A Wireless Sensor System for Continuous Monitoring of Particulate Air Pollution

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Abstract**—**The aim of this work is to design, develop and test the low-cost implementation of a particulate air pollution sensor system for continuous monitoring of outdoors and indoors particulate air pollution at a lower cost than existing instruments. In this study, measuring electrostatic charge of particles technique via high efficiency particulate-free air filter was carried out. The developed detector consists of a PM10 impactor, a particle charger, a Faraday cup electrometer, a flow meter and controller, a vacuum pump, a DC high voltage power supply and a data processing and control unit. It was reported that the developed detector was capable of measuring mass concentration of particulate ranging from 0 to 500 $\mu g/m^3$, corresponding to number concentration of particulate ranging from 10^6 to 10^{12} particles/m^3 with measurement time less than 1 sec. The measurement data of the sensor connects to the internet through a GSM connection to a public cellular network. In this development, the apparatus was applied the energy by a 12 V, 7 A internal battery for continuous measurement of about 20 hours. Finally, the developed apparatus was found to be close agreement with the import standard instrument, portable and benefit for air pollution and particulate matter measurements.

Keywords**—**Particulate, air pollution, wireless communication, sensor.

I. Introduction

AIR pollution is harmful to the environment and human health, notably as the particulate matter (PM) in the fraction PM10. This fraction refers to particle sizes less than 10 µm in aerodynamic diameters, respectively. Recently, concerns over particulate air pollution have emphasized monitoring and measuring these fractions of a particulate matter. The US Environmental Protection Agency (EPA) promulgated a new regulation for the mass concentrations of PM10. The standards were based on findings from recent health effect studies reporting that PM10 could penetrate the alveoli and bypass the upper respiratory tract because they were small enough to allow deposition in places where they could do the most damage [1]. The hazard caused by PM10 depends on the chemical composition of the particulate matter and on the site where they deposit within the human respiratory system [2]. In order to deal with this problem, PM10 needs to be counted and characterized. For this purpose, particulate air pollution sensors have been developed to monitor indoor and outdoor aerosols for pollution and to control the pollution processes in industry.

Measurement of particulate matter both outdoors and indoors can be performed by a mass concentration method using a filtration method, a beta ray absorption method, a light scattering method, and an electrostatic method. Although the mass concentration method is ideal for studies requiring chemical composition, it has a low time-series resolution and requires an extended period of time for data collection. One key factor in particulate air quality missing from this suite is a real-time particulate matter sensor. Wireless sensor systems for measuring real-time particulate matter concentrations have been available and developed in the last decade [1-6]. However, these sensor systems tend to be relatively large units are not appropriate for integration within other compact devices, fairly expensive with typical starting prices greater than two thousand U.S. dollars. Because of the large number of measuring stations distributed in the region, a particulate air sensor system must have a low cost and continuously give fast response measurement of particulate matter in ambient air. It should also be compact and easy to use, and its maintenance must be possible by relatively low skilled laborers. The ease of moving a sensor should also be considered in measuring and monitoring particulate matter.

In this study, we developed a low-cost implementation of a particulate air pollution sensor system for continuous monitoring of outdoors and indoors particulate air pollution at a lower cost than existing instruments. The novel instrument features real-time particulate air pollution monitoring and wireless sensor system functions. For evaluation, the developed sensor system and an existing commercial instrument were installed in the same place, and the developed system was calibrated using various statistical analyses. This study provides the reference data required for calibration when a new particulate air pollution system is developed to replace existing commercial instruments.

II. Principle of Wireless Particulate Sensor System

A. Particulate Air Pollution Sensor

Fig. 1 shows the schematic diagram of the electrostatic sensor developed in this study. The system consisted of 10 µm

