A system for checking the quality of the air in cities that uses wireless sensor networks

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Abstract: Air pollution is a natural problem that can't be fixed. Air pollution is most common in some places where there is a lot of traffic and new construction. When people take in pollution for a long time, it hurts their health. It costs a lot of money to build air quality tracking sites and use other standard methods to check the air quality. The monitoring points are also not as close together and send out sense data with a low resolution. This piece suggests using a wireless sensor network (WSN) to keep an eye on how clean the air is in towns. It also works with GSM, which is the standard way to send text messages around the world. There are sensor nodes, a gateway, and a control center in the system. The control center is run by the LabVIEW program and can store sensor data in a database. Cars on Taipei's main roads use this way to keep an eye on how much carbon monoxide (CO) they put out. The test results show that the suggested method can be used to use WSN technology to keep an eye on the air quality on a small scale and in real time.

KEYWORDS: Tracking the state of the air; wireless sensor networks; tracking in real time.

INTRODUCTION:

People around the world tend to live in certain places because of work and business. There is a word for this kind of change: "urbanization." For the business, having more people live in towns is good. But having too many people will hurt the earth in many ways, such as by making noise, polluting water, polluting air, and so on. There are many kinds of pollution, but air pollution is the one that we have to deal with because it moves so quickly.

There are different rules about air pollution in many countries now than there were 30 years ago. Because of this, they no longer do as much major damage to people's health. Some people get sick over time because of air pollution, but it's not a direct threat to their lives. For instance, studies [1] show that taking in smog for a long time may be bad for your heart, lungs, and nervous system. So, it is very important and necessary to keep an eye on the air quality all the time.

There might not be any plants in a place where there are a lot of people. We can't clean the air and keep the warmth down as well because there isn't much grass. The area will also be affected by the urban heat island effect [2]. This is also not possible because of the heavy traffic and the large number of people who live in apartments. Taipei's government set up many places to measure air quality in

towns to keep an eye on it. But because they are so expensive to build, there aren't that many of them. Let us now look at Taipei. There are only eight places to measure air quality in an area that is 271.8 square kilometers big and home to about 2.6 million people. In between the tracking spots, there are more than 100 km. If you want to keep an eye on air quality this way, it doesn't help you see space and time better. For places with lots of people and cars, like the one in Figure 1, this study suggests an automatic micro-scaled air qualiy tracking system. Technology for portable sensor networks is used to build the system. and works with the global system for mobile communications (GSM) to send and receive data. The tracking system is made up of a portal and sensor nodes that have devices that can measure air quality. The gateway gets information from the sensor nodes and sends it to the control center over the GSM network with a database. In real time, high-resolution weather data and amounts of air pollution can be sent. This includes temperature, humidity, carbon monoxide (CO) concentration, wind speed, and wind direction. As a first step in our study, we are only interested in the CO content. But in the future, different types of pollution will be taken into account by adding gas monitors to the sensor nodes. CO is dangerous for both people and animals. In the United States, the National Fire Protection Association (NFPA) says that breathing is the main way that CO gets into the body. It's easy to mistake the signs of CO poisoning for those of the flu or food poisoning. Headaches, shortness of breath, and feeling sick are some of the signs. If you don't fix it, a high amount of CO content will kill you within minutes [3].
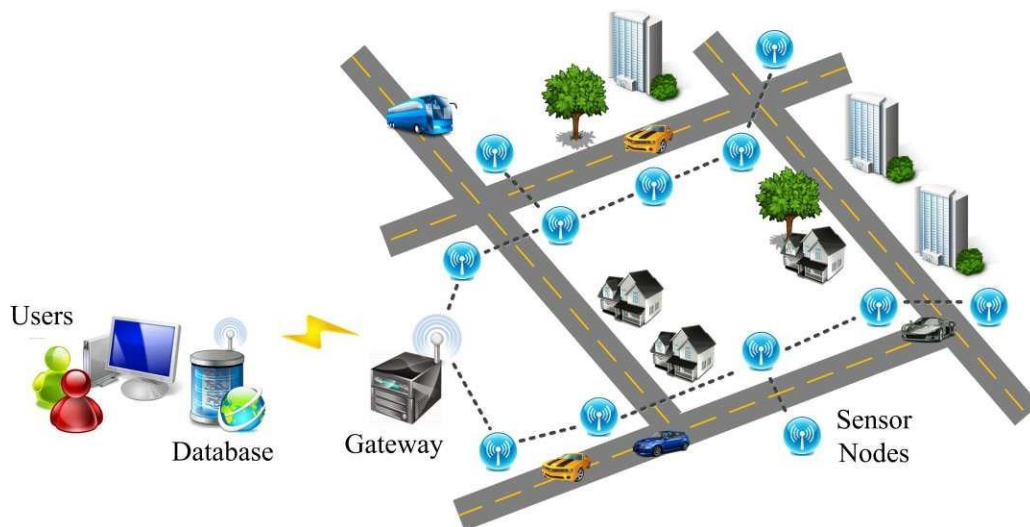

Figure 1. The architecture of the proposed automatic micro-scaled air quality monitoring system

hus, 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.

RELATED WORK:

In this section, we review studies that propose wide-range air quality monitoring systems. The merits and drawbacks of these systems, as well as the reasons why we decide to monitor the concentration of carbon monoxide (CO), are addressed.

