A Study on Pollution Monitoring system in Wireless Sensor Networks

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Abstract——**Air pollution is one of environmental issues that cannot be ignored. The heavy transportation and urbanization result in the air pollutants concentrated in certain areas. Inhaling pollutants for a long time causes damages in human health. Traditional air quality monitoring methods, such as building air quality monitoring stations, are typically expensive. In addition, monitoring stations are generally less densely deployed and provide low resolution sensing data. This paper proposes an urbanair quality monitoring system based on the technology of wireless sensor networks (WSNs). It also integrates with the global system for mobile communications (GSM). The system consists of sensor nodes, a gateway, and a control center managed by the LabVIEW program through which sensing data can be stored in a database. This system is deployed to the main roads in the Taipei city to monitor the carbon monoxide (CO) concentration caused by vehicle emissions. The experimental results show that the proposed system is suitable for micro-scale air quality monitoring in real-time through the WSN technology.**

Keywords——**air quality monitoring; wireless sensor networks; real-time monitoring.**

I. INTRODUCTION

Drawn from industrial and commercial activities, the world's human population concentrates on specific regions. Such a phenomenon is known as 'urbanization'. Although the urbanization brings a higher economic development, the excessive population concentration will cause environmental damage and pollution like air pollution, noise pollution, water pollution, etc. Among various kinds of pollution, air pollution has a direct impact on our lives, because of the rapid emission of pollutants. Over the past decades, governments of many countries have imposed different regulations on air pollutants, so the severe damage brought to human health is reduced considerably. Although there may be no the immediate damage to human lives, however, air pollution still causes some chronic diseases. According to epidemiological studies [1], for example, the long-term exposure to pollutants may result in the harm to respiratory, nervous and cardiovascular systems. Therefore, the real-time monitoring of the air quality is particularly important and necessary.High urbanization in an area may lead to the absence of vegetation in that area. Air cleaning and temperature cooling become more difficult because of the lack of vegetation, and the area will be inevitably influenced by the urban heat island effect [2]. Moreover, the crowded tall buildings and heavy transportation also prevent air pollutants from dispersing. Thus, the government in Taiwan built many air quality monitoring stations to monitor the air quality in urban areas. However, the cost of building the stations is very expensive, so the deployment density is rather low. Let's take the Taipei city as an example. There are approximately 2.6 million people living in an area of 271.8 square kilometer, but only eight air quality monitoring stations are deployedin the area. The distance between the monitoring stations is more than dozens of kilometers. Such a strategy for air quality monitoring does not provide a higher spatiotemporal resolution. This paper proposes an automatic micro-scaled air quality monitoring system for areas with a high density of population and vehicles as shown in Figure 1. The system is based on the wireless sensor network technology and integrates with the global system for mobile communications (GSM) employed for data transmission. The monitoring system consists of a gateway and sensor nodes equipped with the air quality detection sensors. The gateway collects the data received from the sensor nodes and transmits the data to the control center with a database by the GSM network. The high-resolution meteorological data and concentrations of air pollutants can be provided in a real-time manner, including rainfall, wind speed, wind direction, temperature, humidity and the concentration of carbon monoxide (CO). For a preliminary research result, we only target the concentration of CO. In the future, however, a variety of pollutants will be considered by equipping the sensor nodes with corresponding gas sensors. CO is toxic to humans and animals. The National Fire Protection Association (NFPA) in the United States indicates that the main way that CO enters human body is through breathing. The symptoms of CO poisoning are very similar to the symptoms of getting the flu and food poisoning. The symptoms include shortness of breath, nausea, dizziness, and headaches. A high level of CO concentration is fatal, causing death within minutes if not treated [3]. Thus, in our research, a real-time monitoring system is proposed and implemented in the real environment. This system not only overcomes the problem that many monitoring systems cannot immediately send sensing data back but also provides a good way to monitor air pollution parameters such as CO concentration. This paper is organized as follows. Section II provides the related works. Section III outlines the architecture of the WSN and introduces our monitoring system. The section IV shows the experimental results. The final section concludes the paper.

figure 1. the architecture of the proposed automatic micro-scaled air quality monitoring system

