A Cloud Integrated RFID based System for Vehicular Pollution Monitoring

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ABSTRACT

Internet of Things (IoT) aims to connect billions of smart devices to the internet. This promises many new applications for sustainable and smart cities. Vehicular pollution tracking and control is a challenge in modern cities. In the previous works, researchers have proposed various network based solutions for monitoring of air quality in cities. However, majority of these works do not include vehicular pollution monitoring. There is a need for a quick, reliable, low cost system for vehicular pollution tracking. In this regard, Internet of Things (IoT) integrated Radio Frequency Identification (RFID) is a promising solution for vehicular pollution tracking and control. This paper presents a novel and cost-effective RFID based three stage intelligent communication system for tracking and notification of vehicles causing pollution. The system has an RFID based smart sensor node equipped with carbon monoxide and methane gas sensors. The sensor data is written in RFID tag by Arduino Uno controlled RFID writer. RC522 RFID reader/ writer module used in this work is low cost and supports quick (848 kbaud data transfer speed) and secure data transmission. A raspberry pi microcomputer is programmed as exhaust monitoring and data forwarding gateway node. It reads the unique sensor node RFID tag via the attached RFID reader. The sensor information received by the gateway node is communicated via WiFi to thingSpeak server for each vehicle. The thingSpeak server stores and displays the information and sends automatic twitter notification to the vehicle owner's account. The rules for notification can easily be configured at the remote server as per needs. By integrating RFID based vehicular pollution monitoring system with social networking platform twitter, we increase the chances for effective persuasive influence and control for vehicular pollution. To date, this unique and synergistic combination of cloud and twitter integrated RFID based vehicular pollution monitoring and control has not been proposed. The system was successfully tested and found to be an effective, convenient and economical solution for improved vehicular pollution monitoring. The low cost of the developed RFID based sensor nodes make the deployment of the system on a large scale feasible, particularly for developing countries.

Keywords

Radio Frequency Identification (RFID), Internet of Things, WiFi, cloud, ThingSpeak, Twitter, vehicle pollution, sensors, Arduino uno.

1. INTRODUCTION

Internet of Things(IoT) aims to connect billions of smart devices to the internet. This promises many new applications for sustainable and smart cities [1]. Over the next decade, IoT will encompass networks of smart devices that can monitor and regulate traffic [2], aid waste management in smart cities [3], and also enable smart healthcare[4, 5], smart grids and power distribution[6]. The emerging Internet of Things (IoT) based systems for smart farming also hold the promise of significantly improving crop production and reducing crop damage[7]. Air pollution is also a major concern in cities throughout the world. A major contributor to air pollution in cities is road transportation. Vehicle exhaust contain toxic gases such as methane (CH_4), ethylene (C_2H_4), oxides of nitrogen (NO_x), carbon monoxide (CO), particulate matter (PM) in significant amount. Emissions from a large number of inefficient and poorly maintained vehicles, in high traffic density deteriorate air quality index substantially. Exposure to these gases and particulate matter cause severe respiratory diseases such as asthma, pneumonia etc. [8]. Technologies such as Internet of Things, Cloud computing and Intelligent Fog can together help to implement an efficient network for vehicular pollution tracking and control.

Mobile air pollution sensing and crowdsourced air pollution sensing are areas of growing research interest in recent years [9]. In [10], Khiat et al. present a study on Internet of Things (IoT) and connected objects importance in daily lives and use of Crowdsourcing based on Connected Objects for measurement of pollution. In [11], Liu et al. proposed a novel system Third-Eye. The proposed system uses crowdsourced photos from people's smartphones to infer PM2.5 levels in the city environment using deep learning techniques on cloud. In [12], Narayanan et al. developed a GPS enabled system based on ESP8266 module to monitor air quality and send the data to a centralized server for identifying pollution free driving routes. In [13], Sampson et al. proposed a GSM based smart system that automatically sends alert to regional transportation office when a vehicle pollution exceeds the limit. In [14], Adarsh et al. proposed a WiFi enabled cloud integrated system for monitoring the concentrations of sulphur dioxide in automobile exhaust. In [15], Bhoi et al. present an implementation of urban vehicular ad hoc network prototype to monitor CO_2 levels and localize high CO_2 zones in the city. In [16], Rahi et al. have proposed a smart system for air quality monitoring. The proposed system uses meta-heuristic firefly optimization algorithm for selection of features to predict air quality index level using support vector machine. Majority of the above literature have proposed wireless network based solutions for monitoring of air quality in cities.

