Design and Evaluation of USN-Based Environmental Air Pollution Monitoring System in Subway Systems

Jongwon Kwon1, and Hiesik Kim1*
1 Department of Electrical Computer Engineering, University of Seoul, Seoul, 130-743, Korea
drhskim@uos.ac.kr

Abstract: Environmental Air Pollution Monitoring System (EAPMS) is an application for monitoring environmental phenomena. In this paper, EAPMS was developed using wireless sensor networks technology for subway systems in Smart City. Recently, government agencies of many countries use portable instruments or the large high-priced instruments to measure air pollution at designated areas. However traditional EAPMS has many constraints to cover the large-scale location. The paper includes how to interface environment sensors, how to design Smart Sensor H/W, S/W (TinyOS2.0-based), and how to implement a routing protocol toward seamless communication with considering practical situations in underground subway systems. This paper might lead the digital convergence age through continual researches and development of innovative core technologies for Smart City.
Jongwon Kwon, and Hiesik Kim. **Design and Evaluation of USN-Based Environmental Air Pollution Monitoring System in Subway Systems**. *Life Sci J* 2013;10(3):1005-1011] (ISSN:1097-8135). http://www.lifesciencesite.com. 146

Keywords: Ubiquitous Sensor Network (USN), Air Pollution, Monitoring System, Smart City, Subway System.

1. INTRODUCTION

Smart City is a research and development project initiated by the Korean government based on advanced ICT infrastructures. The project's major objective is that various types of computers, sensors and information systems are built into a city. Therefore Smart City can provide better life and enormous opportunities to citizens with various ubiquitous services. They can also seamlessly enjoy high-quality converged services at anytime and anywhere.

To achieve the ultimate goal, this paper focuses on the Environmental Air Pollution Monitoring System (EAPMS) for subway systems in Smart City. The city's extensive subway system made it easy for people to get about [1]. So the subway system is regarded as the major transportation method as well as typical multiple-use facilities. Many researches about indoor air quality including PM10, PM2.5, VOCs, and CO2 in subway systems throughout the world pointed out the seriousness of environment air pollution on the ticket floor, on the platforms, and onboard of trains in the subways[2,3,10]. Especially, the underground portion of the subway system is a confined space that may permit the concentration of contaminants either from the outside atmosphere or generated internally. It is well known that some of these chemical pollutants have increased the occurrence of diseases such as lung cancer, pneumonia, asthma, chronic bronchitis, coronary artery disease, and chronic pulmonary diseases [2,10].

