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The Real-Time Dispersion Modeling System

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Abstract

The real-time modeling system, named AirWatch System, has been developed to evaluate the environmental impact from a large source. It consists of stack TMS (TeleMetering System) that measures the emission data from the source, AWS (Automatic Weather Station) that monitors the weather data and computer system with the dispersion modeling software. The modeling theories used in the system are Gaussian plume and puff models. The Gaussian plume model is used for the dispersion in the simple terrain with a point meteorological data while the puff model is for the dispersion in complex terrain with three dimensional wind fields. The AirWatch System predicts the impact of the emitted pollutants from the large source on the near-by environment on the real-time base and the alarm is issued to control the emission rate if the calculated concentrations exceed the modeling significance level.

Key words : Real-time, Dispersion, Modeling, TMS, Environmental impact, Meteorological data

1. INTRODUCTION

In order to manage an air quality effectively, it is very important to understand the nature and amount of air pollutants emitted from various sources as well as to evaluate their impacts on the environment based on the scientific evidence.

The Korean Ministry of Environment provided by law to install the stack TMS to monitor the concentration level emitted from large air pollutant discharging facilities such as power plants, municipal waste incinerators, chemical plants, etc. The number of companies required to install the stack TMS are expected to be more than 600 in 2005. The ambient TMS on the 209 stations are also operated over the Korean peninsula to monitor the air quality in Korea.

In order to utilize the collected data of stack and ambient TMS in the management of the air quality, it is necessary to develop the real-time dispersion modeling system evaluating the relationship between the emission sources and the impact of emitted pollutants on the near-by environment. The real-time dispersion modeling system in this study was named the AirWatch System. The hardware components, software modules, basic dispersion theories and application examples of the AirWatch System will be presented in this paper.

2. A SYSTEM OUTLINE AND DISPERSION THEORY OF THE REAL-TIME AIR DISPERSION MODELING

2. 1 A structure of the system

The hardware of the AirWatch System consists of

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stack TMS that measures the emission data from the source, AWS (Automatic Weather Station) that monitors the weather data, and computer system for the dispersion modeling software as shown in Figure 1. The software of the AirWatch System has three separate modules; the TmsWatch collects TMS data and converts them to emission rate data for the dispersion modeling, the WeatherWatch also collects the weather monitoring data from the AWS and converts them to the meteorological input data for the dispersion modeling, the AirWatch finally receives the emission data from TmsWatch and the meteorological data from WeatherWatch and then evaluates the environmental impact from the stack to the neighboring area by performing dispersion modeling.

The TmsWatch monitoring stack gas velocity and temperature and 8 pollutants such as SO_2, Dust, NO_X, HCl, HF, NH_3, Cl_2, and CO transmits the emission data to the AirWatch in every 5 minute. The WeatherWatch measuring a wind direction, wind speed, temperature, humidity, pressure, and solar radiation also transmits the meteorological data such as wind direction, wind speed, stability class, and mixing height to the AirWatch system in every 5 minute. The measured solar heat flux and wind speed by the AWS were used tc derive the stability classes. In the calculation of the convective mixing heights, the modified Carson method was used (Carson, 1973).

The raw data from the stack TMS and AWS should be checked for noises and abnormal signals by error handling methods in TmsWatch and WeatherWatch software modules prior to be sent to the AirWatch (Koo *et al.*, 2002). In the model prediction, the minimum average time of the concentration is 5 min. and the longer average time than 5 min. such as 1 hour, 1 day, and so on is also predicted in the system.

2. 2 Theory of air dispersion model

The dispersion theories used in the AirWatch System are the steady state Gaussian plume model and unsteady state puff model in the prediction of concentration. The Gaussain plume model is normally used for the dispersion in the simple terrain with a point meteorological data while the puff model is used for complex terrain with three dimensional wind fields.