Radio Frequency Identification (RFID) is an information and communication technology commonly used in tracking and localisation applications in several industries. RFID based sensing and tracking systems for various applications is an emerging area of research. In the works mentioned below, RFID is used primarily for vehicle identification for pollution check. In [17], Leelaram et al. proposed a system where zigbee based sensor node installed at the vehicle exhaust send the exhaust content to a gateway node. The gateway node receives the data and uniquely identifies the vehicle via the RFID tag attached to it. The gateway node combines the sensor data and the vehicle tag ID and sends to the central hub via GPRS. In [18], Manna et al. , proposed a similar system where zigbee sensor nodes, composed of gas sensors and microcontroller, are placed on the roadside. These nodes gather sensor data continuously. Whenever the sensor nodes sense abrupt rise in pollution, the RFID readers attached to the sensor node uniquely identifies the vehicle tag ID and send the information via GPRS to the server. It is to be noted that in both of the above papers, RFID is used only for vehicle identification and not for communicating the sensor data. This makes both of the above systems redundantly complex and costly, requiring a separate RFID reader and zigbee base station node. In [19], Vong et al. developed a system that loaded the measured sensor data on RFID tag via an analog to digital convertor. The data is read with the help of an RFID reader and sent to a central hub via 3G connection. If vehicle crosses the limit, the owner is notified via e-mail or text message. A limitation of the above system is that the use of analog to digital convertor to write sensor readings on the tag is slow, cumbersome to debug and extension and augmentation of device functionalities is also not easy.

The system proposed in this research paper attempts to overcome some of the limitations of the above mentioned works. In this regard, the use of microcontroller controlled programmable RFID tags is a promising solution for vehicular pollution tracking and control and has not been explored, so far in literature. The low cost, reduced power consumption and easy integration with sensors make RFID technology suitable for vehicular pollution tracking. This paper presents a novel and cost-effective RFID based three stage intelligent communication system for tracking and notification of the vehicles causing pollution. The system has an RFID based smart sensor node equipped with carbon monoxide and methane gas sensors. The sensor data is written in RFID tag by Arduino Uno controlled RFID writer. RFID reader/ writer module RC522 used in this work is low cost and supports quick (848 kbaud data transfer speed) and secure data transmission. RFID data is CRC encoded. A raspberry pi microcomputer is programmed as exhaust monitoring and data forwarding gateway node. It reads the unique ID and sensor values written on RFID tag via the attached RFID reader. The sensor information received by the gateway node is communicated via WiFi to thingSpeak server for each vehicle. The thingSpeak server stores and displays the information and sends automatic twitter notification to the vehicle owner's account. The rules for notification can easily be configured at the remote server as per needs. By integrating RFID based vehicular pollution monitoring system with social networking platform twitter, we increase the chances for effective persuasive influence for vehicular pollution control. To date, this unique and synergistic combination of cloud and twitter integrated RFID based vehicular pollution tracking and notification has not been proposed. The system was successfully tested and found to be an effective, convenient and economical solution for improved vehicular pollution monitoring. The low cost of the developed RFID based sensor nodes make the deployment of the system on a large scale feasible, particularly for developing countries.

This paper presents the design and implementation of a prototype of the above three stage intelligent communication system. This paper also describes the successful testing of the implemented network prototype. The system is found to be economical and convenient for large scale deployment. The paper is organized as follows: Section II describes the architecture of the proposed system and the hardware and software implementation of the system. Section III presents the experimental results and Section IV presents the conclusions.

