Development of a Wireless Sensor Network for Indoor Air Quality Monitoring

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Abstract Indoor air monitoring, which is one of issues of smart environment, is becoming popular in recent years. This paper presents a proposed wireless sensor network (WSN) for monitoring the carbon monoxide levels of an indoor environment. Furthermore, the temperature and moisture of the air are also acquired in the real-time manner. The WSN consists of sensor nodes, relay nodes, and a gateway node. The data are updated to a web database and can be monitored though a website. In the case of an emergency, alarms would be given through this Android application or Short Message Service (SMS). The power saving scheme is concerned in this paper by reducing the number of active sensors in each node and the number of nodes in the WSN. By using the proposed power saving scheme, the lifetime of a sensor node is up to four months. The experiment shows that the proposed system can be applied to real applications.

Keyword Wireless sensor network, ZigBee, Air monitoring

1. Introduction

Indoor air quality is based on the conditions of air for human requirements [1,2]. It can be seen that the demand of air monitoring is increasing [3,5]. Toxic gases such as carbon monoxide (CO) is one that causes serious health problems. Increasing levels of CO would reduce the amount of oxygen carried by hemoglobin in red blood cells. Consequently, vital organs, such as the brain, nervous tissues and the heart, do not receive enough oxygen to work properly. Thus, the level of CO should be monitored by power saving, cheap, flexible and reliable systems. However, current systems are hard to meet these requirements [6-16].

In [6], the authors proposed a new gas detect and alarm system which is controlled by Single Chip Micyoco and the application of constant temperature catalytic gas sensor. However, the network structure of the system is not shown in detail. In [7], the authors propose a wireless sensor–actuator system which aims at quick gas detection and immediate isolation of the gas leak source. The low power wireless sensor node includes catalytic gas sensors, micro processing unit and wireless transceiver which communicates with wireless actuator using ZigBee/IEEE802.15.4 standard and BACnet protocol. However, the power saving only focuses to the sensing part. In [10], the authors presented two environmental monitoring systems based on WSNs which are used for detecting fire and gas pollution in indoor/outdoor environments. They use the over the air programming (OTAP) in order to up-grade/update the sensor nodes in a WSN. The power consumption has not mentioned in this paper. The relationship among different kind of sensing data was not concerned, either. In [11], six gas sensors were used to test air quality in different rooms and areas of a public hospital. However, it lacks of the mechanism to give alarm to responsive peoples. In [12], a prototype of a WSN for monitoring the air quality indoor environment is presented. It deals with an application of wireless mesh networks for monitoring the carbon dioxide. The information of the network was not shown clearly in this paper. In [15], to improve information extraction from noisy sensor signal, the authors use a filter bank to estimate the power spectral density of the gas sensor resistance fluctuations and apply a low power microcontroller to perform the required digital signal processing and system control functions. It would help save the power of the system.

In this paper, we propose a complete solution of WSN for monitoring the carbon monoxide levels, temperature, and humidity of an indoor environment. The WSN consists of sensor nodes, relay nodes, and a gateway node. In the case of an emergency, alarms would be given through this Android application or Short Message Service (SMS). The power saving scheme is concerned in this paper by reducing the number of active sensors in each node and the number of nodes in the WSN. This reduction is controlled by determining thresholds. The experiment shows that the proposed system can be applied to real applications.

2. Working principle

A WSN, which utilize spatially distributed autonomous sensors, to monitor physical or environmental conditions, such as gas, temperature, sound, pressure, etc. The acquired data are transferred through the network to a gateway node and/or processing center.

2.1. Overview of the system

The complete architecture consists of wireless sensor nodes to measure parameters of the CO, humidity, and temperature of the air. The WSN for air monitoring is designed as a star, tree or combined network models (see Fig. 1). It would depend on the architect of the building that we intend to establish the monitoring system.