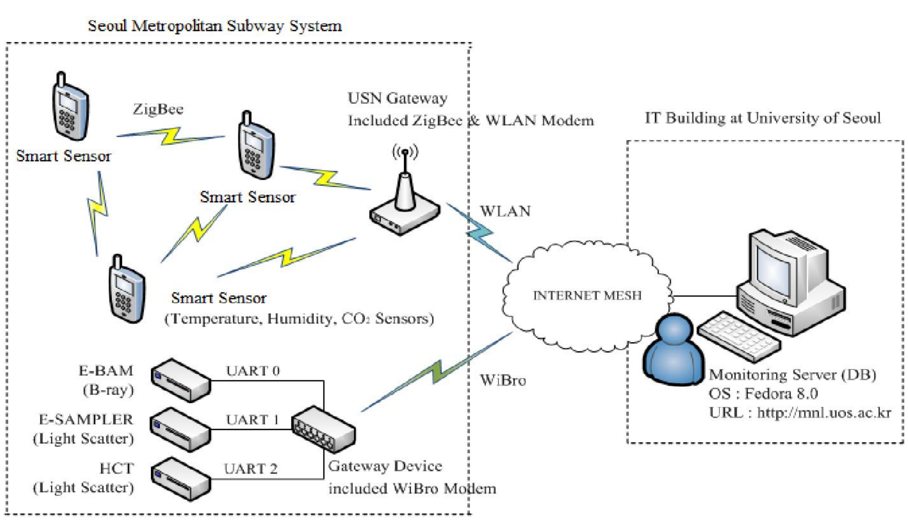


Fig. 1 EAPMS System Configuration

To work out the problems, Korea Ministry of Environment, the Ministry of Labor, and the subway corporations have jointly made an effort launching '5-Year Subway Station Air Quality' campaign, involving a massive 1.7 trillion won investment[10]. But traditional EAPMS [1,2,310] has many constraints to cover the large scale location. In this paper, we developed the optimized EAPMS using wireless sensor networks technology in subway system. The EAPMS monitors and visualizes the concentrations of major pollutant gases aggregated from a large number of Smart Sensors in real time. The Smart Sensors are experimentally deployed either inside the phenomenon. The position of Smart Sensors needs to be engineered or predetermined by ICT experts. Then the levels of CO_2, PM_{10}, temperature and humidity were continuously measured on the platforms in a subway station operated in the Seoul metropolitan area. The pilot project attests its excellence. The EAPMS helps managers working in subway stations through improving air quality and provides clean subway system environments. Figure 1 describes the system configuration of proposed EAPMS.

2. IMPLEMENTATION OF EAPMS

The EAPMS consists of three parts: Smart Sensor, known as a sensor node, a USN gateway, known as a sink node, and Monitoring Server (DB). In this chapter 2, we describe how to develop EAPMS. We obviously focus on compact size, low-cost and reliability to meet remote monitoring application's requirements [4,5,6,8].

The Smart Sensor consists of sensing, data processing, and communicating components. Figure 2, and 3 respectively illustrates Smart Sensor prototype and its block diagram. First, Smart Sensor elementally employs two sensors. One is a NDIR-based CO2 sensor. The sensor has more advanced technologies in terms of long-term stability, accuracy, and power consumption rate during measuring CO2 concentration, since the NDIR method uses the physical sensing principle such as gas absorption at a particular wave length [11]. Hence, NDIR-based CO2 sensors are the most widely applied for the real-time monitoring applications to measure CO2 concentration. Another is a single chip sensor SHT11. The sensor was designed by CMOS technology to measure temperature and humidity concurrently. This SHT11 is a multi-sensor module that can ensure high reliability and excellent long-term stability because it provides superior signal quality and a fast response time [6].

Second, the choice of suitable MCU for Smart Sensor is the most important, since it must reduce the consumption of energy efficiently. So Smart Sensor uses 8-bit RISC core–based ATmega 128L for data processing. The MCU was designed to reduce power consumption by controlling sleep/active modes.