II. MATERIALS FOR EXPERIMENT AND SYSTEM MAPPING

In this study, the micro-scale air quality monitoring system is mainly composed of two parts, including a front-end automatic monitoring system and a control center, as shown in Figure 2. The front-end automatic monitoring system uses the WSN as its core technology, accompanied by the technology of Global System for Mobile Communications (GSM). This monitoring systemcould provide meteorological parameters and air pollution data from a small time scale. It includes a gateway and wireless sensor nodes. The gateway is used to control sensor nodes, collect the sensing data from the sensor nodes, and transmit the data to the control center through the short message service (SMS) provided by GSM. The gateway, on the other hand, is equipped with a weather station module, which provides various meteorological parameters, including temperature, relative humidity, barometric pressure, rainfall, wind speed, and wind direction. Through the LabVIEW program [9], the sensing data can be stored and integrated into the database. In addition, users can make inquiries to the historical data and the latest updated data through the web page provided by the database.
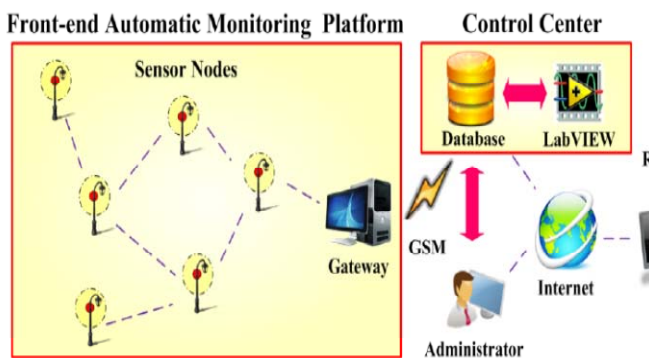
a. Sensor Nodes

Figure 2. The architecture of the micro-scale air quality monitoring system
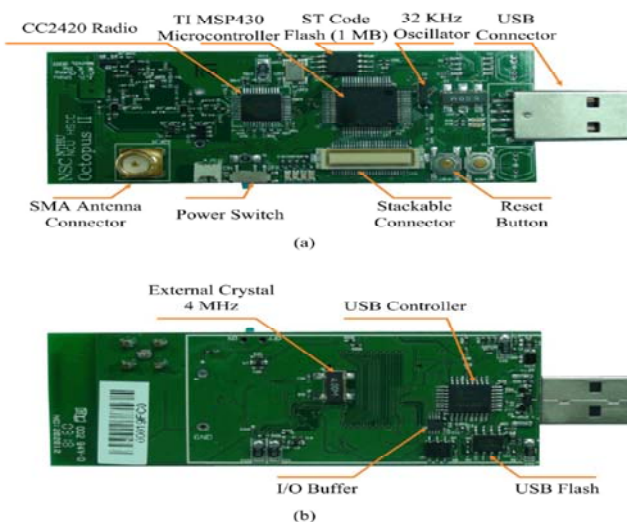

Figure 3. Octopus II wireless communication module utilized in this study. (a) The front of the Octopus II; (b) The back of the Octopus II

1. Wireless Communication Module

The micro-scale air quality monitoring system employs the Octopus II, developed by the Department of Computer Science at National TsingHua University in Taiwan, as its wireless sensor nodes. The configuration of the Octopus II [10] is shown in Figure 3. The Octopus II is based upon the Texas Instruments MSP430F1611 architecture [11]. Fifty pins are available for general purpose input/output and dual 12-bit digital-to-analog (D/A) converters with synchronization. The Octopus II contains a light sensor (Hamamatsu S1087) [12] and a temperature-humidity sensor (Sensirion SHT11) [13] for environmental information acquisition. The memory (10 KB RAM, 48 KB ROM flash, 1 MB extend flash memory) provided by the Octopus II is rather large, so it might serve as a buffer to temporarily store sensing data when thenetwork connection fails. In addition, the Octopus II uses a low-power CC2420 wireless transceiver adopting IEEE 802.15.4 and the ZigBee specification [14] for wireless communication.