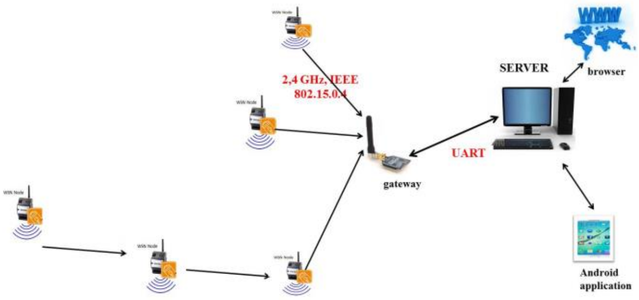


Figure 1. The proposed WSN for air quality monitoring application.

The data will be sent to gateway from each node via Xbee standard. The distance between a node and the gateway up to 7 km and have a 250 kbps RF data rate. The data received from the gateway is duplicated and stored in a database server. Besides, the data are also processed by PC via available designed program. We know about the status of the network and the monitoring of the system components. The real-time data and the results of data analysis are streamed on the Internet in real-time. An alert service such as SMS is implemented to alert to responsive people about the probability of health threats.

2.2. Hardware component of a sensor node

A sensor node consists of sensors, a Wapsmote board, an RF module, and a battery. There are two kinds of sensors in this work: MQ7 and DHT11. MQ7 sensor is used for measuring density of CO gas [17], and DHT11 sensor is used for measuring temperature and humidity of environment [18]. The value of temperature and humidity are also used to correct the value of MQ7 [17]. AVR microcontroller is the main part of the Wapsmote board. The RF module connected to the Wapsmote is Zbee [19].

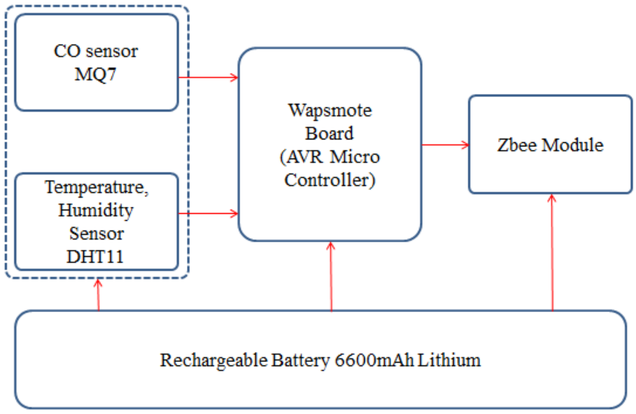


Figure 2. Hardware component of a sensor node

2.3. Software structure of a sensor node

The software part embedded in Wapsmote board includes three main modules:

a. Data acquisition module: This module is developed to provide the capability of collecting data from both digital and analog sensors. The digital signal obtained from the accelerometer is collected using the digital drivers. The analog data are collected from soil moisture and temperature sensor.

b. Data processing module: In the monitoring applications require scheduling the events and managing each node's buffer to avoid loss of events and data. The data processing module is a core component for processing all the incoming and outgoing data from the sensors and transmitting respectively in our WSN. The scheduler module implements three basic functions:

Sensor sampling: This module provides efficient communication between sensors and wireless sensor node. It has the capability to sample and collect sensor data in the user defined inter-sampling rate. And then, data are sent to buffer manager module.

Health monitoring: This module is designed and implemented monitor health of a wireless sensor node. The node health function provides the status of power in the sensor node, the health of the battery.

Power saving: This module is designed to provide a power saving mechanism to wireless sensor nodes. It is implemented by integrating wireless sensor node state transition, such as 'sleep' and 'active' model.

c) Data communication module: This function provides the methods and algorithms to route and configure management in this WSN, which is implemented by routing algorithms and time synchronization methods.

3. Power saving scheme

There are some network standard such as Wi-Fi, Bluetooth, ultra-wideband and Zigbee based on IEEE 802 standard. The Zigbee is the lowest power consumption and it provides self-organized, multi-hop, reliable network with long battery lifetime. Thus, in the paper, Zigbee is chosen to reduce power consumption of the proposed network. Moreover, we introduced a power saving scheme to expend lifetime of the network.

3.1. Power consumption of CO gas sensor

The structure of the MQ-7 gas sensor composed by micro AL_2O_3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made of plastic and stainless steel net. The circuit diagram of the CO gas sensor (MQ7) is shown the Fig. 3.

