Institute of Physics Publishing Journal of Physics: Conference Series **48** (2006) 250–254
doi:10.1088/1742-6596/48/1/046 International Symposium on Instrumentation Science and Technology

Research on Electronic-nose Application Based on Wireless Sensor Networks

A Zhao, L Wang and C H Yao

Tongji University, Shanghai, China

E-mail: angz@sohu.com

Abstract. The paper proposed a structure of Wireless Sensor Networks based Electronic-nose system to monitors air quality in the building. In the study, the authors researched a data processing algorithm: fuzzy neural network based on RBF(Radial Basis Function) network model, to quantitatively analyze the gas ingredient and put forward a routing protocol for the system.

1. Introduction

Modern building is often designed as close room without windows and keeps air clean by ventilator. Because room is separated into many parts to satisfy the need of work, the air quality of each part is different: some place has fresh air, some is bad. When we use air conditioner to improve air quality, problems still exist. It was ever reported many officers are absent of oxygen in a modern building in Shanghai city last year. So it is very important to take appropriate action to keep air fresh. Starting air conditioner selectively is a good method, which can keep each part's air fresh and save much power. In the condition, we have to monitor air quality and take action when air quality turns bad.

This paper put forward an application model to solve the problem: Wireless Sensor Network based Electronic-nose system connects many electronic-nose nodes to network, quantitatively analyzes the gas ingredient with RBF based fuzzy neural network (FNN, Figure 1) and sends message to the monitor center. The monitor center analyzes the data and starts relevant ventilator. In addition, the system can recognize the variety of air ingredient by fire and start fire alarm to evacuate the building.

2. ZigBee based Wireless Sensor Networks

Wireless Sensor Networks (WSN), which is made by the convergence of sensor, micro-electro-mechanical system (MEMS) and wireless communications, is a special self-organizing network which can be an integral part of systems such as battlefield surveillance and microclimate control in buildings, nuclear, biological and chemical attack detection, home automation and environmental monitoring. The sensor nodes can be positioned in the target situation random or designedly and cooperate by communication. Then, they apperceive environment and accomplish the task [1].

In many applications, the position of sensor nodes need not be engineered or pre-determined. So the nodes must possess self-organizing capabilities. And multi-hop communication can solve the problem of long-distance wireless communication. Another most important constraint on sensor nodes is the low power consumption requirements. So IEEE 802.15 working group developed the standard 802.15.4 which is intended to be the key enabler for low complexity, ultra low power consumption, and low data rate wireless connectivity among inexpensive fixed, portable and moving devices.

ZigBee is a networked-wireless standard for control and monitoring applications and based on the IEEE 802.15.4 standard, which stipulates a 20-, 40-, or 250-kbps data rate and those devices using it should run for at least two years without a battery change. Target applications include environmental control, security, industrial sensors, and medical monitoring systems that typically transfer small amounts of data with a low duty cycle.

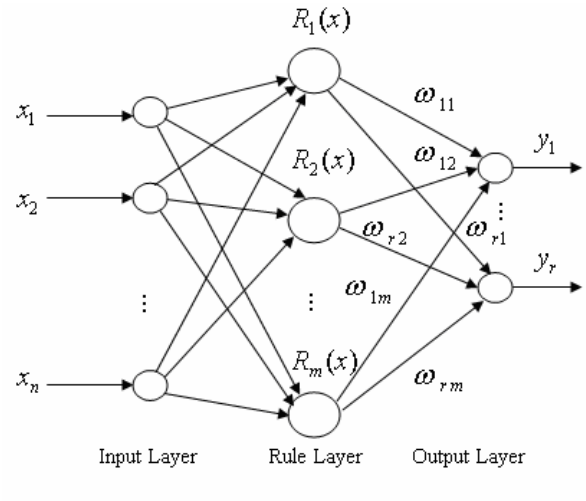


Figure 1. RBF based FNN structure.

