollution are considered a big contributor to the environmental pollution. Air pollution is considered one of the most contributors in the environmental pollution which affect the human health very badly. The climate change scientists and environmentalists have great concerns in consequence of the air pollution and climate change in the whole world [1]. Due to the discharge of the numerous lethal gases from road traffic and from industrial waste not only creating the dangerousness for the city's environment but also for the sea life as well. In the last fifty years the world population migrated from the villages to the big cities to get more faucitis and job opportunity. Due to this reason the cities are under pressure with increasing population to provide them the daily life facilities in adversely the environmental pollution is increasing very rapidly and the cities are becoming unhealthy due to the road and industry pollution. Health problems are increasing due to the poor air quality like stroke, lung cancer, heart diseases and respirational infections like asthma [2]. Due to bad air quality in big cities, it creates major health risk for the city's population. Every year Millions of the premature deaths worldwide are reported in WHO's report because of environmental issues [3]. Worldly powers are focusing to keep environment healthier and having various conferences and meeting to reduce the carbon emission [4]. To keep environment healthier and livable, it is very important to monitor air quality index regularly [6-8]. To provide healthy lifestyle to the citizen, governments are working to build smart cities for the purpose of monitoring environment and road traffic. For the purpose of building smart cities different government agencies are working to build communication network with the support of smart sensor system and Internet of Things (IoT). To handle the environmental pollution and keep environment healthier smart wireless sensors and intelligent systems are installed embedded with IoT to monitoring the air quality index in real time. Real- time air quality monitoring systems are installed in the cities, IoT enabled WSN technology is the future for the smart cities [8]. Live data is collected from installed sensor systems by using Internet of Things (IoT) and analyzed at central office to take further actions for the betterment of the city environment. The one-time installation is cost efficient and reduces the mobility of the hardware at different locations for monitoring purposes.

Various hardware kits are available for this purpose which gather information from environment and process it to be transmitted via IoT to the base station for further investigation [10], an open-source cloud platform named Thing Speak is available for data storage and retrieval by using hypertext transfer protocol (HTTP) over IoT. IoT is great revolution in technological area which serves as

Figure 1: Sensor applications in smart cities.

global network of smart and intelligent physical objects which is capable to exchange information with each other, observing the privacy of the individuals. As the sensor prices are reducing due to novel technologies but still it cost lot as for the monitoring purposes hundreds thousands of sensors are needed to monitor any phenomena [11, 23].The smart sensors are the physical objects which are capable to sense the desired phenomena in the deployed area and it contains processing unit, sensors and UAV with smart cameras and sensors, is connected by using internet, wired or wireless connectivity [12]. By using the IoT and smart sensor systems with common physical objects to build smart city environment monitoring system which help to create healthy and safe environment. By implementing and installing the proposed system for the purpose of building smart and intelligent cities in which environment index can be easily monitoring and further actions are recommended. The proposed environment monitoring system will work by using secure IoT architecture design and presented system have benefit to monitor and control things remotely and fetch real time information from the environment whenever and wherever needed. The framework proposed in the research work consists of multi sensor nodes which are controlled by microcontroller and the collected data transmitted to the control room by using IoT based connectivity for further processing.

2 Literature review

With the use of smart sensor system embedded with IoT promises to social life betterment in the area of civic services and smart cities. These smart systems are capable to be deployed in the various areas such as public health, vehicles, homes, cities, agriculture, hospitals, public buildings, and any place wherever and whenever monitoring is required. A handsome amount of research work is done by researchers in the field of environment monitoring for healthy living and better lifestyle using WSN [13]. In [13], author proposed the system to monitor humidity and temperature of surrounding area and used the ZigBee technology for the communication to the base the station. In [14], researchers proposed the system based on wireless sensor network to monitoring temperature and humidity in the farm area to detect the region which growth with extraordinary likelihood. The authors in [15], used wireless sensor-based system for the monitoring purposes in coffee factory and proposed system is capable to monitor humidity and temperature along with the level of hazardous gases like nitrogen dioxide (NO2), sulphur dioxide (SO2) and carbon dioxide (CO2).

In [16], authors suggested environmental monitoring system for the purpose of monitoring rainwater and soil, the collected information is used for further studies to enhance crop yields. The system proposed in [17] monitors the soil moisture, humidity and environment temperature and communication data every 5 minutes to the base station.