2. Gaseous Pollution Sensors :

In this paper, CO derived from the vehicle emissions is selected as the research target, since it is one of the main sources of air pollution and highly toxic to human beings. We use MiCS-5525 [15] to monitor the CO concentration. MiCS-5525 is a semiconductor-based sensor produced bythe e2v Company as a miniature carbon monoxide gas sensor (CO sensor). MiCS-5525 has the merits of short warm-up time, a smaller size and high sensitivity. Figure 4 shows the conversion of CO concentration and the resistance value. $R0$ is a benchmark resistance of MiCS-5525 under a relative humidity of 40 % and a temperature of 25 °C. Rscan be used to estimate the CO concentration under the same environmental conditions. In general, the across voltage of $Rs$is measured to estimate the concentration of CO in practical applications.
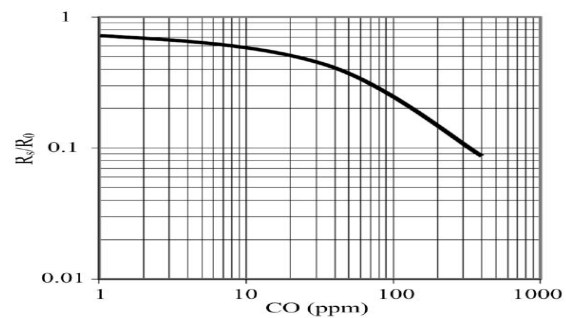

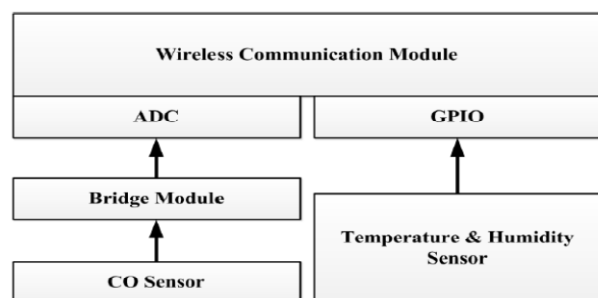Figure 4. Conversion of the CO gas concentration and the ratio of $Rs$to $R0$

Figure 5. The structure of the sensor node

The architecture of the sensor node in our system is shown in Figure 5. The sensor node includes a bridge module, a

wireless communication module (Octopus II), a temperature/humidity sensor, and a CO sensor. We use a 12 V/ 9 Ah battery as the power supply for the node. The CO sensor is also driven by the bridge module. The sensor device is placed inside a waterproof box with two hole affixed with a breathable waterproof membrane as shown in Figure 6.
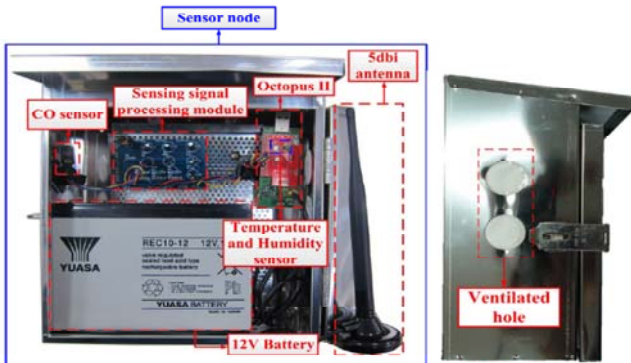

Figure 6. The designed sensor node (a) The front of the sensor node; (b) The lateral of the sensor node

3. Bridge Module

The bridge module is composed of voltage regulation circuits, signal modulation circuits and power switch circuits, as shown in Figure 7. The voltage regulation circuits are mainly used to regulate the voltage fed into the wireless communication module and the CO gas sensor. Thesignal modulation circuits are utilized to modulate the sensing signal generated from the CO sensor, and the power switch circuits are used to turn on/off the CO sensor in order to conserve energy. Figure 8 shows the bridge module.
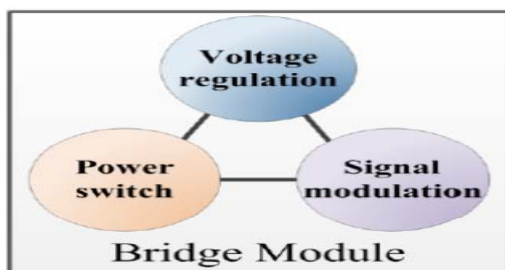