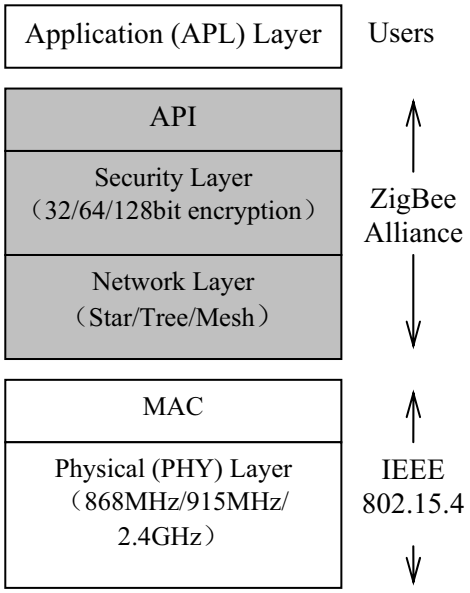


Figure 2. Outline ZigBee stack. sure

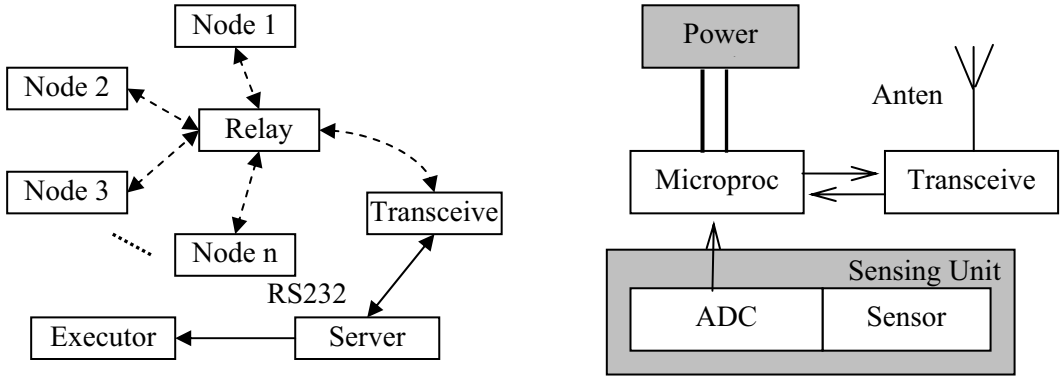
The ZigBee stack architecture, which is depicted in Figure 2, is based on the standard Open Systems Interconnection (OSI) seven-layer model but defines only those layers relevant to achieving functionality in the intended market space. The IEEE 802.15.4-2003 standard defines the lower two layers: the physical (PHY) layer and the medium access control (MAC) sub-layer. The ZigBee Alliance builds on this foundation by providing the network (NWK) layer and the framework for the application layer, which includes the application support sub-layer (APS), the ZigBee device objects (ZDO) and the manufacturer-defined application objects [2].

The ZigBee based wireless sensor networks are adapt for air quality monitor system. When no data are transmitted, the node enter sleep mode with microampere power consumption. And it can continue to work when being awakened. Many nodes being positioned everywhere in the building and transmit data to the server. The MC13193, Freescale's transceiver, can be used with ZigBee for applications [3].

3. System Structure

The ZigBee based electronic nose includes three parts as shown in Figure. 3(a): server, network relay and wireless sensor node. The server connects transceiver by RS232 to transmit command and receive data. After analyzing the data, the server will decide whether start the actor. If the air quality bad, the server will know the position according to the address code and start the corresponding ventilator.

The relay is used to expand the communication range. In fact, a sensor node can also replace it. Multi-hop communication in the wireless networks can effectively overcome some of the signal propagation effects experienced in long-distance wireless communication. Furthermore, it will consume less power than the traditional single hop communication because neighbor nodes are close to each other and transmission power levels can be kept low.



(a) (b)

Figure 3. (a) System structure. (b) The components of a sensor node.

A sensor node is made up of four basic components are shown in Figure 3(b): a sensing unit, a processing unit, a transceiver unit, and a power unit. Sensing units are composed of two subunits: sensors and analog to digital converters (ADCs). The analog signals produced by the sensors are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is associated with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to transmit data. A transceiver unit (MC13193) connects the node to the network. One of the important components of a sensor node is the power unit. Power units provide the energy to the node. Sometimes, there are also other subunits, which are application dependent.

4. Research on data processing and pattern recognition of electronic nose

In 1994, J. W. Gardner, the professor of University of Warwick, published his paper in Sensor and Actors and put forward the definition of Electronic Nose: An electronic nose is an instrument, which comprises an array of electronic chemical sensors with partial specificity and an appropriate pattern recognition system, capable of recognizing simple or complex odors [4].

It contains two parts: sensor technique and pattern recognition method. The former comprises a set of active materials which detect the odor, associated sensors which transduce the chemical quantity into electrical signals. The later classifies known odors or identifies unknown odors by appropriate signal conditioning and processing and using intelligent method. The paper focuses on the quantitative analysis by Fuzzy Neural Network [5].

In order to accurately controlling the ventilator, the sensor node ought to be able to quantitatively analyze the data to obtain the information of air ingredient and consistency. The paper put forwards an algorithm of fuzzy neural network based on RBF (Radial Basis Function) network model and it adapts to quantitative analysis of ingredient consistency in the air.

RBF based fuzzy neural network is shown in Figure 1. Set input vector $x=[x_1 \ \ x_2 \ldots x_n]^T$, and assume the transform function to every input in the rule layer is Gauss function, then the output of rule layer is:

$$R_j(x) = e^{-\sum_{i=1}^{n} \frac{(x_i - c_{ij})^2}{2\sigma_{ij}^2}} \quad ; \quad i = 1, 2, \cdots, n \ ; \quad j = 1, 2, \cdots, m \ ,$$

where the parameter n is the dimension of input vector; m is the neuron node number of rule layer, namely the number of fuzzy rule; c_{ij} and σ_{ij} is the center and width of Gauss function respectively.

