Indian Journal of Science and Technology, *Vol 9(39), DOI: 10.17485/ijst/2016/v9i39/90414, October 2016*

ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

IoT Enabled Air Quality Monitoring System (AQMS) using Raspberry Pi

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Abstract

Background/Objectives: Air pollution due to vehicular and industrial emission has become menace to the living beings. Due to this menace both indoor and outdoor air quality monitoring in real time has become mandatory. **Methods/Statistical Analysis:** The evolution of Internet of Things (IoT) and Single Board Computers (SBC) has made real time remote monitoring as a ubiquitous process. Remote monitoring was facilitiated using classical motes in the past, which has some pitfalls like limited memory, processsing speed and complex programming strategies. This paper portrays the usage of SBC for integration of IoT with WSN for Air Quality Monitoring System (AQMS), where SBC are capable of performing even complex task with enhanced speed and reduced complexity. The integration of cloud services with SBC makes alerting process smart and realtime. **Findings:** With the review and realizing of immense literature in the field of WSN for air quality management, the design of sensor web node becomes essential. The evolution of SBC adds merit towards monitoring and measuring of the critical factors in centralized Air Quality Monitoring System (AQMS) in any plant. Sensor web node is proposed with commercial gas sensors for detecting the gases like CO, CO_2, NH_3 and NOx to monitor both indoor and outdoor air quality. The observed results are properly evaluated using ThingSpeak open source IoT platform. The integration of open source cloud services for SBC in this proposed prototype model confirms low cost, comfort, convenience and rapid prototyping for flexible AQMS. **Applications/Improvements:** This prototype can be easily adapted to any monitoring systems with minor changes and can be made scalable for tomorrow.

Keywords: AQMS, IoT, Raspberry Pi, SBC, ThingSpeak, WSN

1. Introduction

Environmental pollution due to various emissions are the fatal threat to the world. It has been reported recently from[1], that India is rapidly becoming vulnerable to air pollution. Even though there has been lot of restrictions by the government for various emissions, it requires a rapid monitoring system to take effective swift action. In this context, integration of WSN with gas sensors will provide effective solution to observe, monitor and control the diverse critical units in AQMS. Central pollution control board has been working on reducing the pollution level and ordained the methodology for monitoring the air quality index[1], but increase in the number of vehicles and huge number of industries in cities has led to the serious problem of air quality deterioration.

One of the main reason for global warming is carbon dioxide emission into the atmosphere. There are several traditional methods espoused for monitoring the emissions[2], 1. Fossil fuel estimation and accounting raw material consumption, 2. CO_2 flux measurement in air using IR radiation and 3. Development of wireless sensor node and deployment of Wireless Sensor Networks based on the coverage area and scalability issues. A WSN with 100 CO_2 sensing nodes was proposed in[3] where collection tree strategy is as routing protocol and G-GSTWH algorithm is used for optimal node placement. Monitoring of air pollution due to vehiclur emissions is proposed[4] which is a peer-to-peer and grid architecture with two layer network framework is used for processing and ultraviolet radiations are used for detecting the pollutant gases. A WSN for industrial automation[5] pollution monitoring

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and prevention is proposed in[6] where the authors constructed the network to extenuate the damages caused by air pollution with 24 sensors, 10 routers and 1control server. Air pollution monitoring with ubiquitous sensor networks is proposed in[7] where a waspmote is connected with different gas sensor in a board and the data acquired is published through google maps. Monitoring of vehicle gas emission is suggested in[8] where gas emitted by vehicle is monitored using radiography selective detection and remote sensing. The main importance of integrating WSN with IoT is discussed in[9]. In addition to this, the usage of Raspberry Pi as a sensor web node, as an Iot hardware its pros and cons is discussed in[10–13]. Also the requisite of ubiquitous computing and sensing is considered as detailed in[14].