A number of air quality monitoring systems have been developed by researchers. For instance, the Mobile Air Quality Monitoring Network (MAQUMON) introduced a mobile monitoring system that utilized moving vehicles equipped with sensor nodes to monitor air quality in a large area [4]. Each sensor node consisted of a microcontroller, an on-board Global Positioning System(GPS) unit, and a set of sensors to detect the concentrations of ozone (O_3), CO, and nitrogen dioxide (NO_2). The node was able to send the sensing data to the gateway in a car through the Bluetooth connection. When the car moved, the sensor node would detect the concentrations every minute and store the data tagged with location information into a memory. When the car moved to a Wi-Fi hotspot, the gateway in the car transmitted the data to the server, and the data would be processed and published on the sensorMap portal. MAQUMON provides a detailed record regarding air quality and pollutant dispersion within the area. But this monitoring system could not immediately send the monitoring data back. Nor was the meteorological information provided by the monitoring system. Moreover, Choi *et al.* proposed a monitoring system targeting air pollutants, called 'APOLLO' [5]. This system could simultaneously monitor many air pollutants (CO, NO_2, volatile organic compounds (VOC), particulate matter (PM), and carbon dioxide (CO_2)) while integrating the WSN technology into the system to transmit sensing data. In their study, however, only a prototype of the system was developed, and no system was actually deployed for outdoor environmental monitoring.

Some researchers have focused on reducing the cost of air quality monitoring. For example, a joint project among University of Cambridge, University of Leeds, University of Newcastle, and University of Southampton called the Mobile Environmental Sensing System across a Grid Environment (MESSAGE) was initiated, aiming at developing a low-cost air quality monitoring system [6]. In this project, each sensor node was equipped with a GPS module, a ZigBee wireless transmission module, a temperature sensor, a CO sensor, a CO_2 sensor, and a NO_2 sensor. Forty sensor nodes were attached to streetlights and traffic lights in Cambridge to complete air quality monitoring task. The sensor node transmitted sensing data to a gateway via the ZigBee protocol, and the gateway sent the data to a control center via the GSM network. The data allowed researchers to do statistical analyses. However, MSEEAGE could only transfer the sensing data to the control

center every 24 hours; it could not provide sensing data in a real-time manner.

Other researchers have attempted to develop smart wireless networks that can be used to monitor a variety of targets. For example, a project called 'Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors (OSIRIS)' was launched [7]. OSIRIS supported different monitoring tasks, and could be applied to monitoring air pollution, water pollution, forest fire, and industry fire. User could easily get different monitoring data via its integrated architecture. Based on OSIRIS, a Spain research team designed the sensor nodes equipped with air pollutant analyzers and attached them onto the roofs of buses and buildings to monitor air quality [8]. The monitoring targets included CO and NO_2 concentrations and noise. These sensor nodes formed a mobile sensor network. The mobile sensor nodes were allowed to communicate with the anchor nodes. After the anchor nodes transmitted the sensing data to the gateway, the gateway would transfer the data to the control center through the GSM network. OSIRIS, however, could not provide meteorological information, and it also required a large number of sensor nodes to complete monitoring tasks.

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, accompaniedby the technology of Global System for Mobile Communications (GSM). This monitoring system
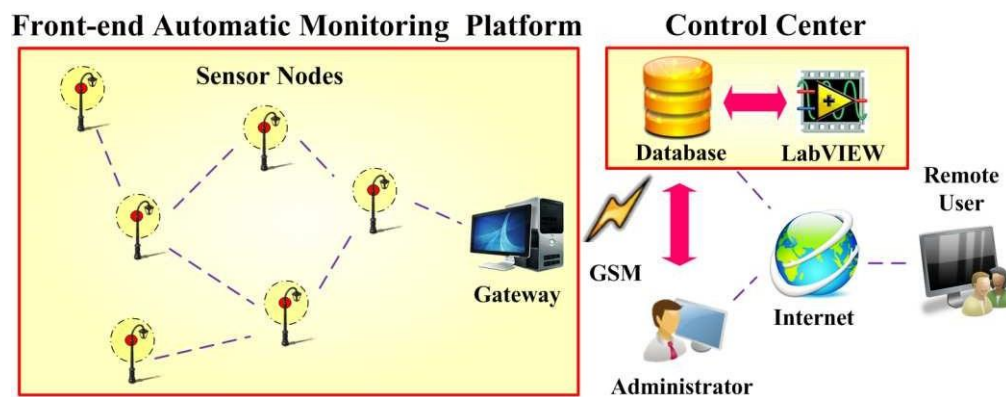

Figure 2. The architecture of the micro-scale air quality monitoring system

could provide meteorological parameters and air pollution data from a small time scale. Itincludes