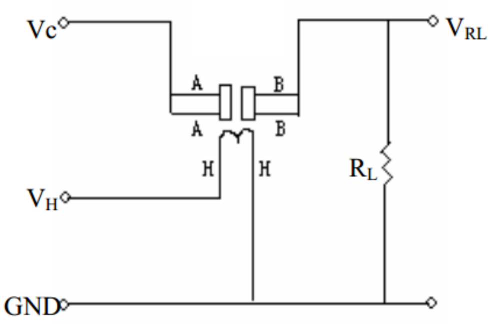


Figure 3. The circuit diagram of MQ7

The MQ7 sensor consists of the heater and sensing components [17]. The heating circuit has time control function (the high voltage and the low voltage work circularly). The sensing component is the signal output circuit, it can accurately respond changes of surface resistance of the sensor. Therefore, the power consumption is total of power consumption of the heater and sensitivity components. The heater consumption (P_h) is $P_h \leq 35$mW and the power of sensitivity body (P_s) is computed as

$$P_s = V_c^2 \times R_s / \left(R_s + R_L\right), \qquad (1)$$

where R_L is the load resistance, and R_s is the sensing resistance which can be computed as

$$R_s = Ro\ (1 + K\sqrt{C}), \qquad (2)$$

where Ro is the electrical resistance of the sensor at zero ppm, K is the constant for the particular sensor, and C is the gas concentration in ppm. It can be seen that Rs depends on the gas concentration. In this work, we choose Vc = 5V, R_s is from 5kΩ to 15kΩ, R_L = 1kΩ. Thus, Ps is in the range of 1.46 and 3.47 mW. Consequently, the total of the power consumption Pt of MQ-7 is from 36.46 to 38.47 mW.

3.2. Power consumption of the humidity/temperature sensor DHT11

The power consuming of DHT11 is computed based on the following table [18]:

Table 1. Working parameters of DHT11

Conditions	Minimum	Typical	Maximum
DC	3V	5V	5.5V
Measuring	0.5 mA	2.2 mA	2.5 mA
Average	0.2 mA	0.8 mA	1 mA
Standby	10 0μA	140 μA	150 μA

In this work, the chosen voltage is 3V. Thus, the maximum power consumption Pmax is 1.5 mW and the minimum power consumption (standby) Pmin is 0.3 mW.

3.3. Power consumption of the Wapsmote board and Zbee module

The consuming power of the Wapsmote board and Zbee module is computed as the following table:

Table 2. Working parameters of the Wapsmote board and Zbee module

Components	Current (mA)		Voltage (V)	Power (mW)	
Wapsmote	15 (Active)	0.055 (Sleep)	3.3	49.5 (Active)	0.18 (Sleep)
Xbee-ZB-PRO module	3		3.3	10 (estimated within the distance of 100 m)	

In the active status, the power consumption of a sensor node (P):

$$P = P_t(DHT11) + P_{max}(MQ7) + P(Wapsmote) + P(Xbee). \qquad (3)$$

From (3), it can be seen that P is in the range of 97.46 to 99.47mW.

3.4. Power saving scheme

The value of MQ-7 depends on temperature and humidity [17]. Thus, for accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence. Consequently, instead of using the conventional scheme as shown in Fig. 6.a, we proposed a power saving scheme that works as shown in Fig. 6.b. In this scheme, the microcontroller read values only from MQ-7. If the value reaches a determined threshold, the data from DHT11 is acquired to compute the corrected value of CO in the air. Based on this corrected value, the final decision of alarm would be made. Moreover, in the normal condition, the number of the active node is reduced 30-50%. The sensor node does not need to send the data packets through the network to the gateway if the indoor environment is safe. It will save the power of the whole system. By using the proposed power saving scheme, the lifetime of a sensor node is up to four months, which is 16 times higher the conventional scheme.

If there is at least an alarm at one node, all nodes in WSN would be set in active mode in order to observe the whole building. Information on temperature, humidity, and CO from each node is sent to the gateway node. The gateway node is connected to a GSM/GPRS module (SIM900 [19]) in order to send an alert SMS to responsive people about the possibility of danger.