The following table about comparison of air quality monitoring reveals that the researchers choose WSN based designs with ZigBee as most reliable communication protocol since couple of years. Therefore, ATmega controller is used to manage the real time data collection. The researchers used Raspberry Pi to monitor the environment for air pollution with integration of wireless sensor network. To transmit data over multiple hopes in Ad hoc network demands lot of energy for signal transmission and transmitted signals took lot of time to the monitoring unit. Researchers need to work lot in the area of power management to reduce the power consumption

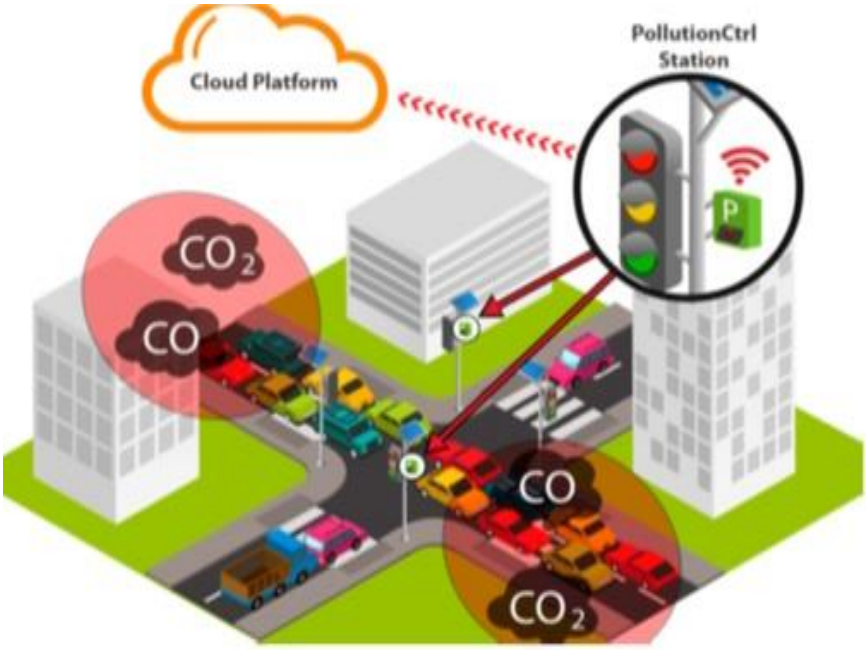

Figure 2: Internet of Thing based solution for pollution monitoring.

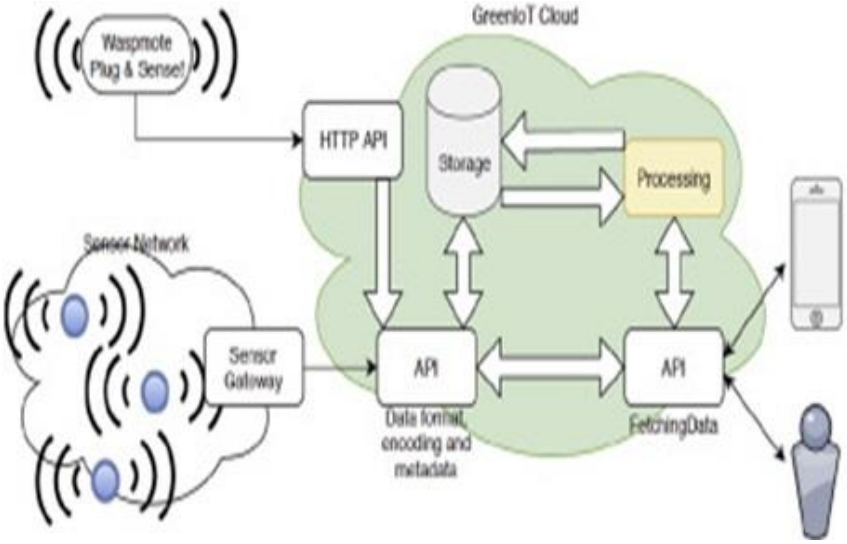

Figure 3: The system architecture testbed [17].

to enhance life and performance of the system [28. In [36] WSN architecture is used successfully to implement the energy saving and cost saving monitoring by researchers. Therefore, the most reliable source for the air pollution monitoring to save energy for increase battery life expectancy and better single-hop communication is IoT based monitoring system. These systems required less efforts for maintenance of system as low latencies and less power consumption.

