EFFECT OF DATA LOGGING FREQUENCY ON TRACER GAS MEASUREMENT

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ABSTRACT

A data acquisition system which uses a computer provides a more useful analysis system. Since the processing speed of computer is continuously increasing, the measurements can produce much more information than it is possible using conventional data acquisition systems. However, the raw measurements also include the signal noise which may lead to difficulty when the signal is analyzed.

This work assesses an algorithm for removing possible signal noise, usually with high-frequency, from the measurement of tracer gas concentration. The code, written by the authors, contains three main parts: fast-Fourier transformation (FFT), inverse fast-Fourier transformation (IFFT), and a digital filter. In this method, the raw data is transformed using FFT from time-domain into frequency-domain. The digital filter, so-called Notch filter, then selects the required signal without the high-frequency noise. Finally IFFT conducts inverse transformation from frequency-domain to time-domain with the frequency data selected by the filter and yields a smoothed time-domain signal back.

Using this technique, the digital filtering algorithm provides the measurement data without the high-frequency noise. It has been found that 1Hz of sampling rate is fast enough to monitor the variation of tracer gas concentration in model experiments.

KEYWORDS

Tracer Gas, Measuring Technique, Measurement Analysis, Model Experiments

INTRODUCTION

Tracer gas technique for indoor air quality (IAQ) measurement or model experiments is a useful tool that has been developing in many ways. Adding a computer to a tracer gas analyzer with an analogue-to-digital (A/D) converter provides a data acquisition system (DAS) that is able to provide more detailed information, in real-time domain, of the measured signal, especially in model experiments.

DAS allows high sampling rate and it reveals some of the otherwise hidden information in the tracer gas concentration signal. This method has a potential application in various signal analysis applications, and as has been reported by Sandberg and Sjoberg (1983), Lay and Bragg (1988), Lee (1993), Kim et al. (1993), and Phillips and Bragg (1994).

Lee (1993) applied the moving average technique for the pre-treatment of the raw measurement which provided useful information from the measurements. However, Phillips and Bragg (1994) pointed out that an averaging technique leads to a loss of useful information from the measurement. O'Neill and Crawford (1991) showed that a proper sampling interval, based on the time constant, is also important.

In this study, a different approach to separate the tracer gas measurement from the raw signal acquired by DAS has been used. A small-scale model has been used for the tracer gas measurement and the tracer gas concentration has been monitored by a DAS. The digitized signal has input into an algorithm, coded by the authors, which contains fast-Fourier transformation (FFT), inverse fast-Fourier transformation (IFFT), and a digital filter.

METHOD

In order to obtain a true measurement of the tracer gas concentration, experiments in a room and signal analysis have been carried out.

For the tracer gas measurement, a small-scale model shown in Figure 1 has been used. The model room, 1.6m x 0.8m x 0.7m H, has two ceiling-mounted openings to supply and exhaust ventilation air in a mixing ventilation system. The air is supplied by an axial fan with speed controller. Carbon Dioxide (CO_2) has been used as the tracer gas and its generation was controlled by a control box connected to a computer.

The analogue signal from the tracer gas analyzer is continuously sampled by the DAS at a preset sampling rate. During the tests, two different sampling rates, 1Hz and 7Hz, were selected to study the effect of sampling frequency on the analysis.

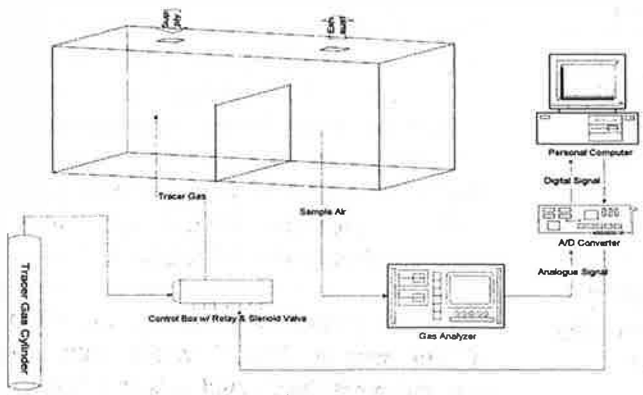

Figure 1 Schematic diagram of model experiment system.

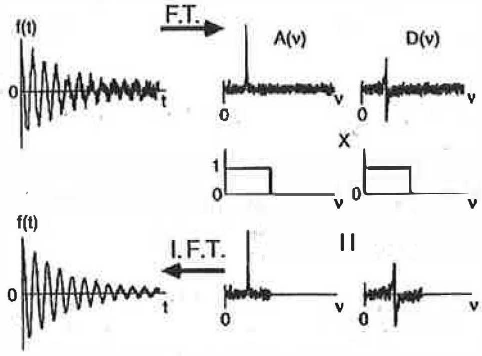

Figure 2 Digital filtering to remove high-frequency noise (Marshall and Verdun, 1990).