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

1.   Wireless Communication Module

The micro-scale air quality monitoring system employs the Octopus II, developed by the Department of Computer Science at National Tsing Hua 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 the
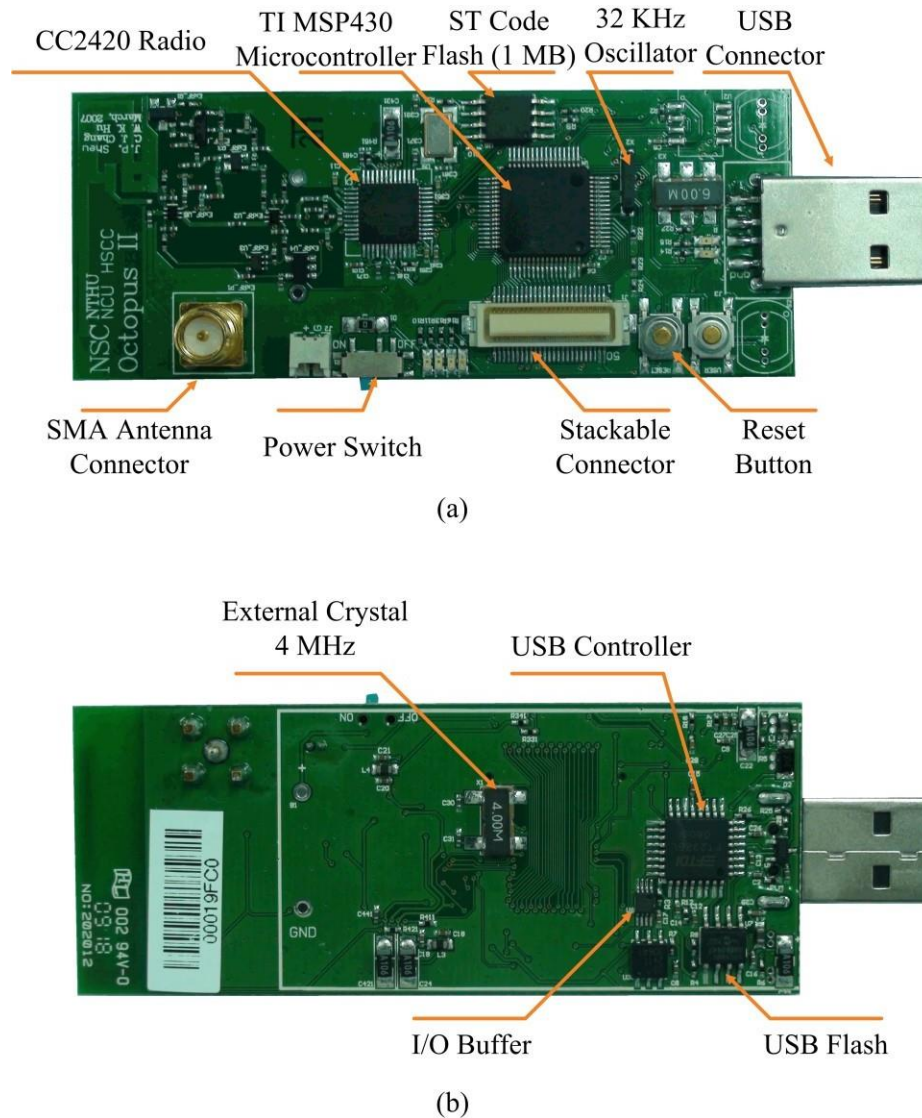
Figure 3. Octopus II wireless communication module utilized in this study. (a) The front of the Octopus II; (b) The back of the Octopus II

network 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 by
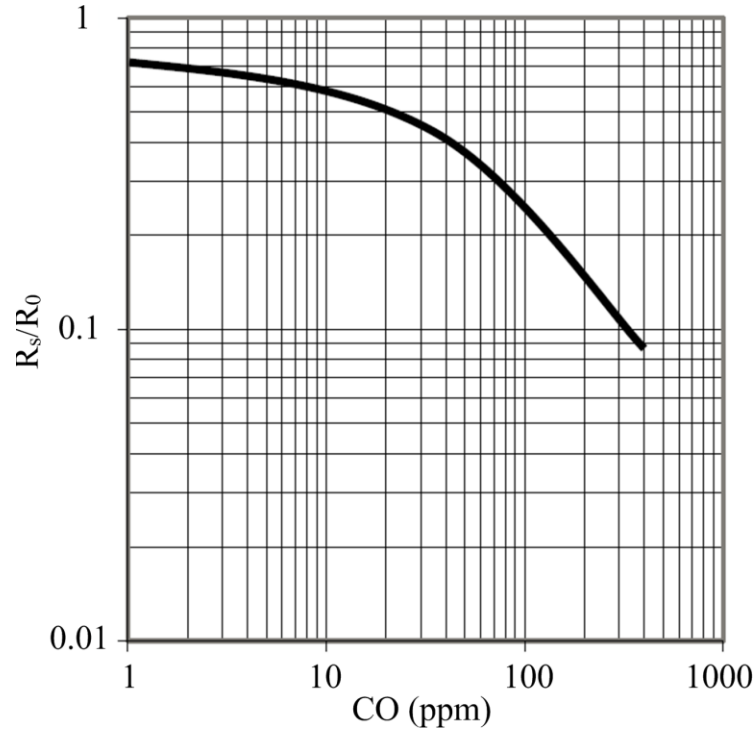
Figure 4. Conversion of the CO gas concentration and the ratio of R_s to R_0

