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Investigations of Wireless Sensor Networks for Indoor Particulate Matter Monitoring

Heng Luo[1]*, Ai Huang Guo[2], Jianping Chen[3], Yu Tang[4], Weizhong Yu[5], Yafei Ji[6]
[1,3,4,5]Suzhou key laboratory of mobile networking and applied technologies,
SuZhou University of Science and Technology, China
[2]School of Electronic and Information Engineering, Tongji University, China
*Corresponding author; email: luoheng1981@163.com[1], tjgah@mail.tongji.edu.cn[2],
alanjpchen@yahoo.com[3], ustsytong@sina.com[4], ustswzyu@sina.com [5], ustsyfji@ sohu.com[6]

Abstract

Precise measurement of indoor mass concentration of particulate matter is criticially important for the health risk evaluation since modern people spend more than 90% of their life indoors. For the sake of accuracy, long-term monitoring systems should be deployed among which wireless sensor network is a sound solution. However, most of the wireless sensor networks are battery powered and thus energy management scheme should be implemented to prolong the lifetime of the whole network. Meanwhile, sample sites must be selected carefully to avoid the results bias. In this paper, the importance of sample interval as well as sample locations is investigated theoretically and practically. Results show that by adopting efficicent power management scheme, more than 67% of energy can be saved. Finally, methods of sample interval configuration as well as sample sites selection are proposed.

***Keywords**: particulate matter pollutants, wireless sensor network, sample interval, sample location, energy reduction*

1. Introduction

Extensive epidemiological studies have provided strong evidence of associations between indoor particulate matters and adverse human health, especially for young children, because a large part of lifetime, exceeding 90%, of modern people was spent indoors. The results in [1] showed close relationship between indoor particulate matters and the risks for respiratory diseases in young children. Other studies also demonstrated the connection between particulate matters and pulmonary injury [2], neurodegenerative disorders [3] and cardiovascular disease [4].

Great efforts, therefore, have been devoted to study the long-term variation of concentration of particulate matters indoors [5][6], the relationship between indoor and outdoor PM pollutants [7][8], spatial variation of PM pollutants [9] and factors influencing variability in the infiltration of PM pollutants and its components [10]. The results obtained in much literature, it is observed, use long-term samples before which a wireless sensor network should be deployed to avoid destroying original room structures and record the density of particulate matter pollutants without the care of human beings while maintaining accuracy.

However, most of wireless sensor networks are battery powered due to the constraints of sample locations and absence of prefixed power infrastructure. As a consequence, energy conservation schemes should be implemented to prolong the lifetime of sensor network so that more samples can be collected automatically. Meanwhile, sample sites selection is also crucial since random sample locations may lead to up to 20% difference among final measurement results **Error! Reference source not found.**.

In this paper, the problems of energy reduction and sample sites selection are investigated carefuuly followed by proposing an energy saving scheme baseing on the observation that the difference between two neighboring sampling results is marginal. The paper is organized as follows. Section 2 describles the experiments tools and theoretical simulator. The third part discusses the experiment and simulation results and estimates the energy reduction level by using energy saving schemes. The final section concludes this paper.

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2. Research Method

Practical measurement and theoretical analysis are combined to investigate the issues in particulate matter wireless sensor networks indoors.

2.1. Sampling Equipment

The direct reading monitoring device, Dylos Air Quality Monitors (Model DC1700, with external dimensions of 17.78mm*11.43mm*7.62mm) were used in this paper. It depends a light scattering technique to determine the density of airborne matter with 2 size ranges small (with diameter > 0.5μm) and large (diameter > 2.5μm). An air sample is continuously drawn into the instrument by a pump. The incoming air passes through a laser beam in a photometer and the density of particulate matter is displayed and recorded.

Figure 1. Sample Device

2.2. Sampling Locations

Five sampling locations in the school campus are chosen and two are shown in Figure 2. The building was constructed in 2000 and there isn't any air-conditioner system in all five locations.