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cut-off diameter impactor, particle corona charger, Faraday cup electrometer, flow system, high voltage power supply, and data processing and control system. In this study, the flow system was regulated and controlled by mass flow controllers with a vacuum pump. Sampled PM was first passed through an impactor to remove PM outside the measurement range, particles with diameter larger than 10 µm based on their aerodynamic diameter [7]. Sampled PM was then directly introduced into the corona diffusion and field charger to electrostatically charge the particles by attachment of ions produced by the corona discharge inside the corona charger [8]. The electrical charges carried by PM then enter into the Faraday cup electrometer and was measured electrically in a Faraday cup electrometer downstream of the charger [9]. The readout of the system showed a relationship between the time and the number concentration of PM by the data acquisition and processing system [10]. The main component of the data acquisition and processing system was the Microchip PIC18F46K80 microcontroller. It was equipped with 64 Kbytes on-chip flash program memory and 64 MHz of processing speed. A build-in 12-Bit A/D converter converted all analog outputs from the electrometer circuit into digital signals fed to the microcontroller. To display the measurement of the sensors and the current time, an LCD module was connected to the microcontroller. The data logger allowed browsing through the recorded data and changing the sampling interval. Data stored in the memory could be accessed directly with an external computer through a USB connection. The graphical user interface software was developed using LabView. The software allowed complete or partial downloading of data from memory; it also enabled changing sampling parameters such as date, time and sampling interval. The data could be plotted with the built-in graph plotter or exported to Excel for further analysis. The specification of the developed particulate air pollution sensor is shown in Table I.

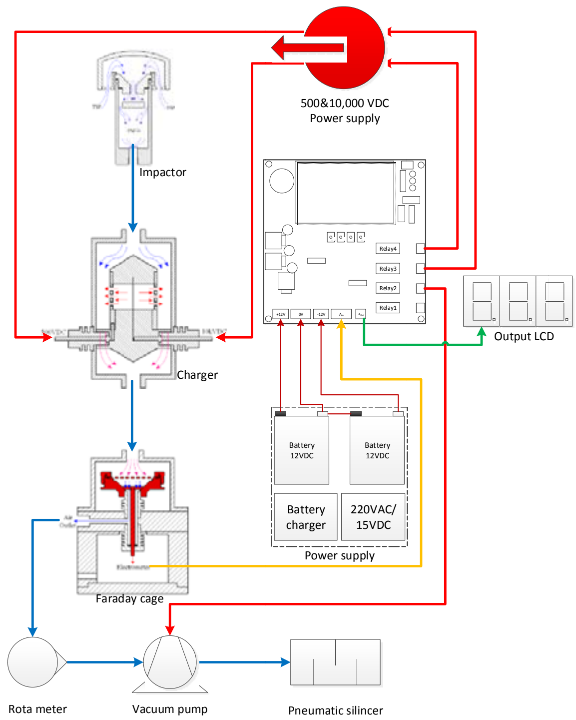
TABLE I
SPECIFICATION OF THE PARTICULATE AIR POLLUTION SENSOR

Specifications	
Measurement technique	Electrostatic
Particle size range	< 10 µm
Concentration range	0 – 500 µg/m^3
Measurement time	100 ms
Aerosol flow rate	5.0 L/min
Operating temperature range	10 – 40^{o}C
Dimensions	400 × 570 × 260 mm
Weight	5 kg

B. *Wireless Sensor System*

Fig. 2 shows the diagram of wireless sensor system, which uses a GSM module as a communication device to transmit