the 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. R_0 is a benchmark resistance of MiCS-5525 under a relative humidity of 40 % and a temperature of 25 °C. R_s can be used to estimate the CO concentration under the same environmental conditions. In general, the across voltage of R_s is measured to estimate the concentration of CO in practical applications.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 bridge module.
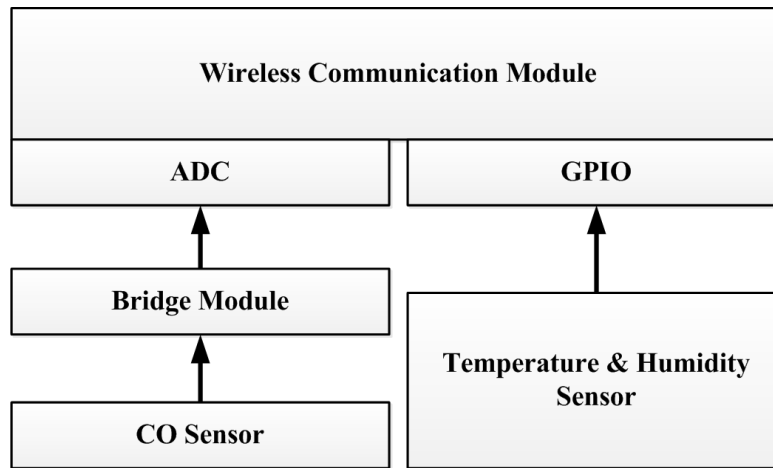
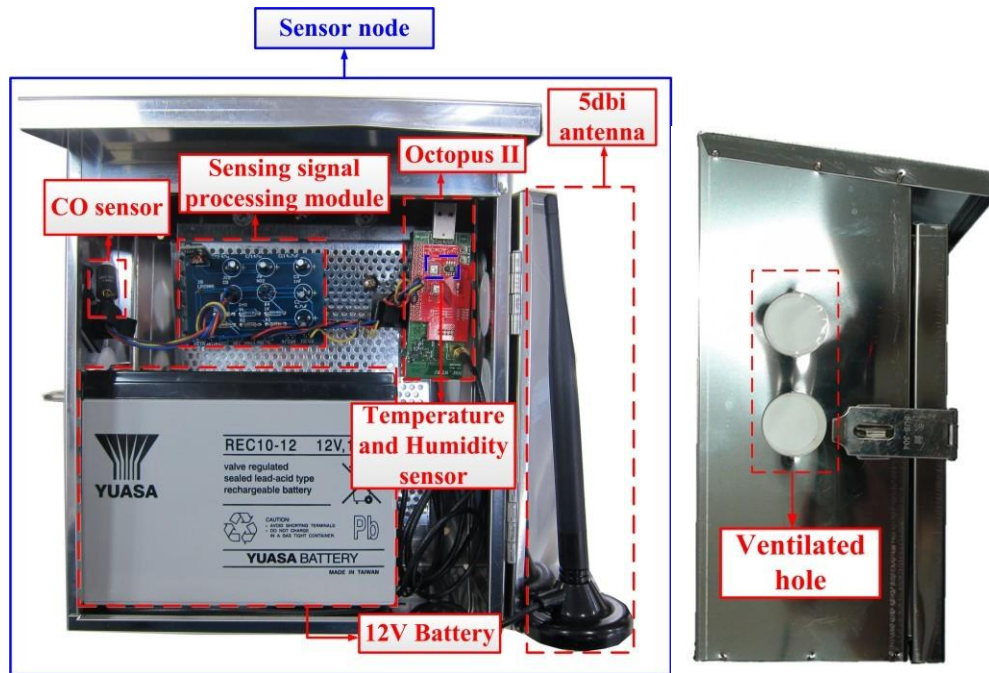Figure 5. The structure of the sensor node

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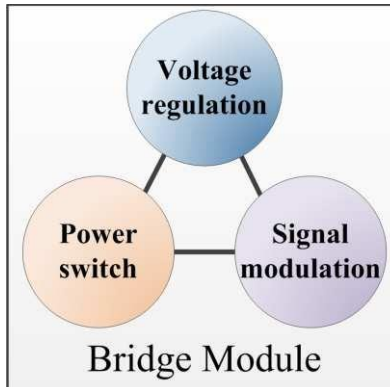
Figure 7. The three sub-circuits of the bridge module

Figure 8. The sensing signal processing module

signal 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. We will introduce the detailed design of the three portions of the bridge module in the following section.

- Voltage Regulation Circuits

The monitoring system is powered by a 12 V/ 9 Ah battery. The voltage regulation circuits regulate the voltage to 5 V from 12 V using the buck regulator for Octopus II and CO sensor. In addition, the voltage regulation circuits can provide several outputs of 5 V as shown in Figure 9. The sensor node records the information regarding the battery voltage in order to determine the timing of changing the battery.
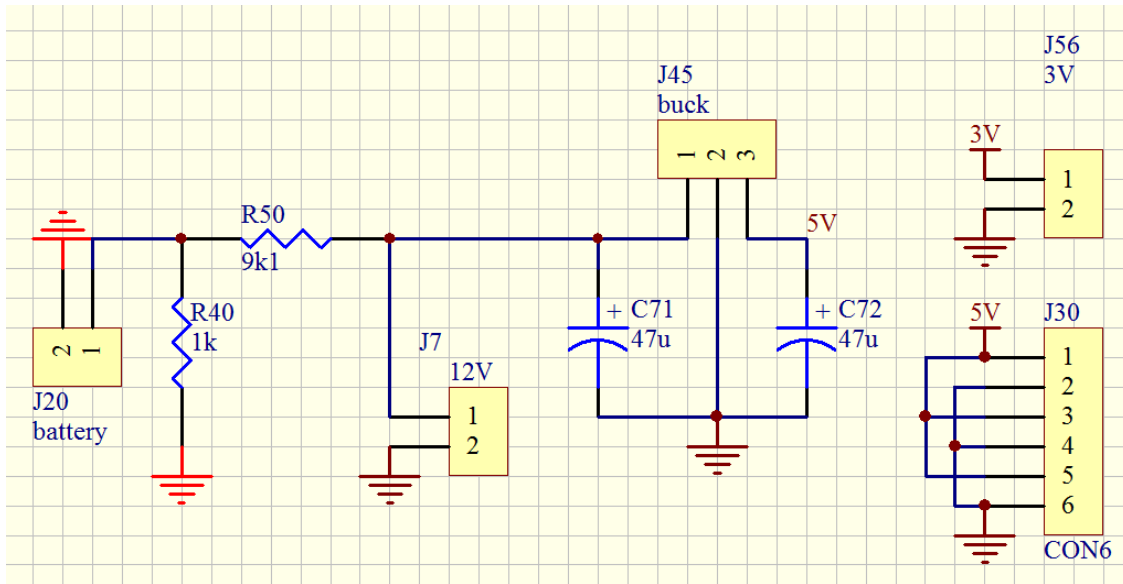
Figure 9. The schematic of the volatge regulation circuits