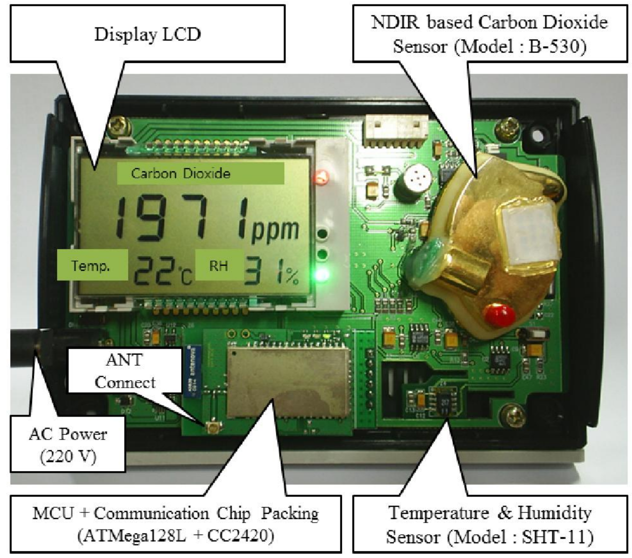


Fig. 2 Smart Sensor Prototype

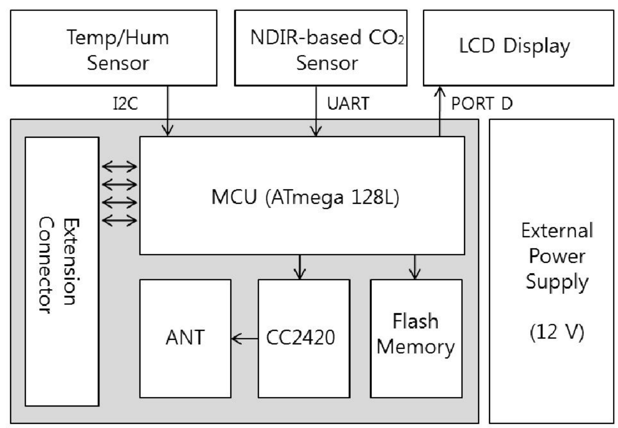
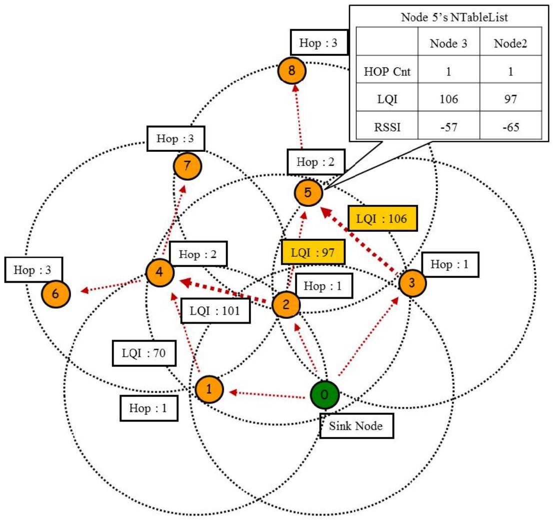


Fig. 3 Block Diagram of Smart Sensor

Third, Smart Sensor use Chipcon CC2420 to transmit data among Smart Sensors or between Smart Sensors and a

USN gateway (i.e. sink node) through wireless channel. The transceiver operates in the 2.4 GHz unlicensed ISM band and supports IEEE802.15.4/ZigBee stack.

The Smart Sensor was operated based on TinyOS2.0. Smart Sensor provides the reliable mesh networking, and self-configuration to relay measurement data efficiently [9]. Previous research reported that 2.4GHz frequency considerably depends on LOS environment and can be absorbed by people much greater than low frequency [7,12]. In other words, it means that characteristics of Physical Layer and routing scheme of Network Layer must be considered to transmit seamlessly between Smart Sensors to a USN gateway.



We developed the reliable multi-hop routing protocol based on the tree structure to retain seamless network connection. It was implemented with the gradient flooding mechanism, and based on TinyOS2.0. It adaptively selects the paths to relay data throughout the networks by the analysis of present multiple link qualities. To setup paths, it uses index that has hop count from the destination node and link quality metrics including LQI and RSSI.

Proposed routing scheme basically selects the next node by the minimum hop count to set up good paths for relaying data. On the other hands, if all link qualities are

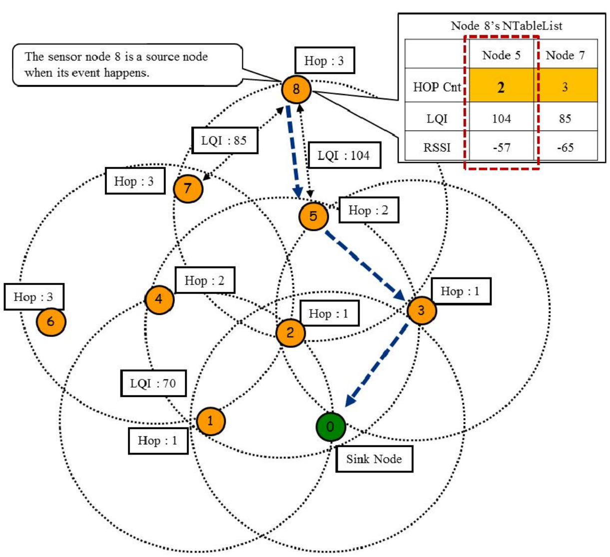


Fig. 5 Data Delivery Phase using Hop Count Priority

lower than the boundary value, it selects the next node by the link quality metrics are higher than the boundary value [7] (RSSI≥-85 or LQI≥98).