The output is:

$$y_i = \left(\sum_{j=1}^{m} \omega_{ij} R_j(x)\right) \Big/ \sum_{k=1}^{m} R_k(x) \qquad i = 1, 2, \cdots, r \ ,$$

where r is the dimension of output vector; ω_{ij} is the weight from rule layer to output layer. Set error cost function is $E = 1/2 \sum_{i=1}^{r} (y_{di} - y_i)^2$, where y_{di} and y_i is expected output and actual output.

So learning algorithm of RBF based fuzzy neural network is: (Where β>0 is learning ratio)

$$\begin{cases} \omega_{ij}(k+1) = \omega_{ij}(k) - \beta \dfrac{\partial E}{\partial \omega_{ij}}; i = 1, 2, \cdots, r; j = 1, 2, \cdots, m \\ c_{ij}(k+1) = c_{ij}(k) - \beta \dfrac{\partial E}{\partial c_{ij}}; i = 1, 2, \cdots, n; j = 1, 2, \cdots, m \\ \sigma_{ij}(k+1) = \sigma_{ij}(k) - \beta \dfrac{\partial E}{\partial \sigma_{ij}}; i = 1, 2, \cdots, n; j = 1, 2, \cdots, m \end{cases}$$

Table 1 show the sample's forecast value A and expectation T, and calculate the relative error R.E., the formula is $|A\text{-}T|/T \times 100\%$. From the result, this method can evaluate the ingredient consistency effectively and send the information to the server timely. Furthermore, since sensor nodes may be densely deployed in a building, sensor nodes can relay the exact origin of the fire to the server before the fire is spread uncontrollable.

Table 1. The sample's forecast relative error.

	1	2	3	4	5	6	7	8	9	10
T (ppm)	550	650	750	850	1950	2050	2150	2250	3450	3550
A (ppm)	683	739	807	879	1987	2084	2182	2277	3426	3533
R. E.	24.12	13.67	7.58	3.41	1.90	1.67	1.50	1.21	0.70	0.48
	11	12	13	14	15	16	17	18	19	20
T (ppm)	3650	3750	4950	5050	5150	5250	5350	5450	5550	5600
A (ppm)	3641	3753	4931	5036	5149	5267	5384	5446	5565	5584
R. E.	0.24	0.09	0.38	0.28	0.01	0.32	0.62	0.07	0.26	0.28

5. Network Routing Algorithm Design

The ZigBee network is based on data transmission and its routing protocol is different from traditional Ad Hoc network: used for special application and lack of catholicity; contain redundant information and need fusion process; Sensor nodes are limited in power, computational capacities and memory.

As wireless application of electronic nose system, the network has special characters: The position of nodes can be pre-determined; the transmission data have to contain position information and the nodes number is limited, so every node has its identification; data throughput is a little and real-time requirement is not high, several seconds latency can be accepted.

It simplifies the design of routing algorithm and an improved diffusion protocol is proposed:

(1) The server S broadcasts the data to all nodes, which contains server address A_0 and gradient parameter H_0 (= 0).

(2) The node A which receives the data with gradient H_0 transmits the message which include its address A_{Ni}, sender's address A_{Ni-1} and its gradient H_{Ni} ($H_{Ni} = H_0 + 1$).

(3) After processing the data, when $\begin{cases} H_{Ni} = H_0 + 1 \\ A_{Ni} = A_0 \end{cases}$ is satisfied, the server S saves the corresponding node as communication object in the routing table. On the analogy, we can build routing table for each node which only receive the data from the node in the routing table. This method can avoid the implosion and overlap of information The number of nodes is limited, so the routing table in each node only occupies a little memory space. And it can advance transmission efficiency.

6. Conclusion

The wireless sensor network based electronic-nose system analyze multi-gas ingredient quantitative, and monitor the air quality of building completely by ZigBee wireless sensor network. It needn't install complicated communication wire and easy use and replacing for building. As a self-organizing network, when parts of nodes fail, the system can still work as possible. Besides, the system can be used in the battle field, chemical plant and measures consistency of certain gas for special purpose.

References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci 2002 Wireless sensor networks: *A survey, Computer Networks* **38** 393–422.

[2] David Geer 2005 Users Make a Beeline for ZigBee Technology *Computer* **12** 16−19

[3] Jr. Edgar H Calllaway 2003 *Wireless Sensor Networks: Architectures and Protocols* Auerbach Publications 3−5

[4] J W Gardner and P N Bartlett 1995 Application of conducting polymer technology in microsystems *Sensors and Actuators* **51** 57−66

[5] Polikar R, Shinar R, Honavar V, Upda L and Porter M D 2001 Detection and identification of odorants using an electronic nose *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)* (*Salt Lake city, US, 8-11 May 2001)* **5** 3137−40