- Signal modulation circuits

The input voltage of the CO sensor is 5 V, and the resistant R_h of the CO sensor ranges from 66 to 82 ohm. In order to avoid damaging the CO sensor caused by the massive current and to match the signal range that can be read by the ADC, we let an 82 ohm resistor connect to R_h in series to divide the input voltage of 5 V. Thus, the divided voltage of the input voltage is obtained from 2.23 V to 2.5 V as shown in Equation (1) and Equation (2). Following the design, the processing circuits can still activate the CO sensor while satisfying the goal of power maximization of 81 mW.

$$V_{H\,max} = \times \frac{82}{82+82} - \text{V},\ V_{H\,min} = \times \frac{66}{82+} - \text{V} \tag{1}$$

$$P_{H\,max} = \frac{V^2}{R} = \frac{2.5^2}{82} = \text{mW},\ P_{H\,min} = \frac{V^2}{R} = \frac{2.23^2}{66} = \text{m} \tag{2}$$

- Power switch circuits

The power switch circuits use the IC LP2985 to turn on/off the CO sensor. The switch is controlled by the Octopus II. When the Octopus II sends a command to switch on the CO sensor, the circuits will open the power channel for the CO sensor. The schematic of the power switch circuits is shown in Figure 10.

b.   MAC Protocol of the Front-end Automatic Monitoring Network

This Medium Access Control (MAC) protocol is designed by the nesC language, and TinyOS is adopted as its operating system. The designed protocol allows the wireless sensor nodes to sense environmental parameters, transmit sensing data, and fulfill the self-organization. As shown in Figure 11, four phases are included in our proposed MAC protocol, including 1) network establishment phase; 2) configuration phase; 3) data collection phase; and 4) sleep phase. In the network establishment phase, each node establishes its links with the parent nodes. The sensing data is sent back to the gateway through one of these links, which is chosen by the sensor node according to the received signal strength indication (RSSI).
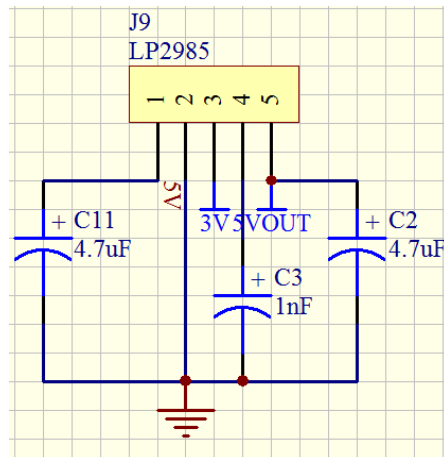

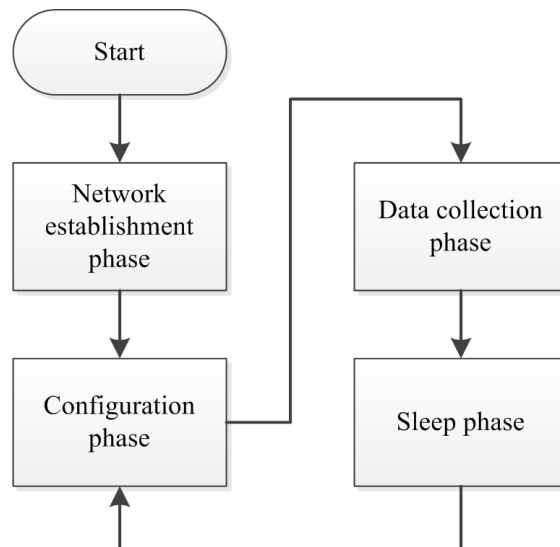Figure 10. The schematic of the power switch circuits

Figure 11. The flowchart of operation of sensor nodes

In this phase, the nodes listen to the information of neighbor nodes for self-reorganization. In the third phase, the entire sensor nodes transmit the data from the bottom layer to the top layer after collecting the sensing data. After all nodes transmit their data, they will enter the sleep phase. After a given period of time, the nodes will wake up and enter the configuration phase. Afterward, they undertake a new data collection task.

c.   Gateway

The gateway is responsible for controlling the sensor nodes, collecting the sensing data received from the nodes, and transmitting the data to the control center. The data to be transmitted to the gateway includes not only the readings received from the sensor nodes – such as temperature, relative humidity, concentration of CO, and the voltage of battery – but also the meteorological information acquired through the La Crosse Technology WS-2316 weather station module [16]. Figure 12 shows the architecture diagram of the gateway. The gateway is made up of anindustrial PC (IPC), a base node, a GSM module, a weather station module, and a Stevenson screen as its shelter. All of the external devices are affixed to the gateway via Universal Serial Bus (USB) interfaces, and they are controlled by the program written by the JAVA language [17]. Figure 13 shows the actual settings of the gateway. All the external devices affixed to the gateway will be introduced in the following section.
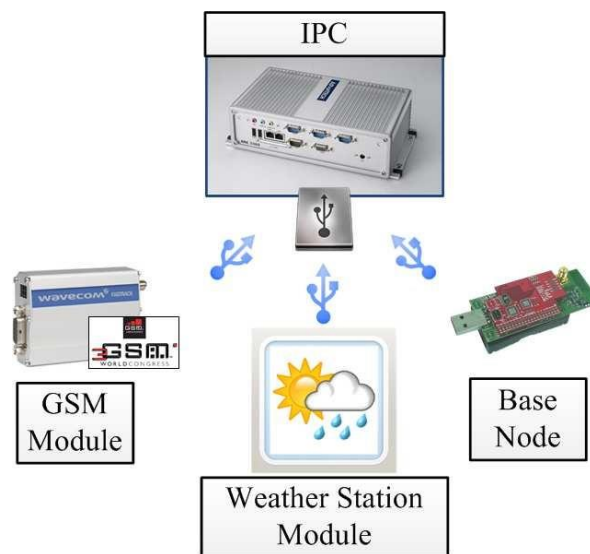