Figure 4 describes the processing phases to transmit data. First, the USN Gateway periodically broadcasts its neighbor nodes a short initiation message (INIT) with the gradient flooding mechanism. Then if the initial gradient setup complete, every Smart Sensor has own minimum hop count to the USN Gateway in Figure 5 illustrates the general setup method by the minimum hop count.

For example, if the Smart Sensor 8 has a sensing data (DATA), it simply transmits DATA to Smart Sensor 5 of its neighbor nodes after referring to own Neighbor Table List. As result, the scheme can save the energy by selecting the shortest path with the hop count priority. Remember that the link quality of all neighbor nodes is over the boundary value. Figure 6 describes the special setup method in the poor network conditions by the link quality metrics. In this case, although Smart Sensor 4 has the same hop count, Smart Sensor 5 transmits DATA to the Smart Sensor 4 due to the higher LQI value than the boundary. In conclusion, the reliable multi-hop routing protocol is superior with others in terms of the energy consumption and transmission reliability.

Fourth, USN gateway was developed using an inexpensive embedded Linux system based on ARM 11 core. The gateway plays a role as sink node in wireless sensor networks. It employed two types of radio modem to connect among heterogeneous wireless devices flexibly.

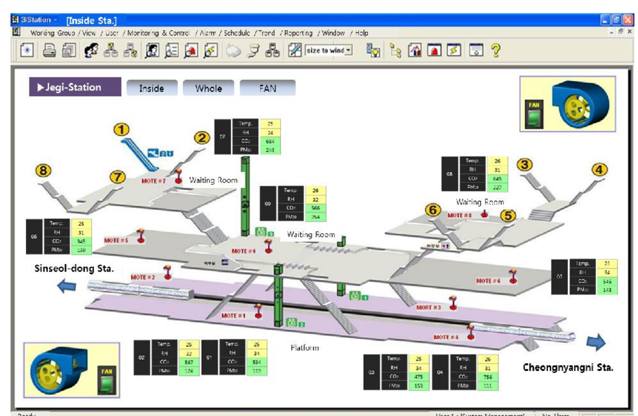
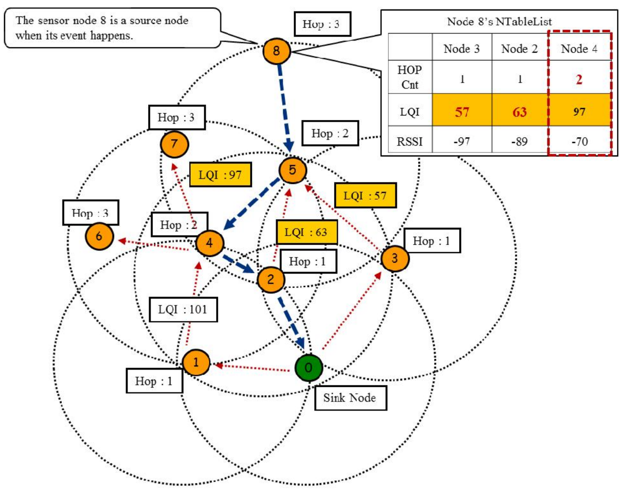


Fig. 7 Remote Monitoring & Control Software

Fifth, we developed PC-based programs on notebook to collect data from three instruments for measuring PM_{10}. The two β-ray-PM_{10} instruments and one the light



scatter-PM_{10} instrument were used to compare their reliabilities. The PM_{10} data is consecutively transmitted by UART interfaces to the notebook. After producing the one data package, it was transmitted by a WiBro modem to a Monitoring Server every 1 minute.

Finally, the Monitoring Server was developed based on web server using PHP and MySQL to collect and monitor real measurements from each Smart Sensor in the pilot. The web server always communicates with gateways through Internet. Therefore, anyone can check the ambient air quality if you can use Internet Explorer.