Most of the early work in air pollution monitoring has been reported using sampling and analysis techniques. WSN based monitoring techniques were also reported, but the online remote and mobile monitoring and alerting process demands additional sophisticated infrastructure like an additional device gateway for collecting data from all nodes and requires additional memory for data analytics. But integration of IoT enabled centralised monitoring system will be more effective than existing methods. It provides realtime online monitoring and alerting facilities in addition to high memory and data base facilities. In this work a Raspberry Pi based centralised Air Quality Monitoring System has been designed and integrated with Internet of Things (IoT) gateway. Wi-Fi (IEEE 802.11 N) has been used for data communication between sensor node database, internet and cloud services. Remaining of the paper is organised as four different sections. Section 2 depicts the overall system architecture and Section 3 depicts the proposed hardware model. Section 4 dicusses the results obtained by implemting the sensor web node for online monitoring of air pollution and finaly Section 5 concludes the work with the advantages of sensor web nodes in montoring applications and future perspective.

2. Overall System Architecture

In this work, in lieu to generic sensor nodes/motes, sensor web nodes are designed using Raspberry Pi as processing unit, GrovePi+ electronic shields are used for interfacing sensors and Wi-Fi is used as transceiver for data communication between web node and server. A sensor web node is an independent node capable of connecting to the web server and cloud services without intermediate device gateway but with help of router/gateway. Each web node has a local MySQL database in it and also its capable of connecting and storing of data to the network database server. Each web node can act as a device gateway and also as a data base server for legacy WSN. The intended model stands distinct from generic AQMS as certain data processing are carried out on the cloud server. The main reason for including the cloud services is for execution of data management, data centric aggregation, decision making and data analytics services for the data from the multiple web node, which usually demands more resource and infrastructure for running at the node/cluster head level. Figure 1 describes the overall architecture of the proposed sensor web node. It includes a sensor web node built with Raspberry Pi single board computer, a network gateway or router through which node is connected to ThingSpeak cloud database and client devices for monitoring. The data from the cloud database can be accessed using any mobile devices or any other portable IP enabled hand held devices. The client or the users can monitor the real time data streams by logging to the public channel of the ThingSpeak cloud services. The admin can automate certain timely decision making methods for initiating reaction process.

3. Proposed Hardware Model and Work Flow

3.1 Why Raspberry Pi and ThingSpeak

Owing to the evolution of SBC in the recent trends[15] a miniature and low cost SBC called Raspberry Pi based on quad-core ARM Cortex-A7 cluster is selected as the principal hardware for web node. Table 1 and Table 2 shows the basic comparision of Raspberry Pi with generic sensor nodes and other SBC's available in commercial markret. A plug and play, easy to use type electronic shield called GrovePi+ is piled over Raspberry Pi. The GrovePi+ hardware shield consist of a controller with ADC and i2c support. The Raspberry Pi and GrovePi+ shield communicates using i2c interface. Multiple analog and digital sensors can be interfaced to Raspberry Pi via GrovePi+ shield. The i2c based sensor can be interfaced to GrovePi+ and Raspberry Pi can access directly to those sensors via these buses.

The grove sensors, grove DHT (for temperature and humidity), grove gas sensor modules like dust, MQ-5 (for smoke), MQ-7 (for CO) and MQ-135 (for CO_2) are interfaced to this shield for monitoring in our proposed

Table 1. Raspberry Pi comparison with other SBC's

Parameter	Raspberry Pi	Arduino	Intel Galileo	UDOO NEO	Beagle bone
Processor	Broadcom BCM2836 900Mhz quad core	ATMEGA8, ATMEGA1280	Intel Quark X1000 – 400MHz single core	Freescale i.MX 6SoloX 1GHz ARM Cortex-A9 with Cortex-M4	AM3359 1GHz ARM Cortex-A8
RAM	1GB	16 – 32 KB	512 Kb on-chip SRAM 256Mb DRAM	512MB or 1 GB(full)	512MB DDR3 RAM
POWER	10W	5W	15W	10W	15W
OS	Raspbian, Debian, Fedora, ARCH Linux ARM) and FreeBSD	N.A	Arduino Linux distribution for galileo. Windriver Rocket	Android Lollipop and Linux UDOObuntu2 (14.04 LTS)	Android, Debian, Angstrom, yacto, Fedora, Ubuntu
COST	$40	$30	$70	$65	$55