Gaussian plume equation used in the AirWatch System is (USEPA, 1995);

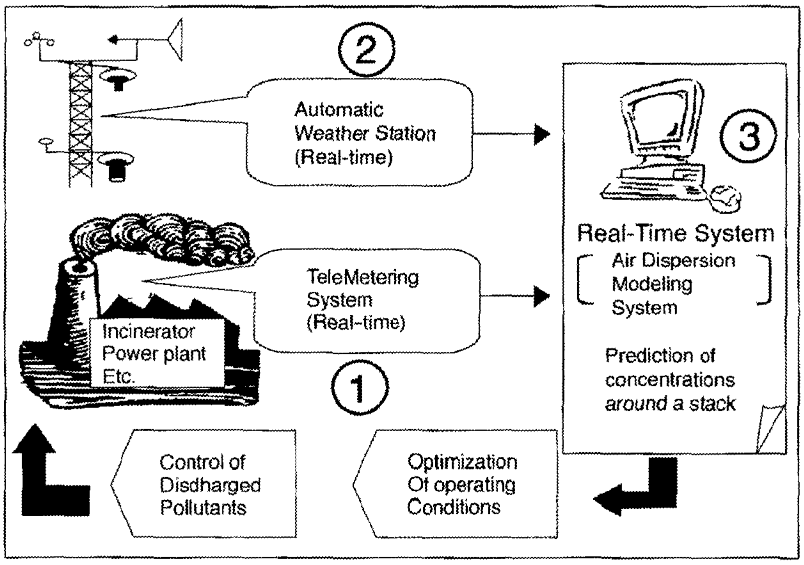


Fig. 1. A diagram of the real-time model system for the management of the air pollutant emission facility.

$$C(x, y, z) = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \quad (1)$$

where,

C : the concentration at receptor (x, y, z)

x : the coordinate of downwind direction

y : the coordinate of croswind direction

z : the coordinate of vertical wind direction

Q : pollutant emission rate

K : a scaling coefficient to convert calculated concentrations to desired units

V : vertical dispersion term

D : decade term

σ_y, σ_z : standard deviations of lateral and vertical concentration distribution (m)

u_s : wind speed (m/s) at stack exit.

The puff model considers the continuous plume from the stack as the number of discrete puffs of the pollutants. The puffs are released from the stack with a certain time interval and the released puffs then move along the wind field and are then distributed over the calculation domain. The total concentrations at the receptors are the sum of the contributions of all nearby puffs. The location of individual puff is monitored by the following equation (Scire, 2000).

$$\begin{aligned} X(t+\delta t) &= X(t) + U(t+\delta t) \times \delta t \\ Y(t+\delta t) &= Y(t) + V(t+\delta t) \times \delta t \\ Z(t+\delta t) &= Z(t) + W(t+\delta t) \times \delta t \end{aligned} \quad (2)$$

where U, V, and W are the mean wind components varying with time and δt is a time interval.

And the concentration from the growth of individual puff is then calculated from the following equation.

$$C(x, y, z) = \frac{Q}{2\pi \sigma_x \sigma_y}\, g \exp\left[-\left(\frac{d_a^2}{(2\sigma_x)}\right)^2\right] \exp\left[-\left(\frac{d_c^2}{(2\sigma_y)}\right)^2\right]$$

$$g = \frac{2}{(2\pi)^{\frac{1}{2}}} \sum_{i=-\infty}^{\infty} \exp\left[-\left(\frac{H_e + 2ih}{(2\sigma_z)}\right)^2\right] \quad (3)$$

where,

C is the ground level concentration contributed by the puff near the receptor.

Q is the amount of the emission assigned to the puff.

σ_x, σ_y, and σ_z are the standard deviations of the Gaussian plume in corresponding directions.

d_a and d_c are the along and cross wind distances from the puff center, respectively.

g is the vertical term of the Gaussian plume equation.

H_e is an effective puff height and h is a mixing height.