2. THE PROPOSED SYSTEM

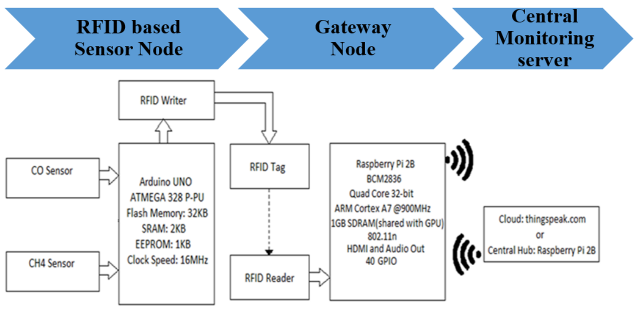

Fig. 1. Architecture of cloud integrated RFID based system for vehicular pollution monitoring.

The architecture of the cloud integrated RFID based system for vehicular pollution monitoring is shown in Fig1. The proposed system has three main stages- RFID based Sensor Node, Gateway Node and WiFi enabled Central Monitoring Server.

RFID based Sensor Node is located at the exhaust of each vehicle. It comprises gas sensors that measure the volumetric gas concentrations in the vehicle exhaust, a microcontroller that samples and processes the sensed data, a microcontroller driven RFID writer that periodically updates the sensed data on the vehicle RFID tag.

The Gateway Node is a microcomputer at the traffic monitoring booth that reads each vehicle RFID tag number and the sensor data written on the sensor node tag via the RFID writer module connected to it. It also stores, displays and forwards the received data provided by the wireless sensor nodes to the thingSpeak server via WiFi.

WiFi enabled central monitoring server receives, stores, displays and analyzes live data from the sensor nodes via the Gateway node. It is used to generate/ send twitter notifications to the vehicle owner when the exhaust levels breach the emissions standards.

2.1 RFID based Sensor Node

The RFID based sensor node is developed using an Arduino Uno microcontroller based on ATmega328 chip. The main considerations when choosing the microcontroller for the prototype were ease of use, low cost and ability to handle the system requirements. Moreover, Arduino Uno has 14 general-purpose input-output (GPIO) pins, suitable to our requirement of interfacing two sensors and an RFID writer in the module. Arduino Uno requires a power supply of 7V-12V. It operates at frequency of 16 MHz. It has 32 KB flash memory, 2 KB SRAM memory, USB Device interface, SPI interface, I2C-bus interfaces, UART serial ports, 14 digital input-output pins, 6 PWM pins and 6 analog input pins [20].

For measurement of gases like methane and carbon monoxide present in exhaust fumes, conducting polymer, electrochemical and metal oxide semiconductor based sensors are available commercially. Conducting polymer based gas sensors show good sensitivity, but low selectivity and are prone to erroneous measurement in humidit environment. Electrochemical sensors measure the varying current through a reagent as the reagent reacts with a gas. Electrochemical sensors for gases show high sensitivity as well as accuracy. However, their performance depends highly on temperature. Also, environmental conditions have a strong influence on the sensors operation and lifetime. Metal oxide semiconductor (MOS) based sensors are essentially MOSFETs with a catalyst coated gate. The catalyst interacts with the gases resulting in a change of the gate charge and channel conductivity. MOS based gas sensors are low cost, portable and ripe technology with quick response and long term stability without requiring maintenance. In the proposed system, we have used low cost MOS based sensors, MQ4 and MQ7 for methane and carbon monoxide concentration measurement, from Hanwei Electronics Co. Ltd. The main advantage of these sensors are portability, easy use, low power operation, robustness and good accuracy. With temperatures reaching up to 600-700 degree Celsius in exhaust of vehicle, sensors with very high temperature tolerance are required. Available sensors with high temperature tolerance (in terms of both electrical and physical characteristics), are usually very expensive. The issue of high temperature in the developed prototype is solved to a large extent simply by placing the sensors at the vehicle exhaust. MQ4 estimates the methane content by measuring the variation in surface resistance of gas sensitive tin dioxide(SnO_2) layer of the sensor. The change in surface resistance is measured as a change in voltage signal across the resistor. The measuring range of MQ4 sensor is 20ppm-2000ppm. The sensor has good sensitivity and stable operation [21]. MQ7 carbon monoxide sensor also uses the gas sensitive tin dioxide(SnO2) layer. As the concentration of carbon monoxide increase, the conductivity of gas sensitive layer also increase. The change of conductivity is converted to corresponding output signal of gas concentration via a simple circuit. MQ-7 has 6 pins, out of which 4 pins are used to fetch signals, and 2 pins are used for providing heating current. The measuring range of the MQ7 methane gas sensor is 300ppm to 10000 ppm. The outputs of MQ4 and MQ7 sensors being analog signals are read via analog input ports of the microcontroller [22].