The proposed systems by many researchers are capable to detect limited number of gases in air which are harmful to the environment and human health. Some published work addressed the issue of noise pollution as it is also considered major concern for healthy life in the cities. Various proposed systems are using Zigbee for the purpose of communication and it is very useful for the monitoring the environment. In [18], the researchers developed a wireless based system of monitoring system for the purpose of measurement of air quality in the environment. In published work, the authors proposed the system which measures the air quality consists of hardware, firmware and software solution and developed system is using Arduino platform based on network gateway to connect sensor nodes to the base station by using Internet of Things (IoT).

3 Methodology and proposed architecture

Monitoring of the big city environment and taking precautionary measures are very important to keep environment liveable and viable. The proposed framework architecture in this research work is capable of monitoring air pollution in the environment by using smart sensor system embedded with Internet of Things (IoT). The proposed system architecture comprised “n” number of

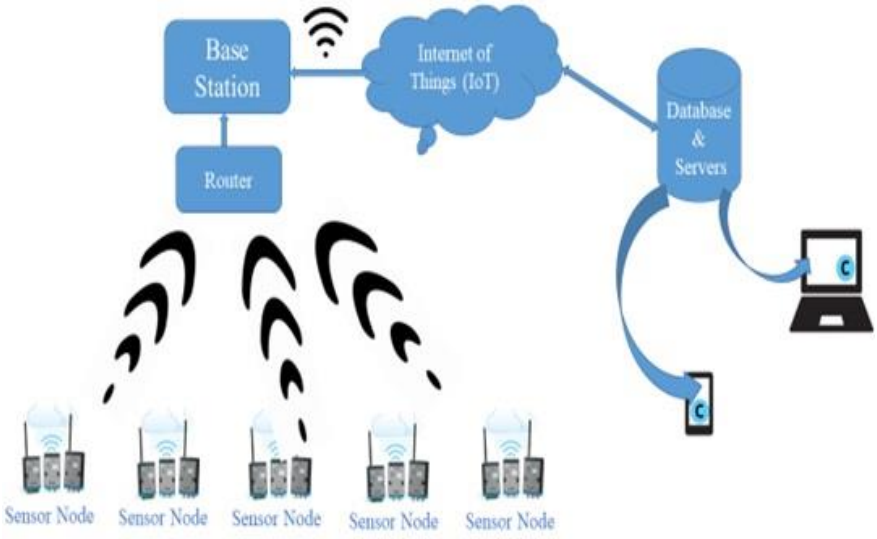

Figure 4: Air quality monitor system based on IoT and smart sensors.

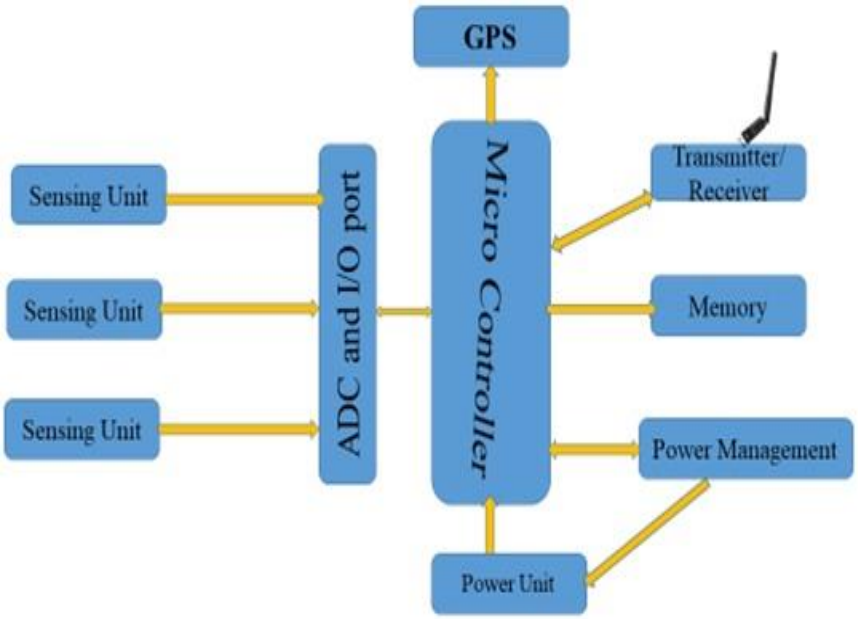

Figure 5: Block diagram of the RF sensor unit.