Matlab, version 5.1.0.421, Mathworks, USA, has been used for coding the signal analysis. First, the FFT is used to transform the raw measured data in the time-domain into one in the frequency-domain.The FFT is a discrete Fourier transformation which applies to a length of N inputs of the vector x as in the equation below (Ramirez, 1985; Johnston, 1991):

$$X(k) = \sum_{n=1}^{N} x(n)\exp(-i2\pi\frac{k-1}{N}), 1 \le k \le N \quad (1)$$

where X = transformed vector in frequency-domain
k = number of spectral data points in frequency-domain
x = original vector in time-domain
n = length of input vector
i = indicates imaginary number

A digital filter, so-called Notch filter, was used to collect the necessary frequency data in the way shown in Figure 2. In this case, the high-frequency noise will be erased from the signal by the filter. Finally, the IFFT was applied to transform the digitized data from the frequency-domain to the time-domain and re-combined as a smoothed version of *x(k)*. The function applies to a length of N input vectors *X* as in Equation (2).

$$x(k) = \frac{1}{N}\sum_{k=1}^{N} X(n)\exp(i2\pi \frac{k-1}{N}),\ 1 \le n \le N \quad (2)$$

where the definitions of variable are the same as in Equation (1)

This process will provide tracer gas concentration measurements without the high-frequency noise that is present in the raw measurement.

RESULTS

The mathematical transformation techniques, FFT and IFFT, and the digital filtering technique derived earlier have been applied to obtain the measurement shown in Figure 3 without the high-frequency noise which affects significantly the data analysis as shown in the second plot of the figure.

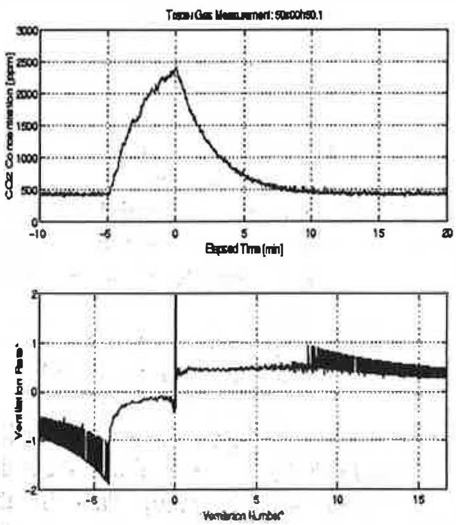

Figure 3 A typical raw signal of CO_2 concentration obtained in the physical model experiments.

Figure 3 shows the raw measurement and the calculation of ventilation rate without applying the digital filtering algorithm. In the top plot, the x-axis is time and the y-axis is the measured tracer gas concentration. In the lower plot, both axes are normalized. The x-axis represents the time normalized with room volume and supplied air volume and the y-axis is the ventilation rate normalized with the room volume and the normalized time.

The lower plot in Figure 3 shows that the calculation with time is not stable although the fluctuations during the large concentration period look minor. In other words, a small input due to signal noise can make significant error on the data analysis at either end of the main signal.

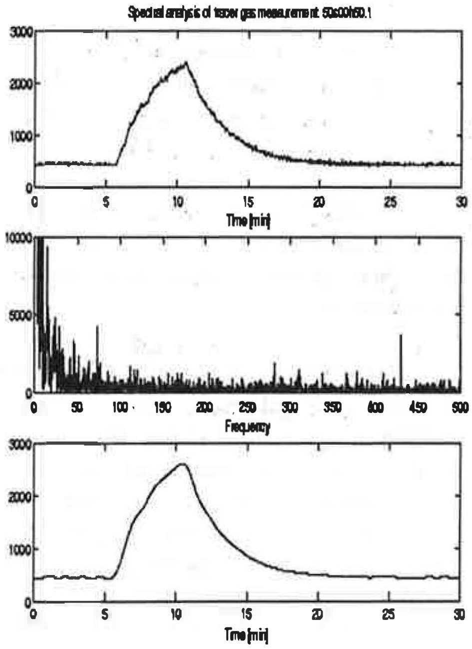

Figure 4 Digital filtering process of a measured signal using FFT, Notch filter, and IFFT in this order.

The filtering algorithm is applied to the top plot in Figure 4, which is the raw measurement that could create difficulty when analyzed. The middle plot is the same as the first one but represented in frequency-domain. The Notch filter then selected the optimal range of frequency to produce the low frequency data which is required. The lower plot is the final IFFT result of the data selected by the filter. The sampling rate for this case was 1Hz.

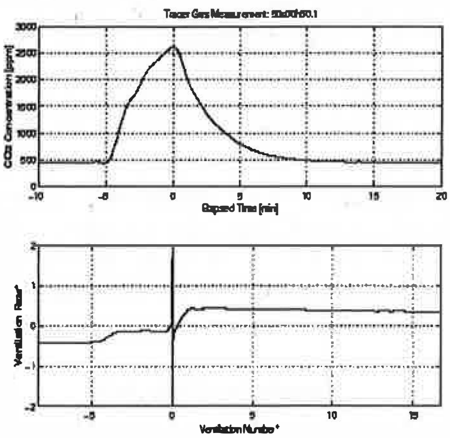

Figure 5 An example of signal analysis using pre-processed data (1Hz).