3. APPLICATION EXAMPLES

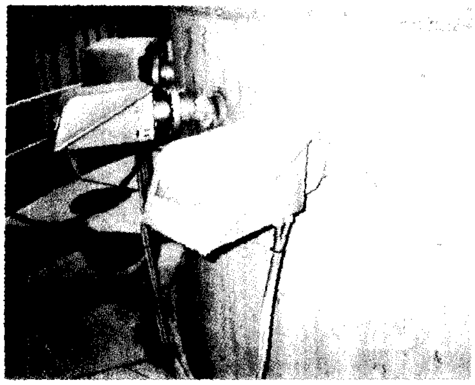
The AirWatch System was applied to the municipal waste incinerator in Anyang, Korea to check the problem in working conditions. Figure 2(a) is the picture of stack emission montoring sensors in TeleMetering System. Figure 2(b) is the automatic weather station installed on the roof of the office building, and Figure 2(c) is the air dispersion modeling system in the field operation.

3. 1 WeatherWatch and TmsWatch

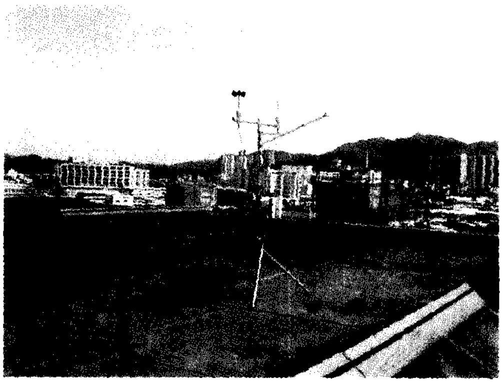
The components of the weather data in viewer of WeatherWatch windows are wind direction, wind speed, air temperature, humidity, pressure, net radiation, stability, and mixing height. The components in the emission data viewer of TmsWatch windows are number of stacks and their TM coordinates, concentration distribution of emitted pollutants, the velocity and temperature of gas. Figure 3(a) is an example of TmsWatch windows operating in the PC and Figure 3(b) is also an example of WeatherWatch windows. The typical example of the predicted concentration by the dispersion model is shown in Figure 3(c).

3. 2 Examples of predicted concentration fields

Examples of predicted concentration fields are presented in Figure 4. Figure 4(a) and Figure 4(b) are the contour maps of the predicted concentration by the Gaussian plume model and puff model, rescpectively. The Gaussian plume and puff models were used in the simulation. The steady state Gaussian plume model shows straight line trajectories in the concentration



(a) Stack TMS



(b) AWS installed on the office building

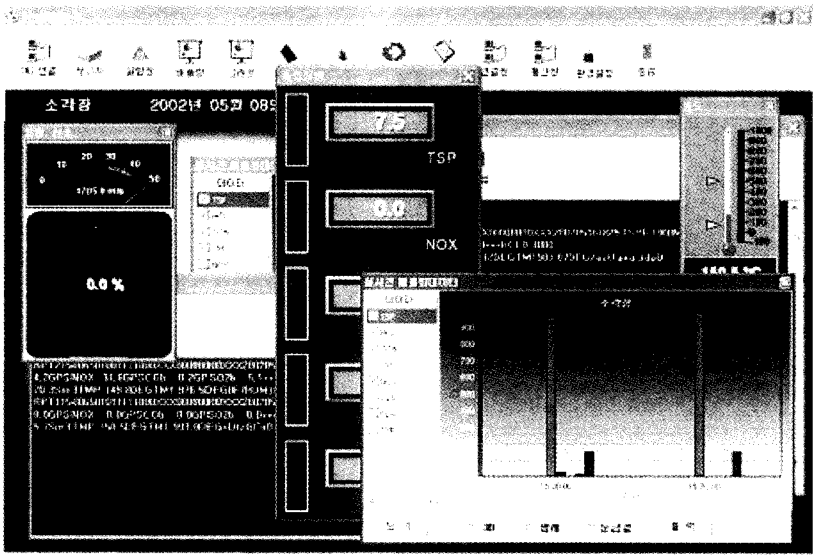
(c) AirWatch System operating in PC.

Fig. 2. Application example of an air quality management system based on real-time dispersion modeling.