3. RESULT AND EVALUATION OF PILOT PROJECT

The EAPMS was built to evaluate its performance on the platforms in Jegi-dong station, Seoul Metropolitan Subway Line 1, located in Seoul, Korea. Figure 9 shows EAPMS installed on the platform. First, the three Smart Sensors equipped with B-530, SHT11 sensors were fasten to a wall of a single-sided platform. Each Smart Sensor was installed in the interval from approximate 70m. IEEE 802.15.4/ZigBee technology was used to communication between Smart Sensors and the USN Gateway. Smart Sensors transmitted measurement data every 3second. Then, the USN Gateway periodically transmitted aggregated data to the Monitoring Server using Wi-Fi every 1 minute. The Server was located in the IT building in University of Seoul. In addition, a notebook with three PM_{10} instruments transmitted measurement data to the Monitoring Server every 1 minute.

In this pilot project, the levels of CO2, PM10, temperature and humidity were continuously measured during five months from May, 2009 to September, 2009. Figure 6 reports real measurements for 7 days from 00 a.m., 21 May to 00 a.m., 28 May, 2009. The period was randomly chosen from entire measurements. Figure 10-(A) shows the measurements of Relative Humidity, Figure 10-(B) shows the measurements of temperature, Figure 10-(C) shows measurements of CO2 concentration, and Figure 10-(D) shows measurements of PM10 during the pilot project. As shown in Figure 10, we found a strong positive relationship among three measurement curves by a regression analysis. The results were affected by atmospheric circulation and diffusion although Smart Sensors were installed different measurement locations. Specially, we observed that Relative Humidity on 21-23rd May was higher than other days. We also observed that temperature was lower than other days as average 5 degree for the same time. Korea Meteorological Administration said 38 millimeters of rain fell in Seoul for the period from May 21 to May 23, 2009. Therefore this paper verified that Smart Sensors provide decent accuracy at a competitive price in the real field.

In this pilot project, three different types of instrument were used to measure PM10. The measuring results illustrate similar correlation to each other. Specially, we confirmed that PM10 concentration was higher during the train operating time, from 5 am to 12 am midnight. In addition, the strong correlation of measurements between HCT and E-BAM has been critical in terms of comparing with two measuring methods, one is β-ray another is light scatter method. Thus, it can be concluded that a light scatter-PM_{10} instrument has a very practical relevance for EAPMS at a reasonable price.

4. CONCLUSION

The objective of this research is to evaluate the performance of EAMPS in subway system through the pilot project. In addition, this paper describes core element technologies to implement EAMPS. The paper includes how to interface environmental sensors, how to design Smart Sensor H/W, S/W (TinyOS2.0-based), and how to implement a reliable routing protocol toward seamless wireless communication considering practical situations in underground subway systems.