Table 2. Raspberry Pi comparison with traditional sensor nodes

Parameter	Raspberry Pi	MicaZ	TelosB	Iris
Processor	Broadcom BCM2836 900 Mhz quad core	ATMEGA128	TI MSP430	ATMEGA128
RAM	1 GB	4 KB	10 KB	8 KB
MEMORY	Up to 64 GB via SD card	128 KB	48 KB	128 KB
OS	Raspbian, Debian, Fedora and FreeBSD	TinyOS, Mote Runner	TinyOS, MantisOS	TinyOS, Mote Runner
PROGRAMMING	C, Cpp, Python, Java	C, NesC	C, NesC	C, NesC
COST	$40	$99	$99	$115

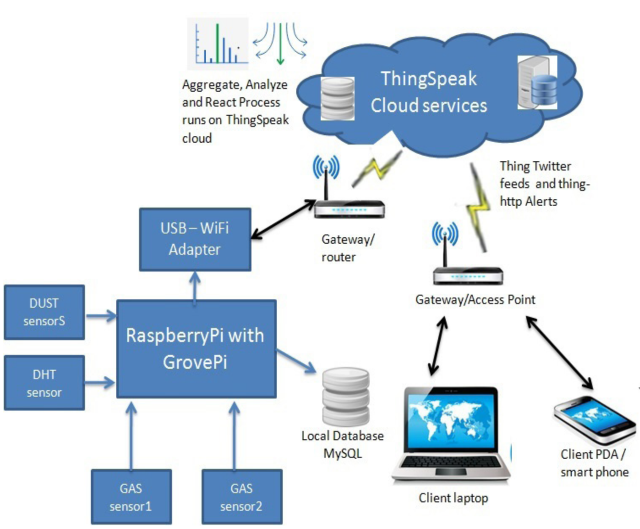

Figure 1. Overall system architecture.

system. Each sensor has various leves of concentration towards the correspoding gases at different temperature and relative humidity. The Raspberry Pi runs with the operating system called as Raspbian, on which the necessary libraries are included and the drivers are developed for accessing the sensors. The drivers and the application scripts are developed using the PYTHON, which is a multi paradigm programming language that helps in rapid development and integration of the application with the systems. An open source cloud IoT platform called ThingSpeak is used as a cloud services for sensor webnode. Apart from remote data monitoring, the ThingSpeak cloud services also provides facilities for running aggregation, decision making and data analytics services. The ThingSpeak platform also offers other services like data visualizations with MATLAB support, alerts, scheduling and device communication. In our proposed model the data from multiple sensor web nodes are uploaded to the desired channels created for corresponding nodes. The channels are set to private or public view depending upon the requirement and austereness of the data for analytics, alert and reaction.

3.2 Raspberry Pi integration with ThingSpeak

An user account has to be created in the https://thingspeak.com/ and there by the required channels are created for monitoring and analysis. The necessary python API's are called and libraries are imported for uploding the sensor data to the cloud inside the application software on the Raspberry Pi. To get a clear location information for remote monitoring client, the latitude and longitude parameters of each node are enabled at corresponding node's channel settings. For external and offline analytics the data can be imported from the ThingSpeak database as CSV or Jason or PHP format. Clients at the remote place with an internet connection can log in into the thingspeak.com and can view all the data's of the different nodes. The same data is plotted in a graph with respective x and y axis parameters settings for each channel. Figure 2 shows the hardware implementation where the Raspberry Pi is connected with grove sensors and Wi-Fi adapters.