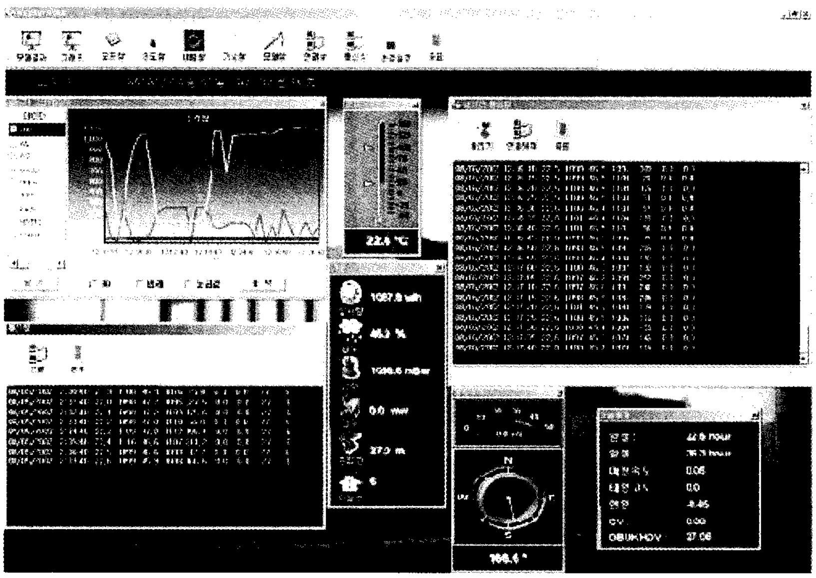
field while the unsteady state puff model clearly demonstrates the memory effect of the previously emitted plume. The impacts of the source to the near-by environment are calculated on the real-time base and could be opened to the public if necessary. If the predicted concentration exceeds the pre-determined incremental level or the modeling significance level, the alarm is issued to control the emission rate from the source. This system can be used to assess the environmental impact from the large emission sources to manage the air quality in the environmentally sound manner.

3. 3 Validations of modeling system

The predicted concentrations by the real-time modeling system were compared with the Indianapolis tracer experiment under same meteorological conditions in Figure 5. Figure 5(a) is the comparison with the Gaussian plume model while Figure 5(b) is the comparison with the puff model. The Q-Q plot shows good agreements with the tracer experiments. The puff model shows better performances in the model prediction since the puff model is the unsteady state model