The sensor node microcontroller is also connected to a Mifare 13.56 MHz MFRC522-ED RFID writer module which writes the sampled sensor data in RFID tag's storage space wirelessly via RFID inductive coupling using its modulated RF field [23]. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE and NTAG standards. The internal transmitter of MFRC522 is able to drive a reader/writer antenna to communicate with ISO/IEC 14443 A/MIFARE cards and transponders without additional active circuitry. The receiver module of MFRC522-ED provides a robust and efficient implementation for demodulating and decoding signals from ISO/IEC 14443 A/MIFARE compatible cards and transponders. The digital module also manages the complete ISO/IEC 14443 A framing and error detection (parity and CRC functionality). The MFRC522 supports data transfer speeds up to 848 kBaud in both directions. Besides, it is easily interfaced to Arduino via serial peripheral interface pins requiring minimal wiring, and a simple library. Arduino Uno initiates a card write through an interrupt request (IRQ) to the RFID writer which requires an additional digital pin to connect. The RFID reader writer module draws its power from the Arduino Uno through the 5 volt power supply and ground. Although the range of this reader writer module is limited to few centimeters, it can be extended to 2.5m using a suitable reader. Implementation of the concept for longer ranges can be done using 860 MHz to 960 MHz range RFID systems. The RFID tag used in the prototype is a low cost Mifare 13.56 MHz passive RFID tag (M841) with a 1KB writable memory sufficient for our application [23]. Passive RFID tags are more cost-effective compared with active tags. The developed RFID based sensor node schematics comprising microcontroller, sensors, RFID writer and RFID tag is shown in Fig. 2.

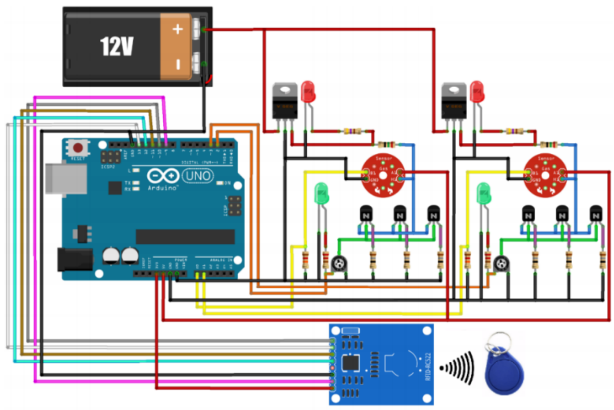

Fig. 2. RFID based sensor node schematics: Arduino uno, MQ4, MQ7 sensors, RFID writer, RFID tag.

The functions of the sensor node include periodic sampling of sensor values indicating exhaust content, sampled data processing and writing on RFID tags via the RFID writer.These functions were implemented by a program in embedded C language, uploaded on the microcontroller using the Arduino IDE (Integrated Development Environment). When the sensor node is powered on, the program automatically starts and follows the logic in the flowchart indicated in Fig. 3.