3.3 Data Analytics and Alert Generation

A MATLAB code is developed for the purpose of data analytics on the ThingSpeak cloud server and made to run periodically. The results of the analytics are colligated to a reaction called generating alert message. The alert

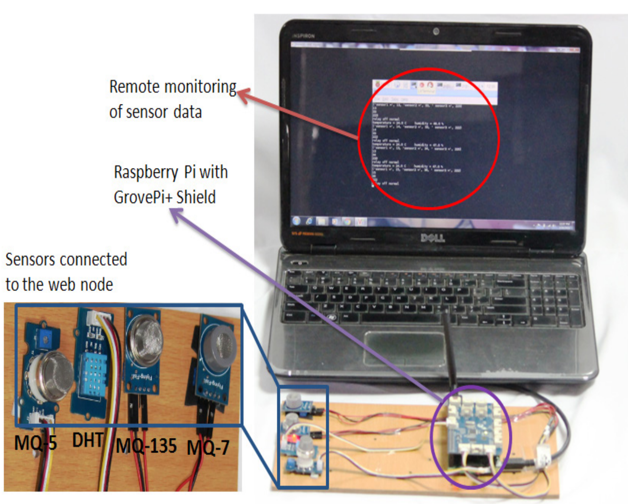

Figure 2. Proposed hardware implementation - Raspberry Pi based sensor web node and monitoring station.

messages are sent to the TWITTER account liked to the ThingSpeak server, so that the process is made smart and to meet realtime constraints.

4. Results and Discussions

The designed sensor node was deployed for monitoring the environmental air quality of both indoor and outdoor environment. Obtained sensor data's from each node are archived in the corresponding local database and ThingSpeak cloud database. Figure 3 shows the screen shot on the ThingSpeak cloud channel creation. The local database is for remote monitoring, future retrieving and trend analysis. ThingSpeak cloud services is used for storing the data in the online cloud database mainly for running analytics services. Private and public view for the channel are configured in this cloud service.

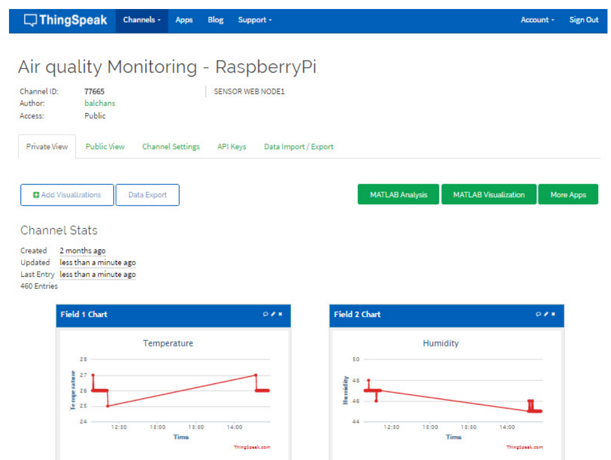

Figure 3. ThingSpeak channel creation for node 1.

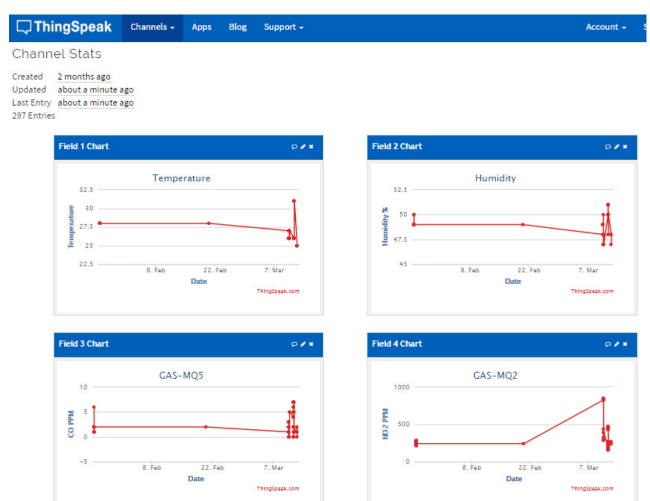

Figure 4. Data collection on ThingSpeak web interface from node 2 with data graph.