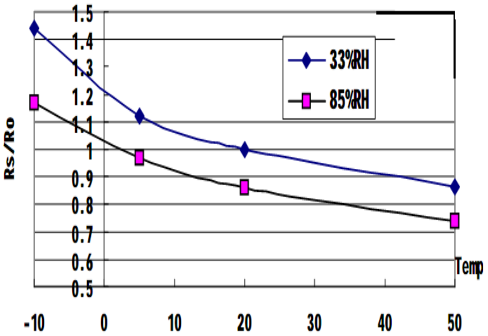


Figure 5. The dependence of the MQ-7's sensitivity (at 100 ppm CO) on temperature and humidity [17].

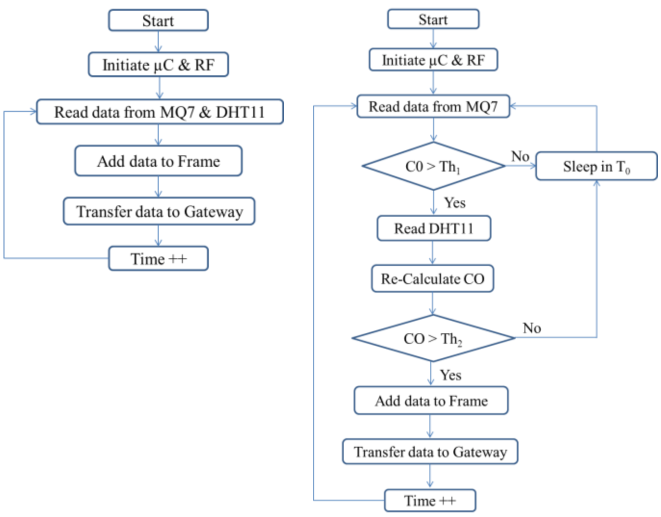


Figure 6. The conventional (a) and proposed (b) power schemes in each sensor node.

4. Experiments

The resistance value of MQ-7 is differently to various kinds and various concentration gases. Thus, the sensitivity adjustment is very necessary [17]. After that, the sensor can be used for measurement (see Fig. 7). Figure 8 shows the real CO density (in ppm) acquired in lab condition. It can be seen that the obtained data reflect well the real CO density in testing conditions.

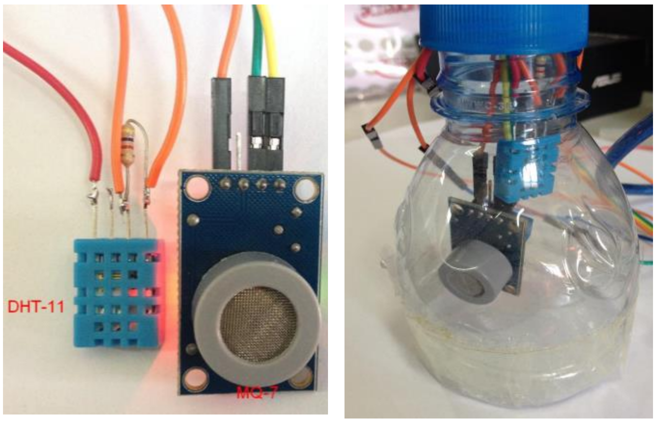


Figure 7. Sensor testing in lab condition

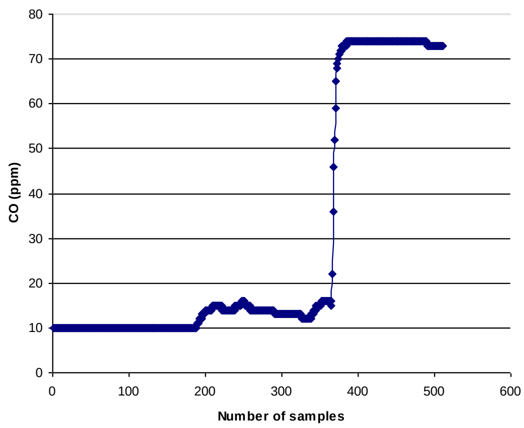


Figure 8. Testing of CO sensor in lab condition

Figure 9 shows a test of the proposed WSN in the lab. The data from each node are updated to a web database and can be monitored though a website (see Fig. 10). By using a GSM/GPRS module (SIM900) at the gateway node, an SMS would send to the responsive people in case of danger.