(a) Classroom #1 (18m*9m) (b) Classroom #2 (6m*9m)

Figure 2. Two Sampling Locations

2.3. Data Collection

The instruments were operated for 47 days from 2 September 2013 to 18 October 2013. The sampling periods are 12 hours from 8 am to 10 pm. The sampling interval is 1 minute originally.

2.4. Theoretical Model-Computational Fluid Dynamics (CFD)

Besides experimental measurements, a theoretical model, computation fluid dynamics model, is employed. By solving a collection of partial differential equations numerically for the conservation of mass, energy and turbulence quantities, CFD model is able to provide the field distributions of contaminants. Despite of some uncertainties in the model the CFD model has become more and more popular with the development of computing capacity.

3. Results and Analysis

Both experimental results and theoretical simulation results are analyzed in this section.

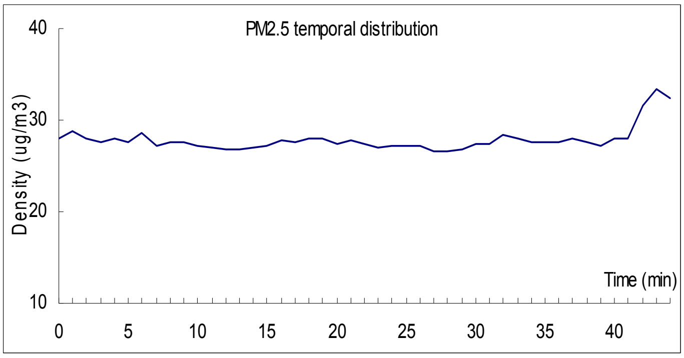
3.1. Sample Interval

(1) Experiment results

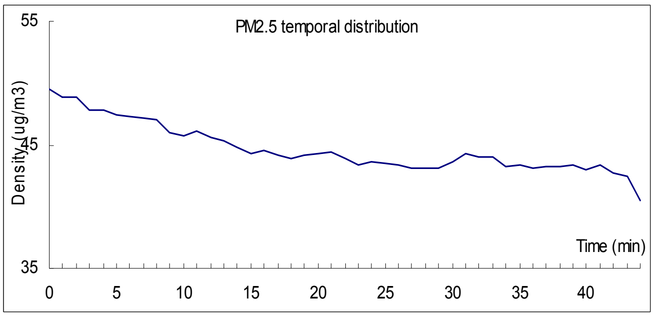
For the sake of space limitations, only two sets of measuring samples are depicted in Figure 3. However, other samples have similar performance.

As seen in Figure 3(a), the mass concentration of PM2.5 decreased slightly with time. However, an unexpected swift growth at the final stage is observed since that lecture was ended 3 minutes ahead of scheduled time. Likewise, the density of PM2.5 in Figure 30(b) declined with time. Nevertheless, it decreased much quicker than that in Figure 3(a).

Meanwhile, it is observed that the mass concentration in Figure 30(b) is higher on average compared to that in 0(a). The main cause is that the window is shut down when temperature decreases and therefore the exchage rate between indoor and outdoor air is small.



(a) Samples in 8:55 ~9:40 on 17 September, 2013 (23℃ ~ 32℃, Sunny)

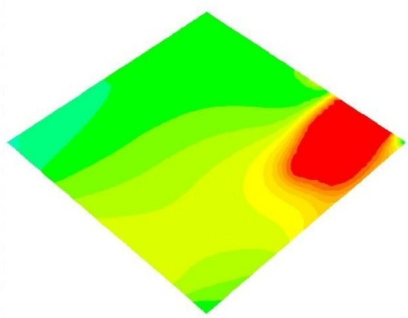


(b) Samples in 8:55 ~9:40 on 8 October, 2013 (20℃ ~ 23℃, Rainny)

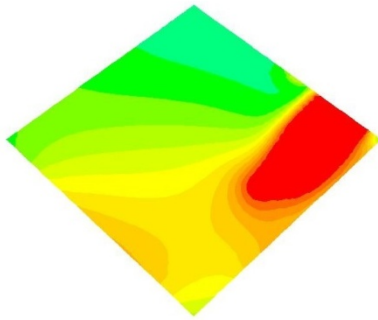
Figure 3. Samples in a Period of 45 minutes in SuZhou University of Science and Technology