Figure 12. The architecture diagram of the gateway

Figure 13. The proposed gateway (a) ARK-3360L Industrial PC [18]; (b) Weather station module WS-2316; (c) The actual settings of the gateway

1. GSM Module

The GSM module, produced by the WAVECOM Corporation, supports the Short MessageService (SMS). Based on a preset SMS format, all of the collected data is then sent to a control center database via the GSM module. Furthermore, using this GSM-SMS technique, the front-end automatic monitoring system can be remotely controlled by the control center through the GSM module. The format designed for the short message packets used in this study follows the design in our previous work [19].

2. Weather Station Module

The weather station module WS-2316, manufactured by the La Crosse Technology, provides a variety of meteorological parameters, such as temperature, relative humidity, barometric pressure, wind speed, wind direction, and rainfall. The specification of the weather station is shown in Table I. When all of the data generated by the wireless sensor nodes are collected by the gateway, the gateway will transmit the data along with the meteorological information, acquired from the WS-2316 weather station module, to the control center via the GSM module.

d. Control Center

The control center includes an integrated management system, built upon the LabVIEW platform, and a MySQL database. The LabVIEW, developed by the National Instruments, is a platform

Table I. The specification of the WS-2316 weather station module

Meteorological Parameter	Range	Resolution	Unit
Temperature	−29.89 ~ 69.89	0.11	°C
Relative Humidity	20 ~ 95	1	RH%
Barometric Pressure	299 ~ 1098	0.34	hPa
Wind Speed	0 ~ 64	0.58	m/s
Wind Direction	0 ~ 360	22.5	degree
Rainfall	0 ~ 100	0.1	mm/hr

based on a visual programming language. The integrated management system can store different types of data into the MySQL database. Through the MySQL database, a webpage service server allows multi-user access to historical data and latest updated data.

Figure 14 shows the flowchart of the integrated management system. In the beginning, the system checks the connection to the GSM module and the signal quality of the GSM network and then
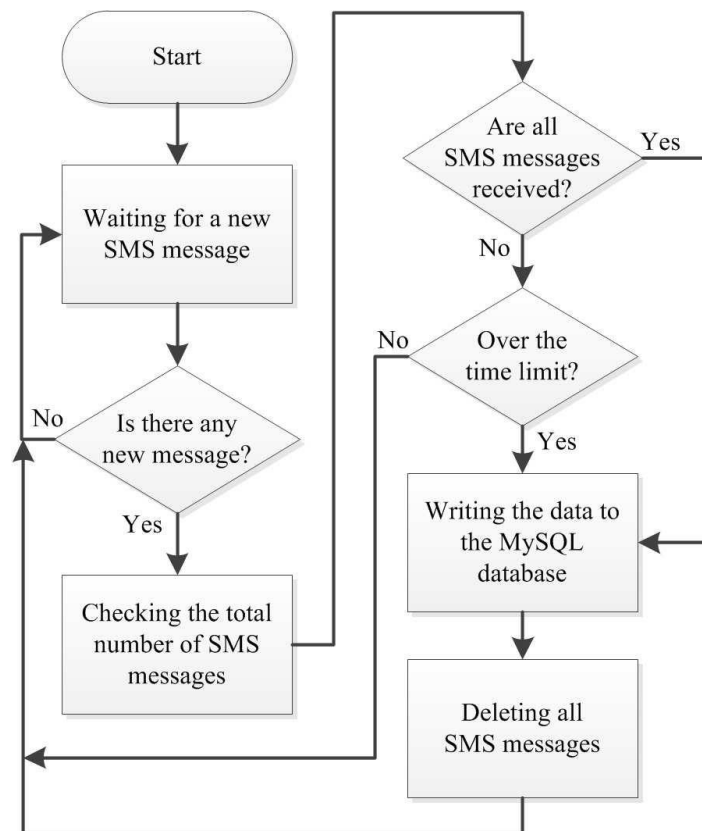

Figure 14. The flowchart of the integrated management system

waits for the SMS message. If there is a new SMS message, the system will know how muchtime is required to record all of the following SMS messages according to the content of the new message. Finally, the system stores the SMS messages into the MySQL database and deletes temporary SMS messages to make more room for other incoming messages.

Furthermore, the database can be modified only through its local computer for security concerns. Remote users are only allowed to make inquiries to historical data and latest updated data through the web pages provided by the database management system to avoid any discredit to the data.

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 15. 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.