Figure 5 shows exactly the same signal as in the Figure 3, but was pretreated to remove possible noise from the raw measurement.

Figure 6, 7, and 8 show the same procedure for removing noise from the measured signal also using the filtering algorithm, but with a sampling rate of 7Hz. These results represent the same test conditions as those shown in Figure 3, 4, and 5. The filtering algorithm shows the possibility of applying different sampling rate, and indicates that the 1Hz sampling rate is fast enough to capture the variation of tracer gas concentration. However, to reduce the data storage requirement the sampling rate could possibly be reduced further without loss of information.

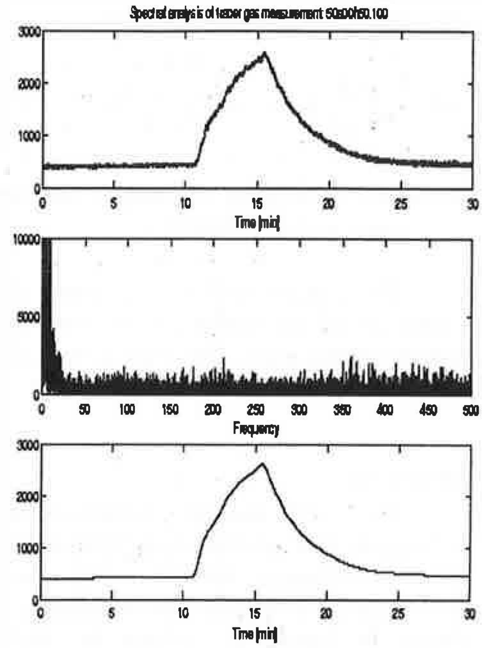

Figure 6 A typical raw signal of CO_2 concentration obtain in the physical model experiments.

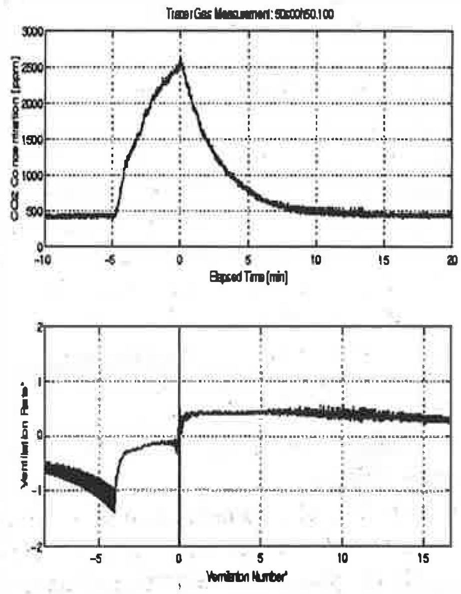

Figure 7 Digital filtering process of a measured signal using FFT, Notch filter, and IFFT in this order.

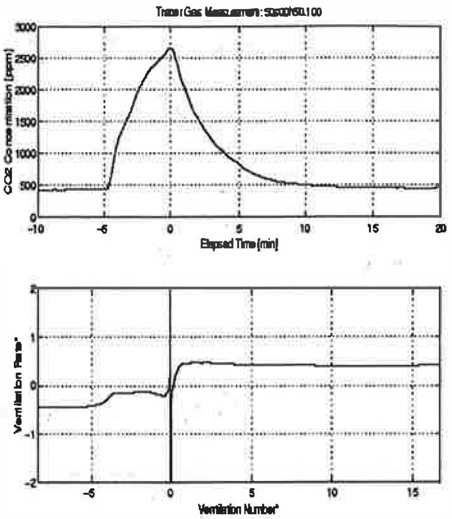

Figure 8 An example of signal analysis using pre-processed data (7Hz).

DISCUSSION

Tracer gas measurements in a small-scale model experiments were used to develop a technique for improving the quality of signal analysis. This was based on continuous reading of tracer gas concentration using a data acquisition system.

The code presented here was used to process the raw measurement which contains possible signal noise. The digital filtering algorithm involved fast-Fourier transformation and inverse fast-Fourier transformation. The FFT transformed the raw data from the time-domain into the frequency-domain. The IFFT transformed the collected data in the frequency-domain into the time-domain and yielded the smoothed version of the raw data.

The main conclusions from the study are as follows:

- The digital filtering algorithm produces data without the high-frequency noise that is present in the raw measurement, which provides a useful tool for the signal analysis of tracer gas concentration.
- A comparison of the data for 1Hz and 7Hz sampling rate showed that the 1Hz sampling rate is fast enough to capture the useful data in the tracer gas concentration signal. Although higher sampling rate can also be used.
- The data from the filtering algorithm shows that the size of the data file is reduced as a result of the smooth, noise free signal.

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