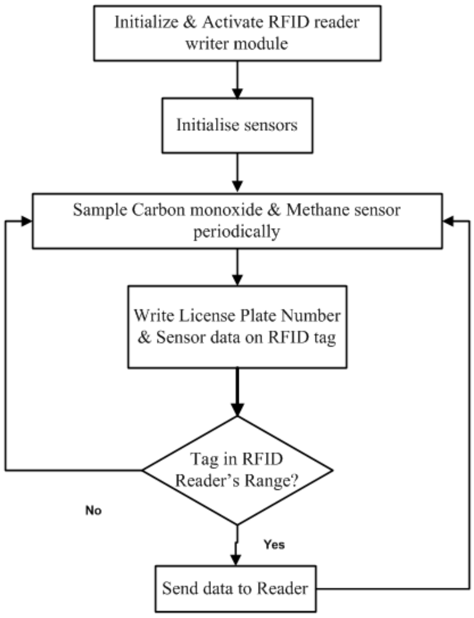

Fig. 3. RFID based sensor node program flow.

2.2 Gateway Node

For the prototype developed in this work, a low power credit-card-sized single-board computer Raspberry Pi 2B is used as gateway node for monitoring, notification and communication to the cloud server. Raspberry Pi 2B was selected for the prototype development as it enabled easier interfacing with LCD display and RFID reader module compared to other microcomputers available, has apt processor speed, capacity, convenient size and weight for the application. It also supports easy data logging and data accessibility. The CPU on the board is a quad-core Cortex-A7 processor with 900 MHz clock speed and 1 GB RAM. The GPU on the board is a Videocore IV 250 MHz unit. It has a variety of interfacing peripherals, including a USB port, HDMI port, 512MB RAM, SD Card storage and 8 GPIO ports. Monitor, keyboard, and mouse can be connected to Raspberry Pi through HDMI and USB connectors and used as a computer. It supports various operating systems including a Debian-based Linux distro, Raspbian, Ubuntu Mate and Windows 10. It supports programming languages as C/C++, Python and Java. Raspberry Pi can also be connected to a local area network through Ethernet cable or USB Wi-Fi adapter [24].

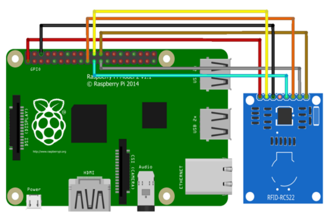

Fig. 4. Gateway Node Schematic: Raspberry Pi micocomputer, RFID reader.

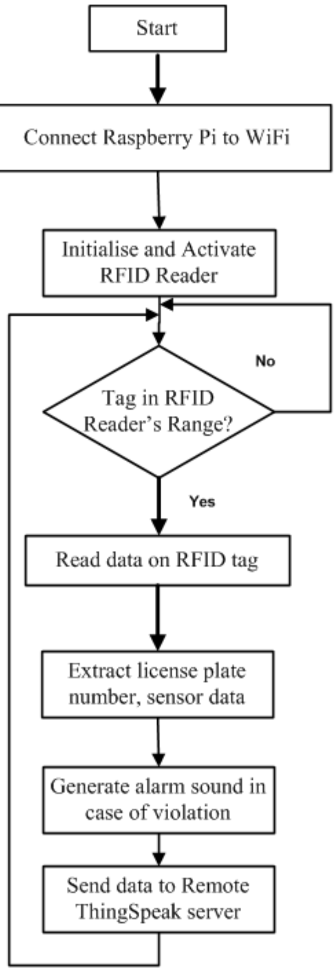

Fig. 5. Gateway node program flow.