(a) Particulate air pollution sensor hardware



(b) Schematic diagram

Fig. 1 Developed particulate air pollution sensor

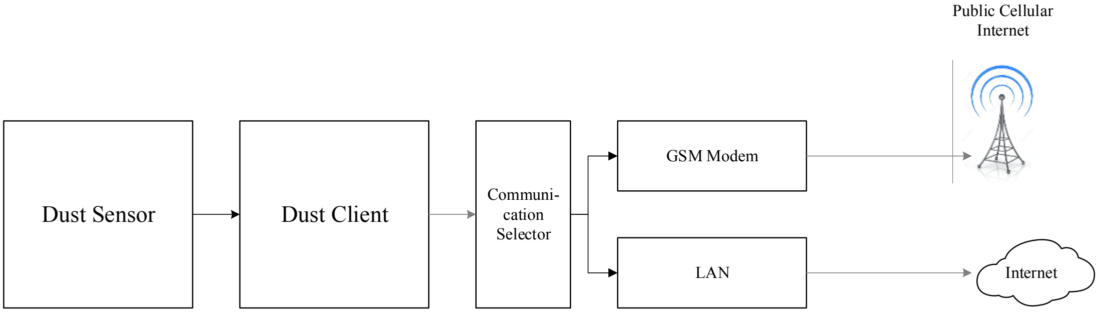


Fig. 2 Wireless dust sensor system diagram

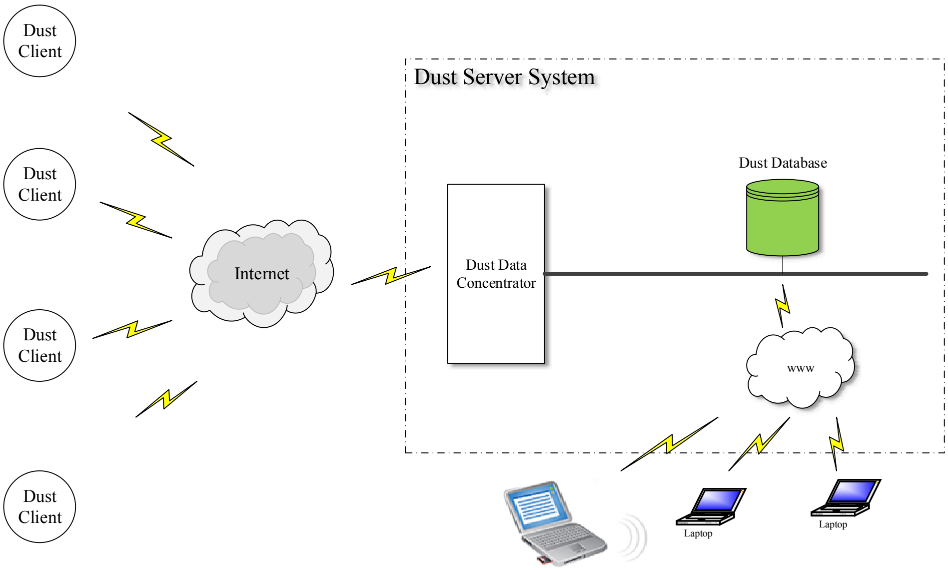


Fig. 3 Dust server communication diagram

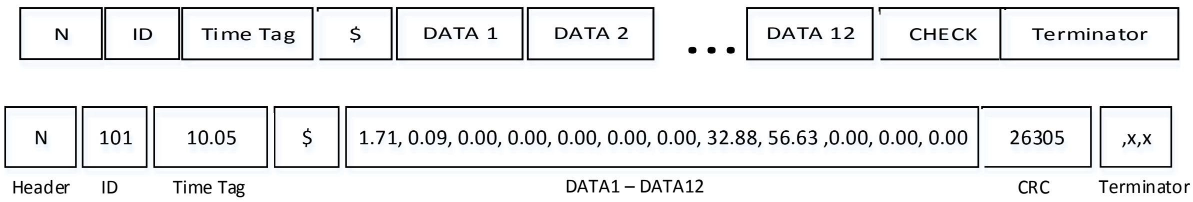


Fig. 4 Message data frame

time, date and level of particulate mass concentration. The module was used for the proposed system has an embedded communication protocol that supports Mechine-to-Mechine (M2M) intelligent wireless Transmission Control Protocol (TCP/IP) features. The GSM module supports an RS-232 interface that allows serial TCP/IP socket tunneling. Fig. 3 shows the dust server communication diagram. The dust server is an off-the-shelf personal computer with accessibility to the internet. Fig. 4 shows a message data frame. The dust server connects to the GSM module via TCP/IP through the internet and a public cellular network. Finally, the server connects to a database management system (MySQL) through a local area network (LAN). Fig. 5 shows the web Application of the particulate air pollution sensor.

III. Implementation and Testing

The performance of the developed wireless sensor system was evaluated simultaneously with a currently available the TEOM Monitor, Series 1400ab, Thermo Fisher Scientific Inc., at ambient condition measurements. The developed particulate air pollution sensor system would measure the same concentrations as the TEOM. Therefore, the measurement location was at Maemoe Power Plant, Lamphang, Thailand for about 24 hours during March 1 – 10, 2015.

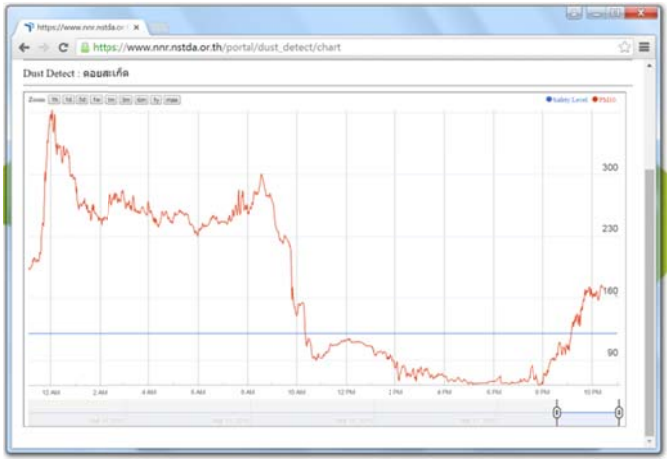


Fig. 5 Web Application of the particulate air pollution sensor

However, there were always differences between the initial measured values of two systems. To minimize these differences, we calibrated the developed particulate air pollution sensor measurements using the correlations from a simple linear regression analysis. The equation of the simple linear regression is given by