Figure 7. The three sub-circuits of the bridge module

Figure 8. The sensing signal processing module

III. EXPERIMENTAL RESULTS

In order to accurately obtain the CO concentration, we conducted a linear regression analysis on the monitoring data provided by the Environmental Protection Administration (EPA) monitoring station and our sensing data generated by the MCS-5521. Based on the linear regression result, we created a calibration equation that can be used to correct the readings of CO concentration from the CO sensor. In the calibration experiment, we set up 9 sensor nodes next to the sensors from the EPA monitoring station at Yonghe in New Taipei City, as shown in Figure 9. Figure 16 demonstrates that our sensor nodes and the sensors from the Yonghe monitoring station were located at the same height. The experiment was conducted from April 22 to May 3, 2011. The sensor nodes sent the sensing data back every two minutes.

Figure 17 shows the linear regression results based on the 9 sensor nodes, and the points represent the averages of 30 sets of sensing data collected every hour. The horizontal-axis represents the readings (V) from the MiCS-5525, and the vertical-axis represents the readings from the Yonghe monitoring sensor (ppm) that measures environmental CO concentration. Table II shows the results of the linear regression. The ID denotes the sensor nodes number, and the C (v) denotes the calibration equations. Hence, the real CO concentration can be acquired through the voltage readings provided by the MiCS-5525.
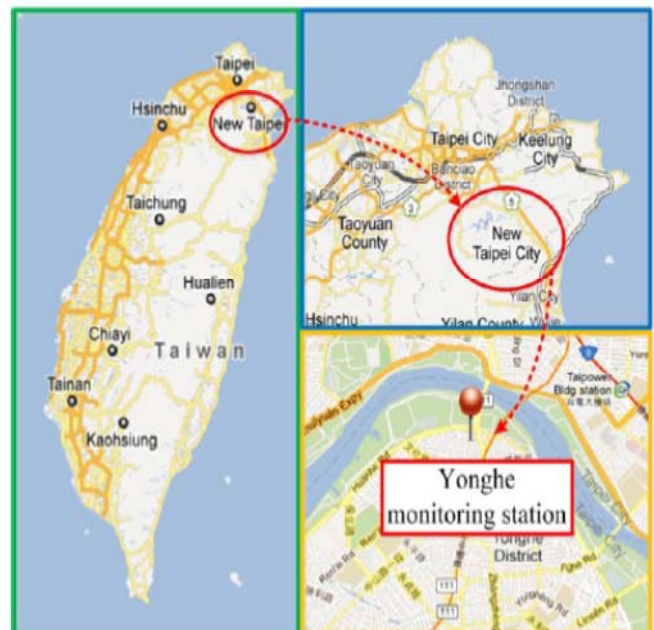

Figure 9. The location of the Yonghe monitoring station

This study focuses on air pollution in the urban areas. The intersection circle of Keelung Road and Roosevelt Road (hereinafter referred to as the Gong Guan roundabout) in the Taipei city has witnessed heavy traffic during the rush hours, and this area urgently requires an air quality monitoring system. We set up a test bed in the Gong Guan roundabout. As shown in Figure 10, the urban air quality monitoring system located in the Gong Guan roundabout includes a gateway and 9 sensor nodes. Figure 11 shows the deployment of the proposed system.

Table II. The calibration equation for each sensor node

ID	C (v)	R^2
2	- 0.8+20.676v	0.7649
3	- 0.9+16.35352v	0.7082
4	- 0.7+72.18853v	0.7793
5	- 0.9+42.64811v	0.7185
6	- 1.4+27.98008v	0.7353
7	- 2.7+26.49416v	0.7173
8	- 2.0+31.07793v	0.8139
9	- 2.8+54.29874v	0.8567
10	- 2.0+39.79569v	0.674

In this study, the sensor nodes were used to collect air pollution and meteorological data every ten minutes, including temperature, relative humidity, CO sensor voltage, wind speed, wind direction, and atmospheric pressure. The CO concentration detected by the nine sensor nodes are shown in Figure 12.