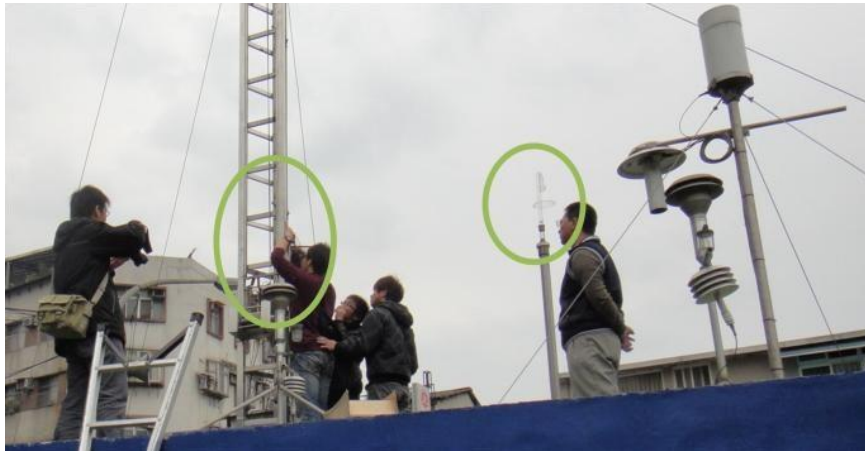Figure 15. The location of the Yonghe monitoring station

Figure 16. The actual layout of sensors in the Yonghe monitoring station. The left circle was our sensor node, and the right circle was the sensing device installed by the monitoring station

Figure 17 shows the linear regression results based on the 9 sensor nodes, and the pointsrepresent the averages of 30 sets of sensing data collected every hour. The horizontal-axisrepresents 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.

Table II. The calibration equation for each sensor node

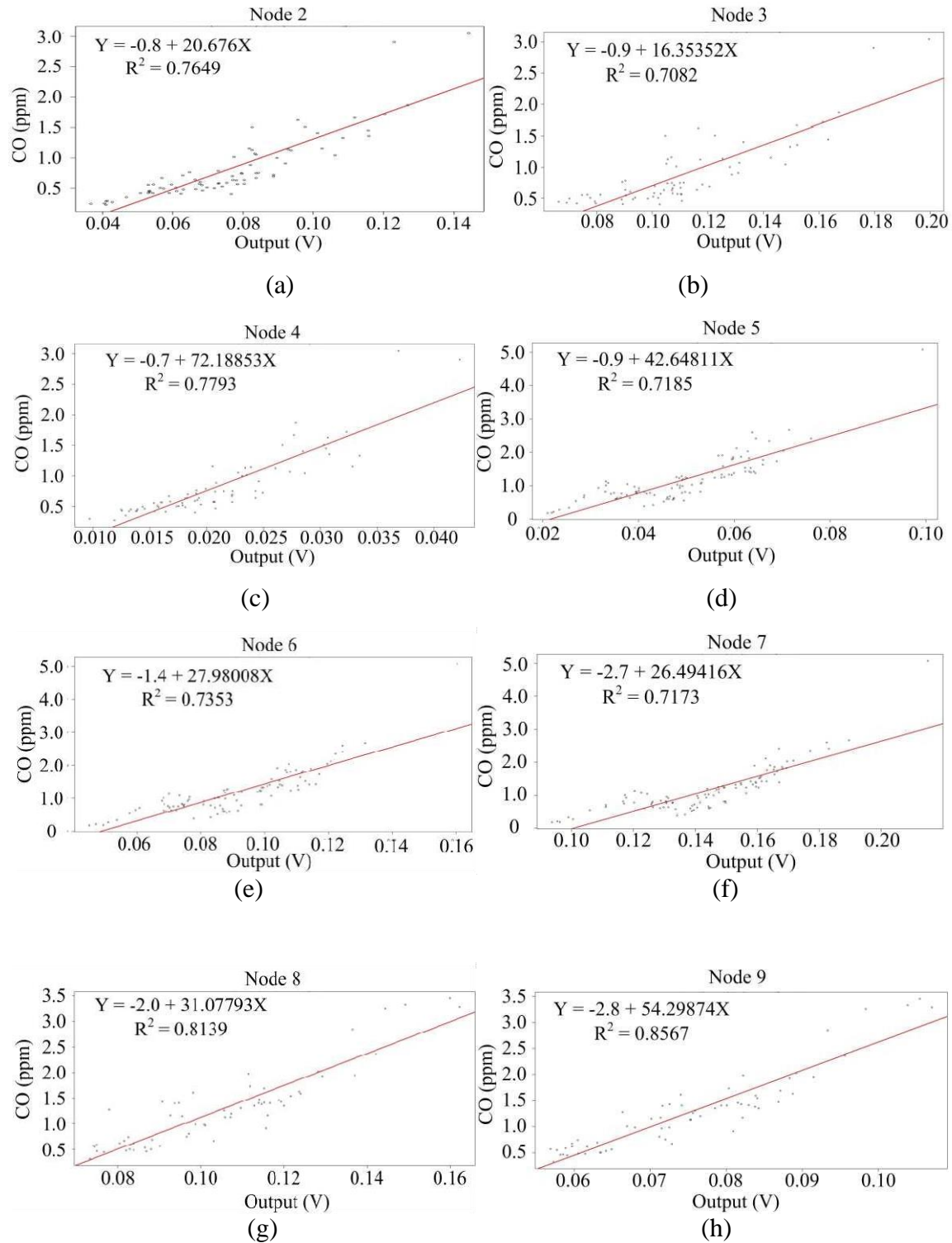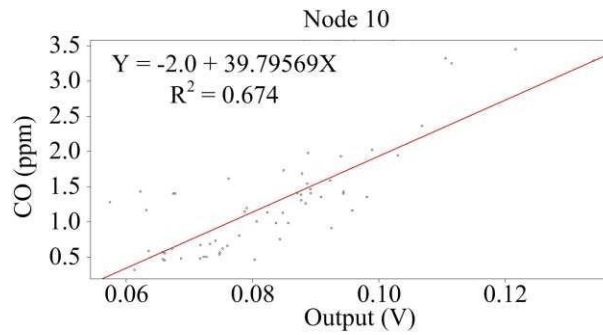| ID	C (v)	R^2
2	$-0.8+20.676v$	0.7649
3	$-0.9+16.35352v$	0.7082
4	$-0.7+72.18853v$	0.7793
5	$-0.9+42.64811v$	0.7185
6	$-1.4+27.98008v$	0.7353
7	$-2.7+26.49416v$	0.7173
8	$-2.0+31.07793v$	0.8139
9	$-2.8+54.29874v$	0.8567
10	$-2.0+39.79569v$	0.674