$$y = aX + b \tag{1}$$

where a is a vector of prediction of the sample from the observed system, X is the vector of the simple linear regression variables calculated with the regression analysis and y is the value of the observed system restructured by (1).

Fig. 6 and 7 show the comparison of particle mass concetration between the developed sensor and the TEOM. There was good agreement for the comparative study. Fig. 8 shows the correlation coefficients of PM10 using developed sensor and the TEOM after simple linear regression. It was shown that the correlation coefficients from the simple linear regression were about 0.887 for PM10. Continuous operation of the sensor did not result in any measurable changes in the performance of the sensor. No visible deposits could be observed. This indicated that the maintenance interval (for calibration, cleaning and etc.) may be greater than 300 hours of operation at relatively high concentrations of particles.

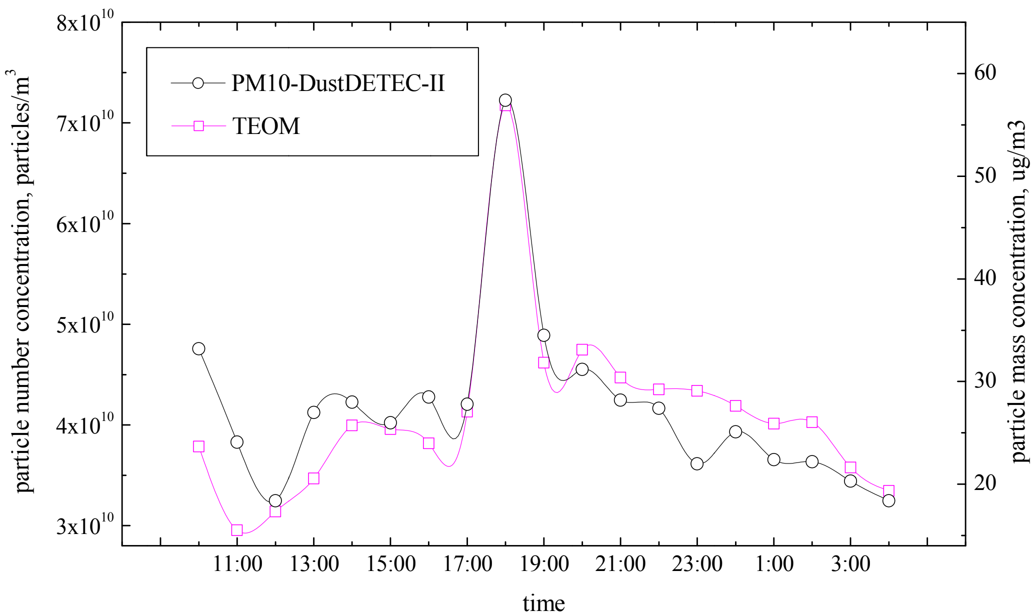


Fig. 6 Comparison between the developed sensor and the TEOM for 24 hours

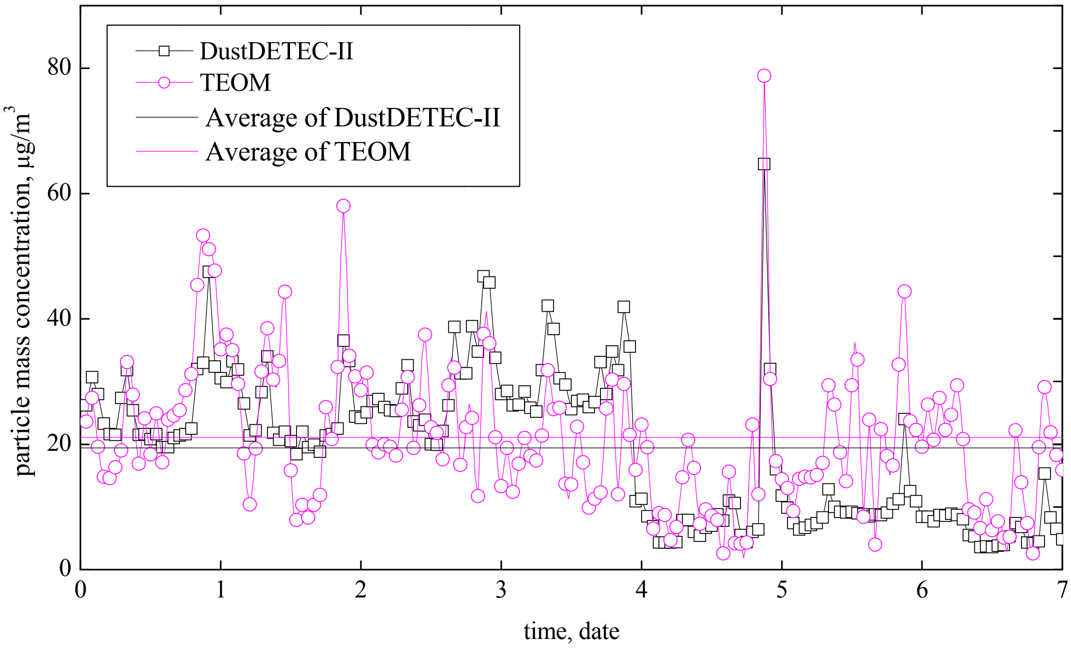


Fig. 7 Comparison between the developed sensor and the TEOM during March 1 – 9, 2015

IV. Conclusion

In this work, the low-cost implementation of a particulate air pollution sensor system was designed and developed for continuous monitoring of outdoors and indoors particulate air pollution at a lower cost than existing instruments. In this study, measuring electrostatic charge of particles technique via high efficiency particulate-free air filter was carried out. The developed detector consists of a PM10 impactor, a particle charger, a Faraday cup electrometer, a flow meter and controller, a vacuum pump, a DC high voltage power supply and a data processing and control unit. It was reported that the developed