fixed sensor, moveable sensors, and unmanned aerial vehicles (UAV) which are equipped with smart sensor system for various purposes. The proposed system architecture is more adaptive and distributed in nature and proposed architecture to be comprised on different layers for management purposes. The first layer of the proposed system is the sensing devices which can directly collect information from environment where it is deployed as shown in the figure 4 below. The installed sensors monitor noises, air pollution, temperature, humidity and gases from the environment and process collected information to be forward to upper layer. Second layer of the proposed system handles sensor nodes which transfer sensed data to the base station. The proposed devices in the system are operated and controlled with respect to the importance, range and sensing duration. For the purpose of handling devices, an alert generated to the base station, defined by using a threshold value. Then from base station the processed data is forward to the server by using Internet of Things (IoT) as shown in figure 4.

Block diagram of the proposed system is given below in figure 5, which comprises various modules that consists of various type of sensors for measuring CO2, humidity, temperature, NO2, noise sensor and VOC sensor which input directly to the controller.

Table 1: Comparison of air pollution monitoring systems based on WSN [35].

Sr. no.	References	Year	Parameters Considered	Architecture	Communication Interface	MCU	Data Access	Remarks
1	Abraham and Li [24]	2014	CO, VOC and CO_2, O_3, RH, temperature,	WSN	ZigBee module	Arduino Uno microcontroller	Web Server	Micro gas sensors were calibrated using least square estimation-based method
2	Kim et al. [25]	2014	CO_2, VOCs, SO_2, NO_x, CO, PM and O_3	WSN	ZigBee	Raspberry Pi	Web server and Mobile	Experiments conducted in three different settings: big areas, medium size areas and small size living room; monitoring alert is generated in real time
3	Alhmiedat and Samara [26]	2017	CO_2, benzene, NO_x and ammonia	WSN	ZigBee	ATtiny85 microcontroller	Simulation environment	A sleep state algorithm and interface circuit used to minimize power consumption
4	Arroyo et al. [27]	2019	Toluene, ethylbenzene, benzene, and xylene	WSN	ZigBee	Not available	Cloud server	Laboratory based case study
5	Saad et al. [28]	2013	RH,temperature, PM and gaseous pollutants	WSN	AT86RF230 radio frequency front end IC for ZigBee standard	ATmega1281 low power MCU	Web Interface	Study was carried within the Lab environment.
6	Pitarma et al. [29]	2016	Luminosity, CO_2, CO, RH and air temperature	WSN	ZigBee module	Arduino	Web portal	A dedicated web portal named as iAQ was designed using PHP to access system data
7	Benammar et al. [30]	2018	RH, ambient temperature, Cl_2, O_3, NO_2, SO_2, CO, CO_2	WSN	ZigBee Pro radio module	ATmega 1281 (Waspmote), Raspberry Pi2 for core gateway	Open-source IoT web server platform	–
8	Tiele et al. [31]	2018	Sound levels, illuminance, CO, CO_2, total VOCs, PM_{10}, $PM_{2.5}$, RH and temperature	WSN	I2C/UART	Feather M0	OLED Display, MicroSD Card	Made use of eNose for data collection, Custom low-cost sensor module was designed using Altium Designer
9	Ahn et al. [32]	2017	VOC, light quantity, RH, temperature, fine dust, CO_2	WSN	UART/I2C, ESP8266 Wi-Fi Module	ATmega328P	Linux Server	Comparative prediction models were designed using LSTM and GRU networks
10	Bhattacharya et al. [33]	2012	RH,temperature, gaseous pollutants and PM	WSN	ZigBee module	ATmega1281 (Waspmote)	HVAC control application, SMS and email-based alerts can be generated on subscription.	Context-Aware Framework was designed to connect sensors with applications.
11	Yu and Lin [34]	2015	CO_2, RH, temperature	WSN	ZigBee	Not available	Web Pages and Mobile App	ARIMA model for prediction is used with fuzzy Log-c to reduce energy consumption

The proposed smart system framework is shown below in figure 6 which consists various modules for processing and data storage server for data processing purposes. The framework shows that sensors are connected directly with cellular system for quick communication with the base station. The smart sensor