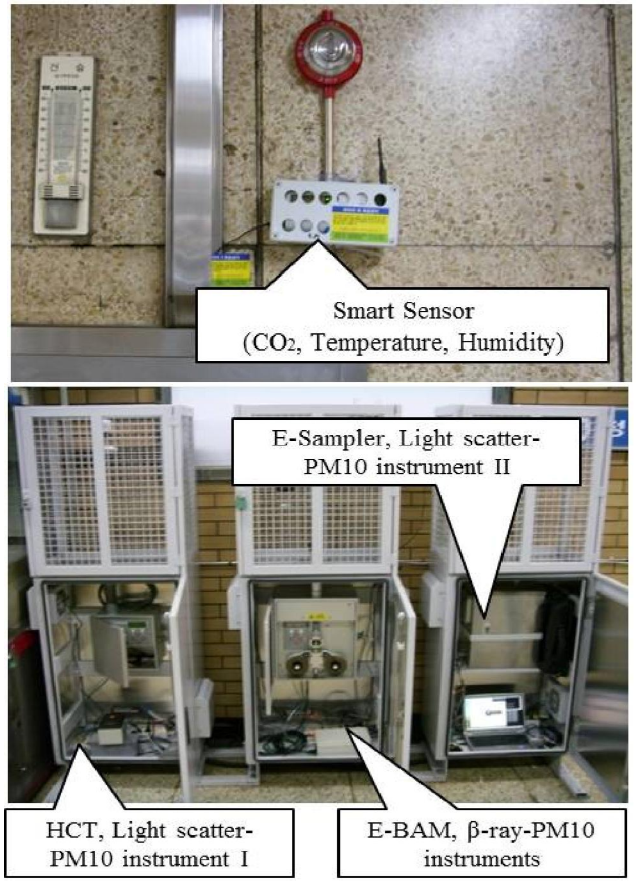


Fig. 9 EAPMS Pilot Project Setup in Subway System

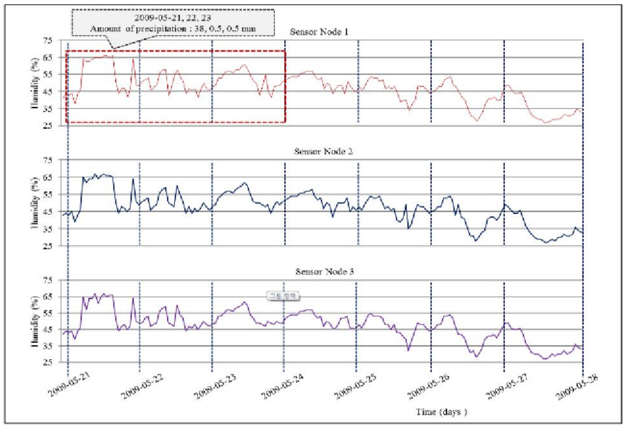


Fig. 10-(A) Measurements of Relative Humidity System

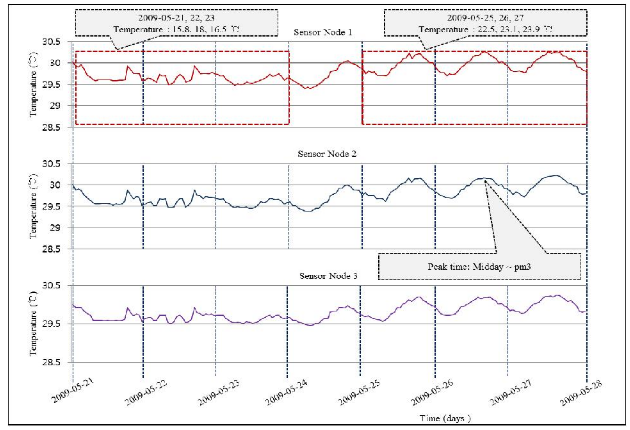
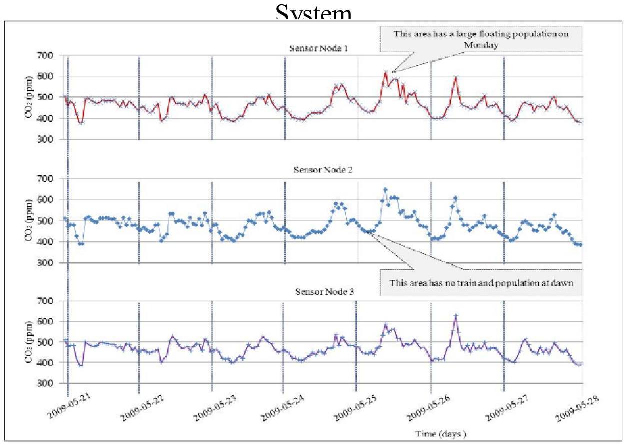