(2) Theoretical simulation results

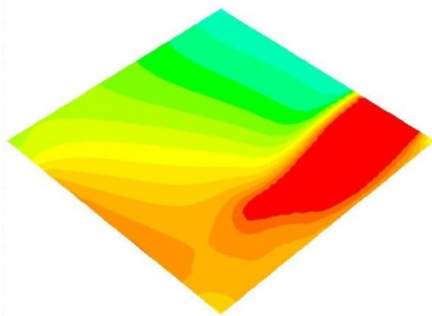
CFD model is used to simulate the temporal distribution of PM2.5. The average outdoor density of PM2.5 is configured to 75 $\mu g/m^3$, which is an average mass concentration in China. As seen in Figure 4 the density of PM2.5 varies with time. However, the difference is not large.



(a) 3 minutes after initial stage



(b) 5 minutes after initial stage



(c) 7 minutes after initial stage

Figure 4. Simulation Results by CFD Model

As seen in Figure 4, the difference all three figures is marginal.

(3) Discussion

(a) Sampling interval optimization

As concluded from Figure 3, the concentration of particulate matters is temperature related. It is observed, however, that the difference between two neighboring sampling results is marginal. As a consequence, the sampling interval, it is suggested, should be prolonged so that much more energy can be saved.

Different sampling intervals are employed to test the reliability of the proposed energy conservation schemes and the results are shown in Figure 5 where, for example, interval_1 means the sampling interval equals 1 minute. As depicted, the difference between “interval_1” and “interval_3” are marginal. However, the difference becomes obvious as the interval increases to 5 minutes. Therefore, the interval, in this case, is set to 3 minutes.

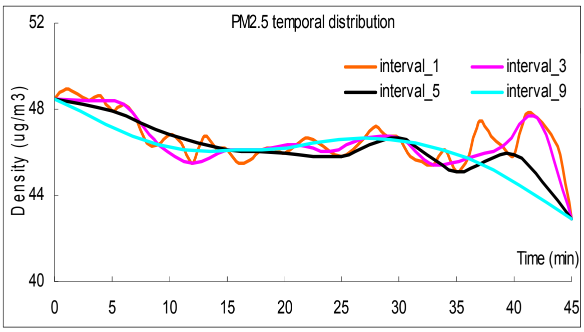


Figure 5. Samples with Different Intervals in 8:55 ~9:40 on 17 October, 2013 (18℃ ~ 22℃, Cloudy)

(b)Transmission interval optimization

Figure 6 describes the power consumption of the whole PM sensor network. As shown, transmission energy cost counts for about 42% of the total energy consumption. Therefore, more energy may be saved by extending the sampling interval.

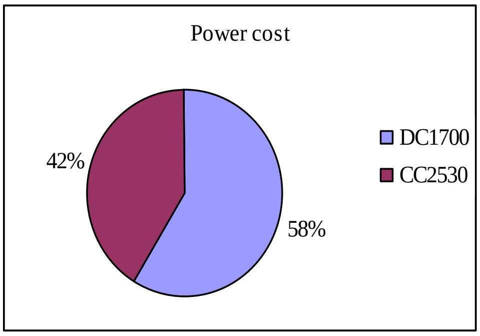


Figure 6. Power Consumption of DC1700 (PM2.5 monitor) and CC2530 (TX device)

(c) Total energy reduction

The total reduced energy is estimated via:

$$P_{reduced\_all} = P_{reduced\_\mathrm{sample}} + P_{reduced\_TX} \tag{1}$$

Where $P_{reduced\_all}$ is the total power reduction, $P_{reduced\_sample}$ and $P_{reduced\_TX}$ denote power reduction by sampling interval increase as well as less transmission times respectively.