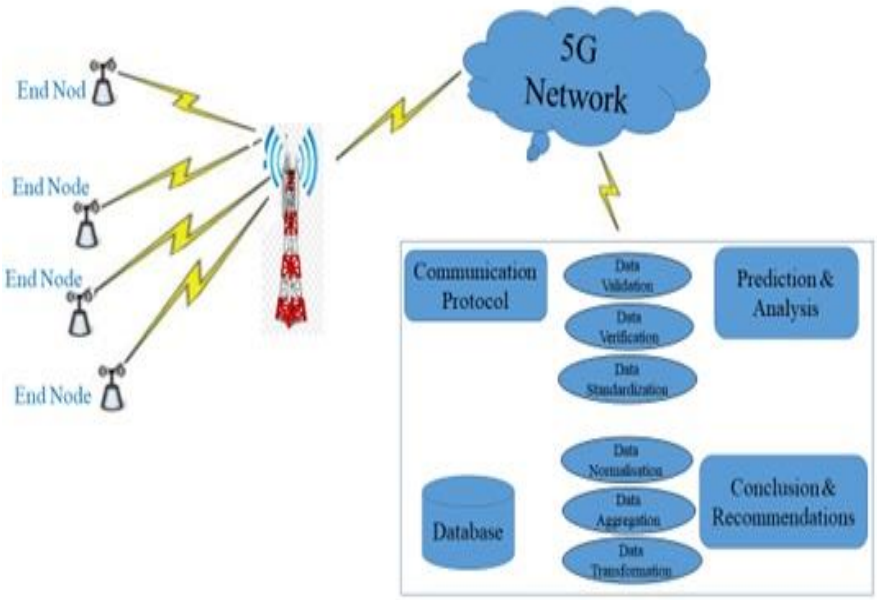

Figure 6: Framework to monitor air quality by using IoT.

system measures the phenomena from the surrounding environment and compute initially processing to reduce communication overhead. Processed information directly sent to base station by using IoT connectivity link for further analysis and to propose further actions to be taken by the environment monitoring agencies. The analysed data is saved with the time stamp for future use for research purposes and recommendations.

The figure 7 shows the flowchart of the control and processing layers, as sensor nodes sense the information from the environment and process it at the nodes to refine the data to reduce the transmission overheads. It shows the sensor nodes start measuring the information from the environment when there is any change, or any event happened. The processed data sent to the controller after processing for further processing and storage to take further actions.

The figure 8 below shows the working principle of the proposed system for the purpose of air quality monitoring and taking necessary actions based on the data analysis. After power on the sensors load the libraries on the sensor nodes for collecting the data and processing it to be send to controller. Then the system checks the connectivity with base station to transmit the processed data to the controller for further processing. Server receive the data to store on the server for visualization in real time for analysis.

The fundamental objective of air quality monitoring is to collect data that can be used to make informed decisions to manage and improve the environment. The main goal of the proposed system is to monitor the pollution in the smart cities which generated by various factors in the cities. The proposed algorithm is used to monitor the environment to control air pollution in the big cities. The developed framework is an integrated climate monitoring system for environment in smart cities that combines information gathered from sensors and other connected devices.

4 Discussion and critical analysis

In this paper a framework is proposed to monitor air pollution in big cities by using smart sensors along with IoT enabled devices. As, it is impossible to install hundred and thousands of sensors to monitor all the area of city to keep it live-able. Real time data will be collected by using the proposed system by installing various areas of the city which will selected by using the traffic information and other factors. The proposed system is capable to measure the humidity, carbon emission, temperature, smoke, sound and other hazardous particulate in the atmosphere and send the measurements to city central office where it is analysed for further actions for the betterment of city environment. Collected data is banked in a data bank for future use and can be shared with other research institute and environmental agencies.

The basic purpose of the proposed system is to collect real-time to monitor air pollution in the city environment and generate the alert messages for the agencies which are involving in this regard. The IoT based system for air pollution monitoring has great potential to ensure lesser power consumption during sensing and transmitting with minimum delays and better reliability in the real time monitoring. While proposing the system one of the major concerns is to reduce the development and installation cost by using the optimal number of sensors which will collect environment parameters from city environment. The proposed system is designed in view of installing in the industrial area, home, public places, and offices as well. In all cases the design requirement and demand is less power consumption, less cost and low power protocols.