Figure 17. The results of the linear regression for the CO sensors (MiCS-5525)

(i)

Figure 17. The results of the linear regression for the CO sensors (MiCS-5525) (continued)

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 18, the urban air quality monitoring system located in the Gong Guan roundabout includes a gateway and 9 sensor nodes. Figure 19 shows the deployment of the proposed system.
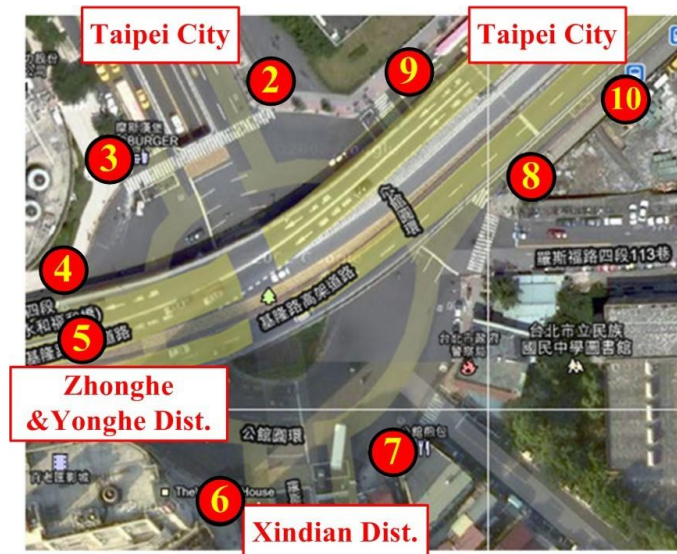

Figure 18. Locations of sensor nodes of the proposed system

Figure 19. Deployment of the air quality monitoring system. A sensor node was attached to the traffic signal pole

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 20. There were 24 data sets per day, coming from the hourly averaged data. Twopeaks 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 and9 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 shouldavoid 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.
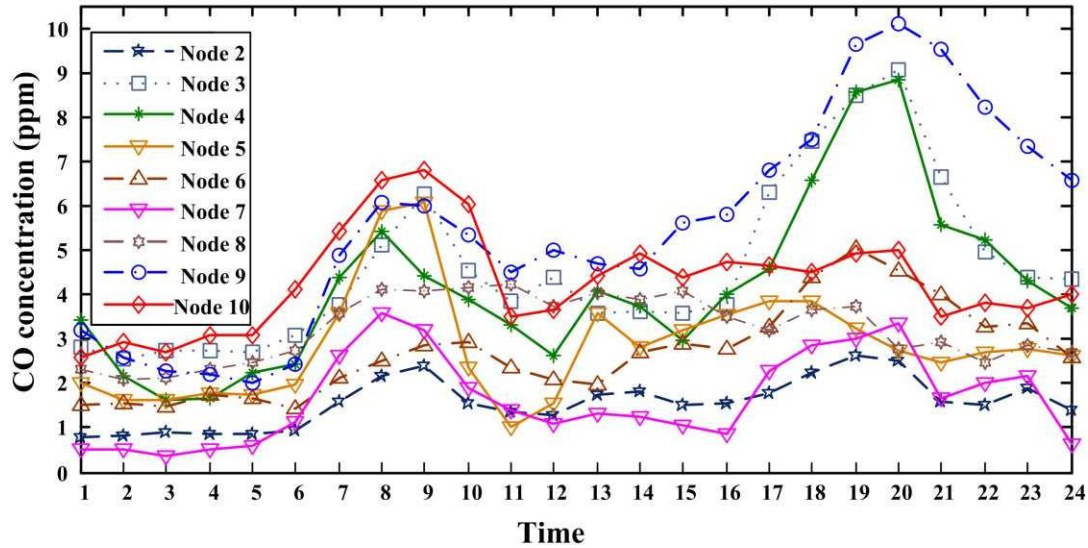
Figure 20. CO concentrations on September 6, 2010, detected by each sensor node

In Figure 20, 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.

CONCLUSIONS:

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, controlledby 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 idle (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 .

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Check out TI's "MSP430F1611 Datasheet" at http://www.ti.com/lit/ds/symlink/msp430f1611.pdf. This page was last looked at on February 6, 2012.

You can get the "S1087 Datasheet" from Hamamatsu in Japan at http://sales.hamamatsu.com/assets/pdf/parts_S/S1087_etc.pdf (viewed February 6, 2016).

Sensirion's "SHT11 Datasheet" can be found at http://www.sensirion.com/en/pdf/product_information/Datasheet-humidity-sensor-SHT1x.pdf. This page was last visited on February 6, 2012.

[14] USA: The "CC2420-IEEE 802.15.4 Datasheet" from TI can be found at http://www.mtl.mit.edu/Courses/6.111/labkit/datasheets/CC2420.pdf (accessed February 6, 2012).

[15]You can find e2v technologies' "MiCS-5525 Datasheet" at http://www.e2v.com/e2v/assets/File/sensors_datasheets/metal_oxide/MICS-5525.pdf. The last time this page was seen was on February 6, 2012.

16: "The weather station module WS-2316 Datasheet," published by LA CROSSE TECHNOLOGY in the USA, can be found at http://www.lacrossetechnology.com/2316/index.php. because of February 6, 2012.