A Mifare 13.56 MHz MFRC522-ED RFID reader is interfaced to raspberry pi through Serial Peripheral Interface pins. It reads the sensor data from RFID tag's storage space wirelessly via inductive coupling and communicate to raspberry pi. Radio frequency identification reader sends a series of inductive pulses. These pulses cause a loop of wire within the tag to power an integrated circuit chip within the tag. The tag responds with a modulated RF signal back to the reader. RFID module communicates with host using either Inter-Integrated Circuit(I2C) or Serial Peripheral Interface(SPI) protocols. In this work, SPI is chosen as the communication protocol between RFID module and raspberry pi. The connection schematic of the gateway node comprising RFID reader and raspberry pi microcomputer is given in Fig. 4. The functions of the gateway node include detecting the presence of RFID tag using MFRC522-ED RFID reader, reading the stored data on the selected tag using RFID reader and displaying and generating buzzer alarm of various levels (high, medium, low etc.) in case of a breach. The functions were implemented by a program in python language and uploaded on raspberry pi. The program follows the logic shown in flowchart in Fig. 5.

2.3 WiFi enabled Central Monitoring Server

ThingSpeak is an Internet of Things analytics platform that enables real time data collection, visualization and analysis. It also supports online analysis and processing of the data in MATLAB. ThingSpeak provides various features such as listening to Twitterverse for specific keywords, use ThingHTTP to connect to other web service or execute an action, send a tweet or trigger a ThingHTTP when channel data satisfy certain conditions etc.[25]. In this work, ThingSpeak cloud channel is configured to receive and display data from the RFID based sensor nodes via Raspberry pi gateway node and generate a tweet on the vehicle owner's twitter account when received sensor data breach the emission standards.

3. SYSTEM WORKING AND RESULTS

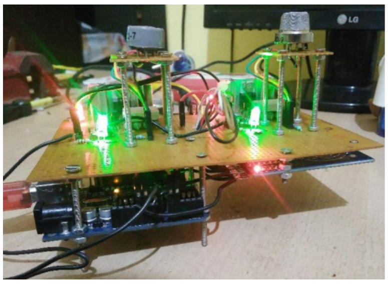

Fig. 6. Testing of the Implemented System Prototype: RFID based sensor node.

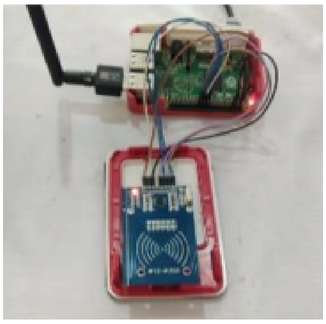

Fig. 7. Testing of the Implemented System Prototype: gateway node.

The system developed in this work was tested for monitoring of vehicular exhaust as shown in Fig. 6 and Fig. 7. Sensor node periodically samples the carbon monoxide and methane measurements and write on the RFID tag via RC-522 RFID reader/writer module. The data is written in tag's sector 1 block 4. First 10 bytes hold the license plate number and last two bytes hold sensor measurements. RFID card when brought in the range of the reader interfaced to raspberry pi, transmits all data written in sector 1. The sample sensor data comprising carbon monoxide and methane content of the exhaust along with vehicle registration number and unique tag ID written on RFID tag of the vehicle sensor node received and displayed by the raspberry pi based monitoring station is shown in Fig. 8. The Raspberry Pi gateway node further processes the received data and generate alarm sound in case of a breach and also

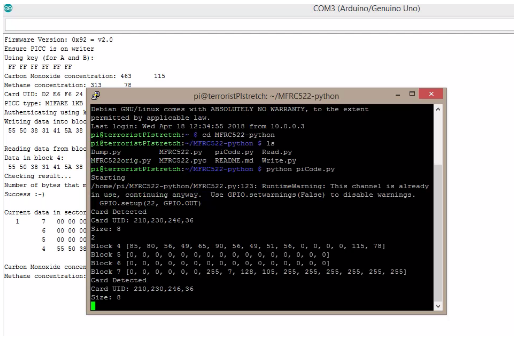

Fig. 8. Received data on Raspberry Pi gateway node.