In the literature review section several real time environment monitoring systems and their comparison is presented. The system and method presented in this paper is more practical solution to improve environment by continuing monitoring and acting against the collected

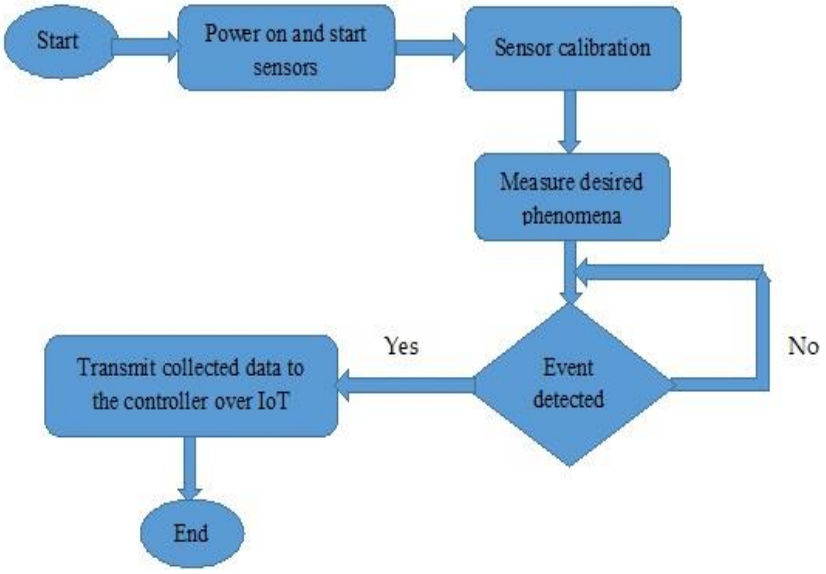

Figure 7: Flowchart of the control and processing layer.

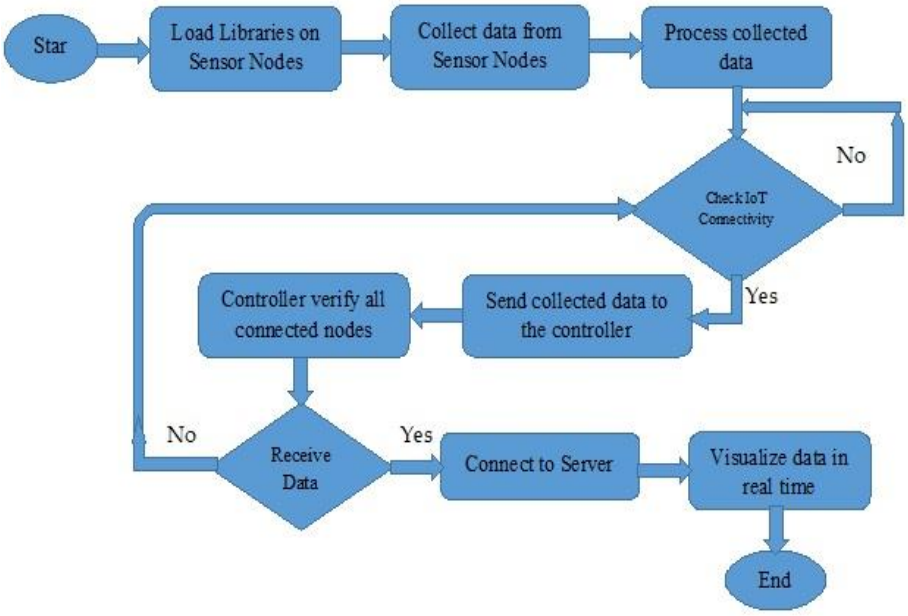

Figure 8: System Flowchart.

data. However few improvements in the proposed system may needed after real time implementation to improve performance and reliability of the proposed system.

5 Conclusion

Due to migration to the big cities from remote area for the betterment of life facilities and avail opportunities has increased significantly in last couple of decades. This migration increased the city's population rapidly as compared to the civic facilities in the cities. The increased in city's population put lot of pressure on the city's environment to remain live-able and healthier. One of the major additions is the road traffic which become the big contributor in air pollution and make the environment very unhealthy. In this research a framework is proposed for monitoring air pollution in the city environment and take actions according to collected data from sensor system. The proposed framework is capable to monitor measure the Humidity, Carbon emission, temperature, smoke, sound and other hazardous particulate in the atmosphere. In the future work the proposed framework will be tested by using the simulation and installing the number of sensor nodes in various area of the city to collect real time data. Based on the real time data, the working principle and finding will be presented in upcoming article.

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