detector was capable of measuring mass concentration of particulate ranging from 0 to 500 µg/m3 corresponding to number concentration of particulate ranging from 10^6 to 10^{12} particles/m^3 with measurement time less than 1 sec. The measurement data of the sensor connects to the internet through a GSM connection to a public cellular network. In this development, the apparatus was applied the energy by a 12 V, 7 A internal battery for continuous measurement of about 20 hour. Finally, the developed apparatus was found to be close agreement with the import standard instrument, portable and benefit for air pollution and particulate matter measurements.

V. Recommendations for Future Works

For most impactors, the cut-point curve is 50% collection efficiency. One of the principle limitations of the inertial impaction method is that a significant fraction of the particles

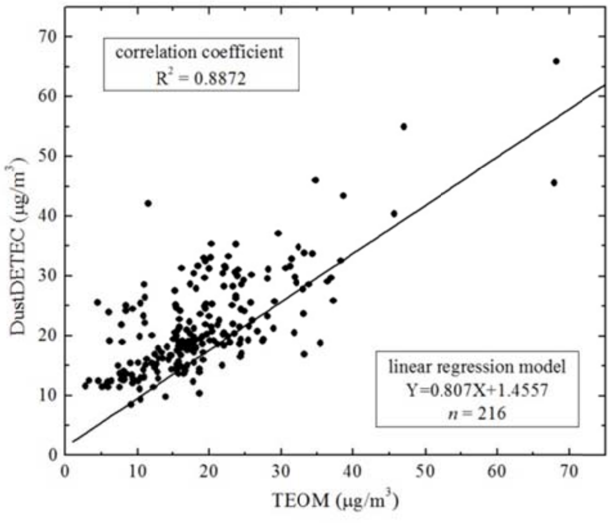


Fig. 8 Correlation coefficients of PM10 using developed sensor and the TEOM after simple linear regression.

greater than the cut-off point diameter (50% is from particle larger than the cut-off point) that pass through the impactor. Therefore, further research should focus on the effect of a fraction of the particles larger than the 50% cut-off point diameter on the overall performance of the sensor.

The actual charging performance of the charger should be investigated with mono-disperse particles to determine the equilibrium unipolar charge distribution of the multiply charged particles at the outlet of the charger. Use of different aerosol generators that cover the greater size range will give a better understanding on the charging performance.

Calibration and comparison of the instrument with other particle measuring devices should be explored further.

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