Figure 10. Locations of sensor nodes of the proposed system

Figure 11.Deployment of the air quality monitoring system. A sensor node was attached to the traffic signal pole

There were 24 data sets per day, coming from the hourly averaged data. Two peaks were found at 7 a.m. and 7 p.m., which echoed the rush hours during the daytime. Especially, in rush hours, there were significant changes in the data collected by sensor nodes 3, 4, 5, 7 and 9, because the sensor nodes were mounted on the traffic signals near the intersection. A high concentration of pollutions was detected and continuously accumulating when motor vehicles waited for green lights.

As a result, the CO concentration detected by sensor nodes 3 and 9 was up to 9 parts per million (ppm). According to the definition of air pollution indicators [20], human body will be harmed when the CO concentration reaches 9 ppm. If so, people should avoid the area or wear masks. Thus, the proposed real-time urban air quality monitoring system can provide warnings to the public by showing a red light to further traffic planning.
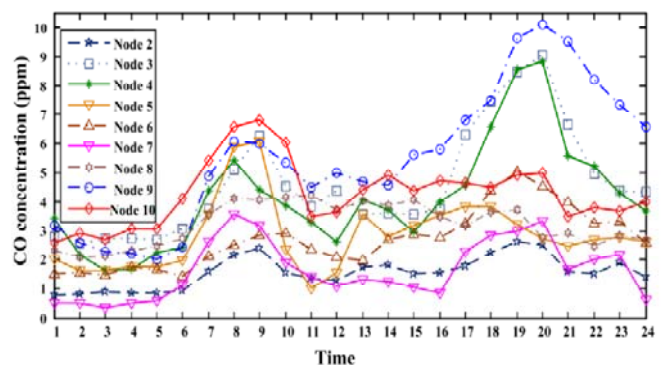

Figure 12. CO concentrations on September 6, 2010, detected by each sensor node

In Figure 12, we made a comparison of the CO concentration during rush hours in the morning and afternoon (7 a.m. to 9 a.m. and 5 p.m. to 7 p.m.). The CO concentration detected by sensor nodes 5, 8 and 10 at the rush hours in the morning were higher than that in the afternoon. As mentioned earlier, the Gong Guan roundabout is an important transportation hub in the Taipei city for people who live in the Zhonghe, Yonghe and Xindian Dist. and have to commute to the city through the roundabout. The readings of the CO concentration in the morning indicated that the traffic flow from Zhonghe and Yonghe (Zhong-Yonghe Dist.) to the Taipei city through the Keelung Road was heavier than that from Xindian Dist. to Taipei. In other words, the traffic flow from Zhong-Yonghe Dist. to the Taipei city generates more serious air pollution than that from Xindian Dist. to the city during morning rush hours. On the other hand, Figure 12 shows that the sensor nodes 3, 4, 6, and 9 detected higher CO concentrations during the rush hours in the afternoon compared with the morning hours, because the heavy traffic flow during the rush hours was from the city to Xindian Dist. and Zhong-Yonghe Dist. Moreover, sensor nodes 3 and 9 were located at a corner of the intersection next to the traffic signal. Comparing with the sensor nodes 4 and 6, sensor nodes 3 and 9 detected that CO concentrations were higher than 9 ppm. Based on the findings, the CO concentration was largely influenced by the direction of the traffic flow and how long cars stopped in front of the traffic signal.

CONCLUSION

This study uses wireless sensor network technologies to acquire and record monitoring data for the goal of completely automatic air-quality monitoring. On the hardware side, we integrate sensor nodes with the CO sensors to perform air-quality-monitoring tasks. The sensor nodes are able to communicate with each other based on the ZigBee protocol. The control center, controlled by the LabVIEW program, successfully communicates with users through sending them SMS messages. It also stores a large amount of data into the database via the MySQL program, so that experts can establish a prediction model of pollution diffusion based on the data. In addition, the monitoring data reveals high-resolution pollution conditions near the Gong Guan roundabout in the Taipei city of Taiwan. The data can be an important source when addressing the issue of the impacts of motorcycles at idles (e.g. waiting for a green light) on air quality. Moreover, to achieve real-time monitoring, the data of CO concentration in a particular place could be reviewed from mobile communication devices, such as PDAs, smart phones, and tablet PCs to help keep air quality in check.

ACKNOWLEDGMENT

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