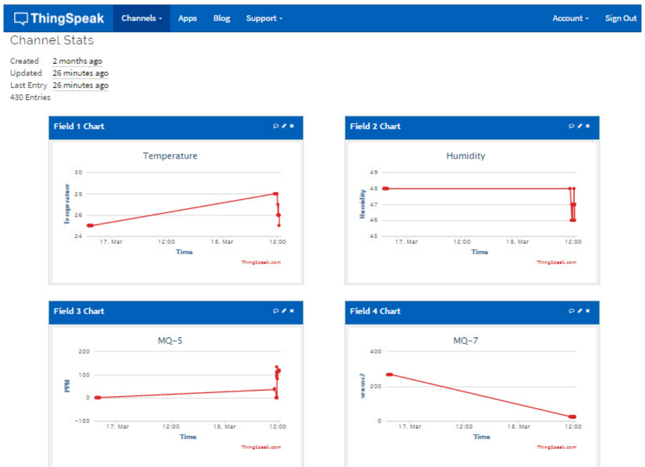

Figure 5. Data collection on ThingSpeak web interface from node 3 with data graph.

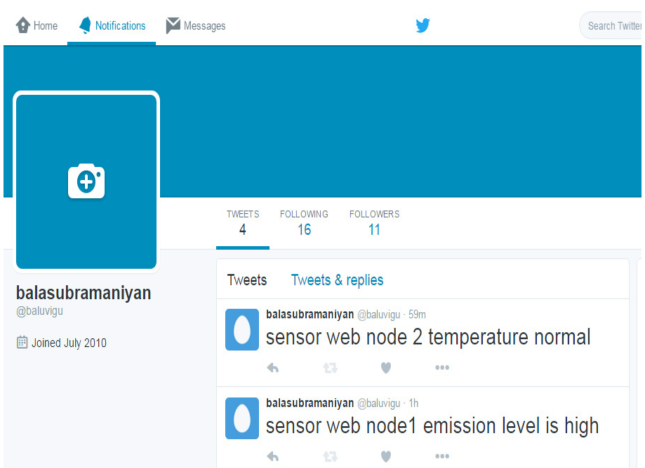

Figure 6. Twitter update for node1 and 2 status

The node has been deployed in four different locations and the measured data's are stored in the database. Figure 4 and Figure 5 shows a screenshot of web interface and data from node 2 and node 3 in the sensor network. The data processing like plotting of data in graphs and analytics using MATLAB are carried out on the cloud database, so that the processing load on the sensor node is substantially reduced which makes the sensor node to maintain optimum power consumption. The data updated to the corresponding channels were analysed in the realtime using MATLAB. Based on the results of MATLAB analysis, the alert messages are published to the TWITTER account linked corresponding channel. Figure 6 shows the screen shot of twitter update with the alert messages for sensor web node 1 and 2. The complete application on Raspberry Pi is made to run at background periodically and it is automatically initiated after the boot process. Another script is made to run to check the network connectivity and re-establish the network connectivity for the deployed nodes.

5. Conclusion

Integration of WSN with IoT has made WSN as an invaluable resource to IoT as enounced in[9,14]. It can be concluded that the contrived Air Quality Monitoring System renders an efficacious integration between WSN and IoT, as a result a staple goal of remote monitoring the air quality in the specific area of interest has been attained and the same has become more user oriented. In this work the conventional application protocol "HTTP" is used for sending and receiving of data and the number of nodes is limited to four. The foci of the future work is on building module for calculating the air quality index as said in[1,16] with the data aggregated from multiple sensor web nodes. Also to establishing the connectivity using IoT specific protocols like MQTT or COAP and also to increase number of node deployments so as to have broad coverage area.

6. Acknowledgment

The authors wish to express their sincere thanks to the Department of Science and Technology, New Delhi, India (Project ID: SR/FST/ETI-371/2014). The authors also thank SASTRA University, Thanjavur, India for extending the infrastructural support to carry out this work. The authors also expressed their gratitude to Ms. Chanthini B, Research Scholar, School of Computing, SASTRA University for her consistent support throughout the project phase.

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