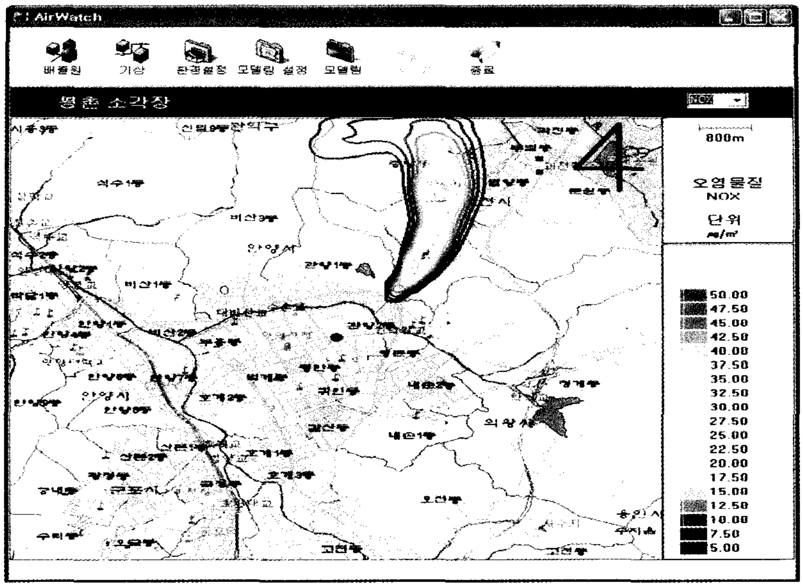


(a) TmsWatch windows



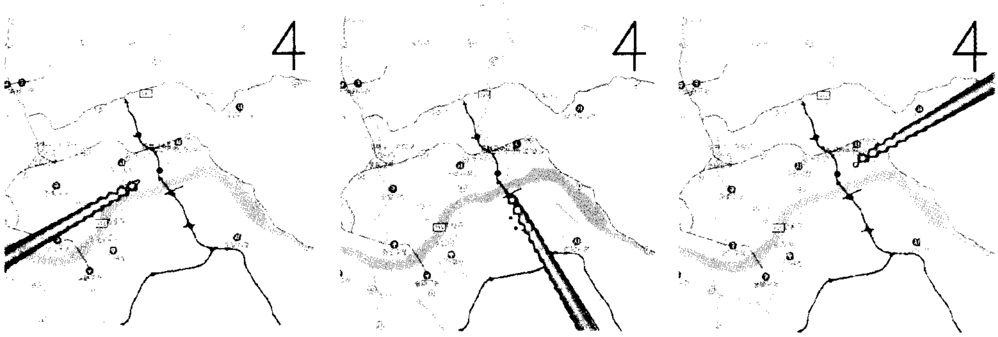
(b) WeatherWatch windows

Fig. 3. Three operating windows in the AirWatch system.

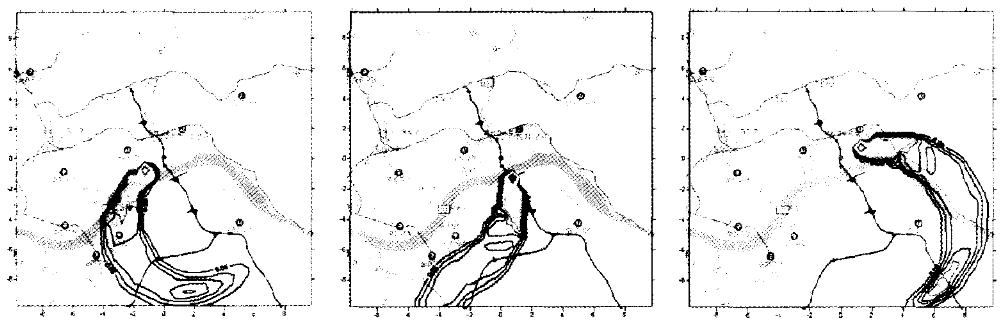


(c) AirWatch windows

Fig. 3. continued.

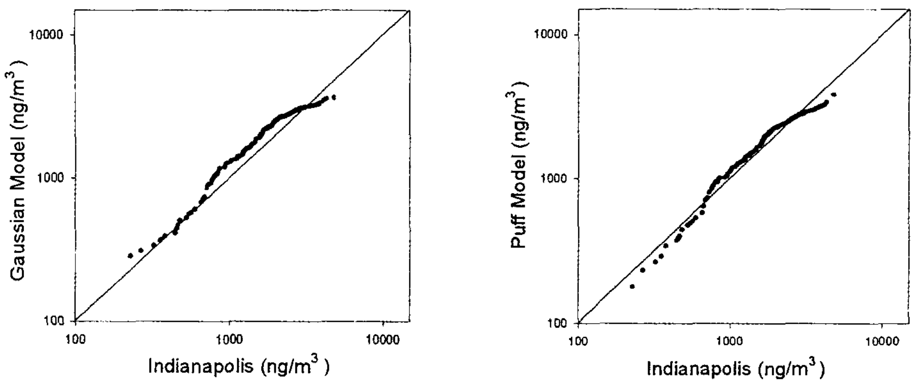


(a) Gaussian plume model



(b) Puff model

Fig. 4. Examples of predicted concentration distributions by Gaussian plume and puff models.



(a) Gaussian plume modeling (b) Puff modeling

Fig. 5. The Q-Q plots of 1 hour concentrations for comparison of the model results with the Indianapolis tracer experiments.

which is capable of simulating the memory effect by retaining the information of old puffs emitted in previous hours. The further validation studies with other tracer experiments are under way.

4. CONCLUSIONS

The real-time air dispersion modeling system (AirWatch System) based on real-time TMS data and AWS data has been developed to manage the large air pollutant emission facilities. AirWatch System predicts the impact of the emitted pollutants from the large source on the near-by environment on the real-time base and the alarm is issued to control the emission rate if the calculated concentrations exceed the modeling significance level. The AirWatch System is an effective tool to manage the large emission facility in the environmentally sound manner.

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