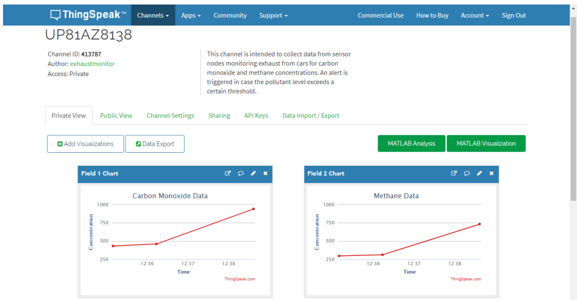

Fig. 9. Received data on WiFi enabled Central Monitoring Server.

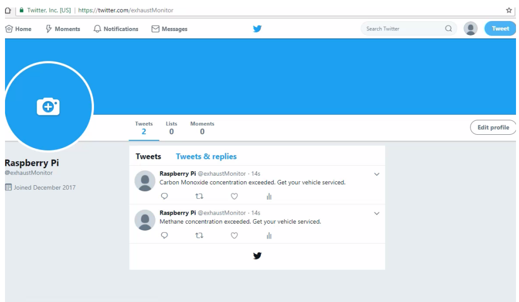

Fig. 10. Received twitter notification by vehicle owner when poor emission.

forwards the data to the remotely located ThingSpeak central monitoring server via WiFi. Fig. 9 shows the received data on ThingSpeak channel in real-time on internet conneceted central monitor. ThingSpeak allows multiple channels at a time. In this system, each channel stores the data of a different vehicle and is named after license plate number. Each channel can support eight fields. Out of the eight fields, we used two fields to store and analyze MQ4 and MQ7 sensor data. The ThingSpeak channel apart from saving and displaying the data, also sends an automatic tweet (message) to vehicle owner twitter account in case of a breach in exhaust content as shown in Fig. 10. By integrating RFID based vehicular pollution monitoring system with cloud platform ThingSpeak and social networking platform twitter, we aim to increase the chances of effective interventions and behavior alterations for vehicular pollution control. This synergistic combination can be a powerfully persuasive tool to improve the efficacy of the system for vehicular pollution tracking and control.

4. CONCLUSIONS

Several recent statistics have highlighted that vehicular pollution is an issue of concern, particularly in developing countries. This paper reviewed the limitations of existing air pollution and vehicular pollution monitoring systems and promising technologies that could enable improved vehicular pollution tracking. This paper has presented details of a successful implementation of a novel cloud integrated RFID based system for vehicular pollution tracking as a solution to identified limitations in existing systems. The system is integrated to a remote cloud server and twitter social networking platform via a gateway node for vehicular pollution monitoring and notification. This system monitors and analyses the sensor data variations and hence makes inference whether the emitted carbon monoxide and methane gas concentrations are crossing the allowed levels. More importantly, this system also sends automated notification on social networking platform twitter when the measured exhaust content lie outside desirable range. The use of wireless system speeds up the process of vehicular inspection, besides being reliable and secure. A major benefit of the proposed system is its affordability. The low cost of the developed RFID based sensor nodes make the deployment of the system on a large scale feasible, particularly for developing countries with dense and massive population. More importantly, the 13.56 MHz RFID tags used in the sensor node can also be read with NFC capable smartphones programmed with suitable apps. With more than 500 million NFC capable smartphone sold and used worldwide, this will minimize drastically the costs incurred for exhaust monitoring stations. Besides, the system also aids the authorities to easily track vehicles with a poor record and quickly manage fine imposition. The proposed system is also useful to the vehicle owner as it can give early warnings for engine maintenance, thereby minimizing fuel consumption and reducing air pollution. The system is easily scalable from local monitoring and tracking at an intersection to city level and national level tracking of vehicle record via integration of available WiFi and cloud services. RFID coupled with WiFi/ Internet is hence a promising wireless communication technology for vehicle pollution tracking for a massive traffic. It may be noted that large scale adoption of such integrated intelligent communication systems can considerably improve vehicular pollution and can also be powerfully persuasive due to integration with social network.

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