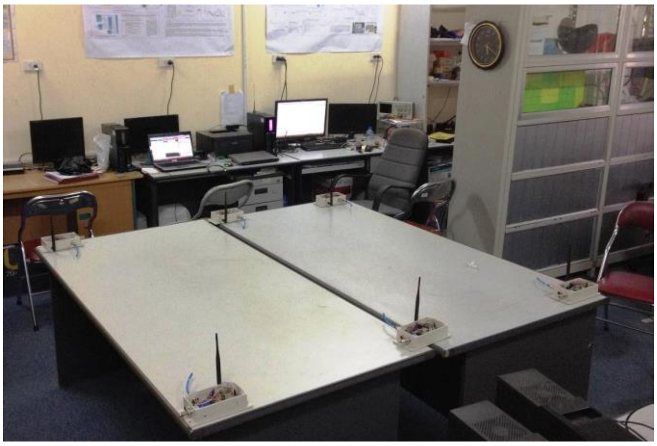
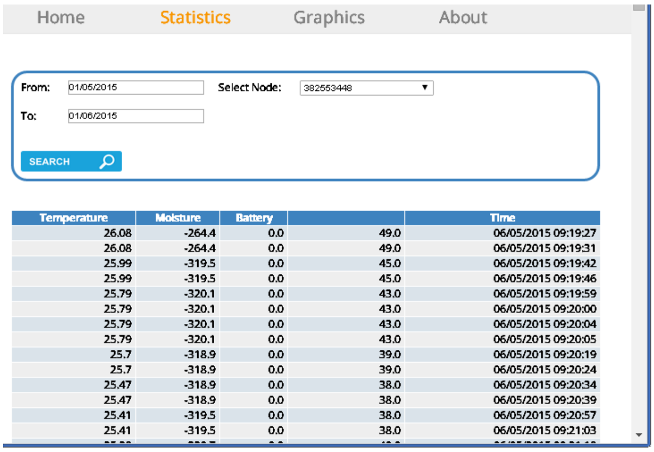


Figure 9. WSN testing in lab condition



Temperature	Moisture	Battery		Time
26.08	-264.4	0.0	49.0	06/05/2015 09:19:27
26.08	-264.4	0.0	49.0	06/05/2015 09:19:31
25.99	-319.5	0.0	45.0	06/05/2015 09:19:42
25.99	-319.5	0.0	45.0	06/05/2015 09:19:46
25.79	-320.1	0.0	43.0	06/05/2015 09:19:59
25.79	-320.1	0.0	43.0	06/05/2015 09:20:00
25.79	-320.1	0.0	43.0	06/05/2015 09:20:04
25.79	-320.1	0.0	43.0	06/05/2015 09:20:05
25.7	-318.9	0.0	39.0	06/05/2015 09:20:19
25.7	-318.9	0.0	39.0	06/05/2015 09:20:24
25.47	-318.9	0.0	38.0	06/05/2015 09:20:34
25.47	-318.9	0.0	38.0	06/05/2015 09:20:39
25.41	-319.5	0.0	38.0	06/05/2015 09:20:57
25.41	-319.5	0.0	38.0	06/05/2015 09:21:03

Figure 10. WSN data is managed by a web database.

5. Conclusion

The paper success in building an energy effective air monitoring system consists of sensor nodes to collect data, transmit to gateway node, and send an SMS to responsive people about the possibility of danger. An effective power scheme is proposed by reducing the number of active sensors in each node and the number of nodes in the WSN (if the system is in the normal condition). The system is measured and tested in the lab to evaluate the performance of the proposed system. Basing on an existing system, a power plan to read and transfer data that help to improve significantly the lifetime of the sensor node. The quality of the transmission is also ensured by reducing the collision. In the future, we will apply in real environment.

6. Acknowledgement

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