Fig. 10-(B) Measurements of Temperature



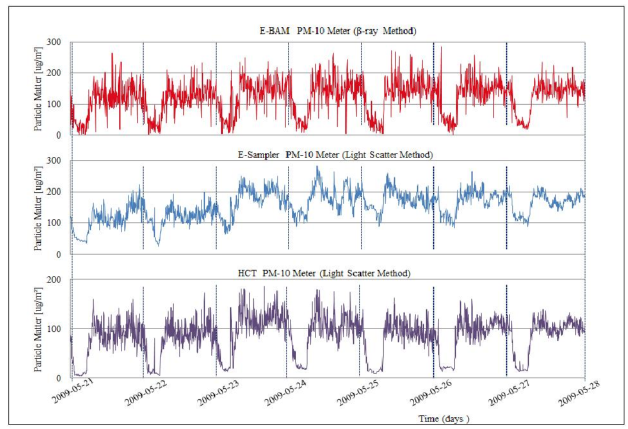


Fig. 10-(D) Measurements of PM_{10} Concentration

Fig. 10 Remote Measurements from Smart Sensors in Underground Subway System

In conclusion, we expect that EAPMS using USNs can expand to the Intelligent Safety Management and Control System in the near future. To achieve that, it is required to solve the remaining technical problems. This paper will make positive effect for constructing Smart City, and propose new, practical business models for Smart City driven strategies.

Corresponding Author:
Jongwon Kwon, and Hiesik Kim
Department of Electrical Computer Engineering, University of Seoul, Seoul, 130-743, Korea
Email: drhskim@uos.ac.kr

References:

1. Dong-Uk Park, Kwon-Chul Ha, Characteristics of PM10, PM2.5, CO2 and CO monitored in interiors and platforms of subway train in Seoul, Environment International **(2008)**, Vol. 34, Issue 5, pp. 629-634

2. Ki Youn Kim, Yoon Shin Kim, Young Man Roh, Cheol Min Lee, Chi Nyon Kim, Spatial distribution of particulate matter (PM_{10} and $PM_{2.5}$) in Seoul Metropolitan Subway stations, Journal of Hazardous Materials, **(2008)**, Vol. 154, Issues 1-3, pp.440-443

3. J.-C. Raut, P. Chazette, A. Fortain, Link between aerosol optical, microphysical and chemical measurements in an underground railway station in Paris, Atmospheric Environment, **(2009)**, Vol. 43, Issue 4, pp. 860-868

4. Wan-Young Chung, Sung-Ju Oh, Remote monitoring system with wireless sensors module for room environment Sensors and Actuators B, Chemical, **(2006)**, Vol. 113, Issue 1, pp. 64-70

5. Yoshika Sekine and Risa Katori, Indoor Air Quality Monitoring via IT Network-Colorimetric Monitoring of Formaldehyde in Indoor Environment Using Image Transmission of Mobile Phone, Proc. of ICROS-SICE International Joint Conference **(2009)**, pp. 4041-4046

6. Jongwon Kwon, Gwanghoon Ahn, Gyusik Kim, Jo Chun Kim, Hiesik Kim, A Study on NDIR-based

CO_2 Sensor to apply Remote Air Quality Monitoring System, Proc. of ICROS-SICE International Joint Conference **(2009)**, pp. 1683-1687
7. Jongwon Kwon, Gwanghoon Ahn, Seoklae Kim, Sanghyuk Kang and Hiesik Kim, A Study on Energy-Efficient Tree Routing Protocol Based on Link Quality Metrics for Remote Air Environmental Monitoring System, Proc. of ICROS-SICE International Joint Conference **(2009)**, pp. 4863-4868
8. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Computer Networks 38(4), **(2002)**, pp. 393-422
9. Kemal Akkaya, Mohamed Younis, A survey on routing protocols for wireless sensor networks, Ad Hoc Networks 3, **(2005)**, pp.325-349
10. Korean Ministry of Environment (MOE), Indoor Air Quality Regulation Act; 2004
11. Yi, S.H. Park, Y.W. Han, S.O. Min, N. Kim, E.S.Ahn, T.W. Novel NDIR CO_2 sensor for indoor Air quality monitoring, The 13th International Conference on Solid-State Sensors, Actuators and Microsystems, **(2005)**
12. M. Li and Y. Liu, Underground Structure Monitoring with Wireless Sensor Networks, In Proc. of the 6th international Conference on information Processing in Sensor Networks, **(2007)**, pp. 69-78.

7/22/2013