Table 1. Estimated Energy Cost for 3 minutes

	sampling power cost (mw)	TX power cost (mw)	Total power cost (mw)
interval_1	1.4 × 3	1 × 3	7.2
interval_3	1.4 × 1	1 × 1	2.4

Table 1 itemizes the power consumption of sampling and transmission part using Eqation (1). As seen, the total power consumption of interval_1 triples that of interval_3, demonstrating the efficiency of the proposed energy saving mechanism theoretically.

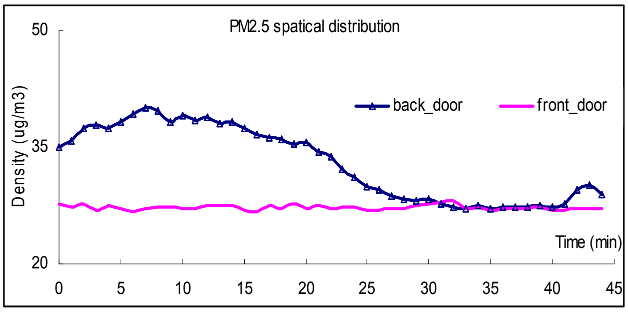
3.2. Sampling Sites

Besides sample interval, sample locations may also have great impact on the accuracy of the monitoring results.

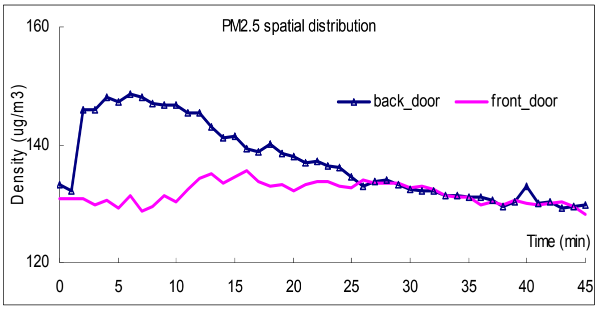
(1) Experiment results

For the sake of space limitations, only two sets of measuring samples are depicted in Figure 7. However, other samples have similar performance.

As shown, the mass concentration of PM2.5 in back door is higher than that in the front door since the back door was always open before class. One more finding is that the concentration of PM was temperature related and it was higher in cold days. Last but not the least, the difference of concentration between the front door and back door samples was large at the initial sampling stage after which those two lines overlapped with time until reaching the same value finally.



(a) Samples in 8:55 ~ 9:40 on 17 September, 2013 (23℃ ~ 32℃, Sunny)



(b) Samples in 8:55 ~9:40 on 16 October, 2013 (13℃ ~ 20℃, Cloudy)

Figure 7. PM2.5 Samples

(2) Theoretical simulation results

Mass concentration of indoor particulate matter in two sites are evaluated. One site is selected near the ventilation site while the other is located in the room. The results are shown in Figure 8. As observed, the difference in two sites becomes smaller with time before overlapping with each other.

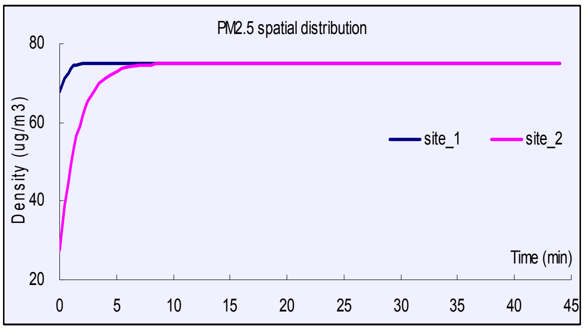


Figure 8. PM2.5 Spatial Distribution

4. Conclusion

Wireless sensor network is a promising alternative for indoor particulate matter pollutants monitoring. However, both the sample interval configuration and sample sites selection may lead to the results bias.

An energy saving scheme is proposed in this paper to reduce the power cost for the sensor network for particulate matter monitoring. Theoretical analysis shows that 66% energy may be saved by this method.

Two locations (the front door and back door) were selected to deploy the sensor networks for particulate matters monitoring in this paper so that the effects of random selection of sample point can be tested. Extensive experiments show that different sample points may result in 50% difference at most.

Acknowledgements

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