Sensors & Transducers, Vol. 170, Issue 5, May 2014, pp. 54-59

Sensors & Transducers

http://www.sensorsportal.com

Research of Tunnel Construction Monitoring System Based on Senor Information Fusion

*** Kaisheng Zhang, Xiaotao Liu, Lifeng He**
Shaanxi University of Science and Technology, College of Electrical & Information Engineering, Xi'an, 710021, China
* Tel.: 02986168628, fax: 02986168628
* E-mail: 80649433@qq.com

Received: 13 March 2014 /Accepted: 30 April 2014 /Published: 31 May 2014

Abstract: With the complex of the tunnel construction, tunnel construction become more and more difficult, in order to ensure the safety of tunnel construction, the paper introduced a kind of tunnel construction monitoring system based on sensor. The system achieves the real-time monitoring of tunnel construction environment including temperature and humidity, gas concentration, dust concentration, location tracking for construction workers through the wireless communication technology, to control of the real-time status of the tunnel, and ensure timely rescue when the accident occurred. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Tunnel construction, Sensor, ZigBee, Construction Monitoring, Personnel location, Kalman filter.

1. Introduction

In recent years, with the development of social economy, the city subway has been developed rapidly. The coverage of high-speed railway and highway is more and more large, followed by the rapid development of tunnel construction in China. The length of the tunnel is more and more long and the geological condition is more and more complicated, so the difficulty of tunnel construction is increasing, the construction technology and safety management difficulty also become more and more large. Therefore, in order to achieve timely security early warning and efficient command dispatching, the comprehensive real-time monitoring of the safety of tunnel construction and environment safety factor becomes more important.

Because of needs of the project, monitoring system of tunnel construction has been applied in practical engineering, to solve some practical problems, such as geological monitoring system and personnel attendance system [1] etc. But the traditional are based on wired information transmission, the flexibility and accuracy of the system is largely limited in complex construction environment of tunnel construction. And the system is independent of each other, information sharing is relatively poor, so it's not conducive to managers to make decisions. From the perspective of investment, it is not inconvenient to install and move the hardware platform, and it also needs a large number of hardware resources, resulting in a waste of resources. Then, the tunnel project is not the long-term project, so the monitoring equipment shall be easy to install and move, in order to facilitate the reuse.

In the construction of the complex environment, in order to ensure the smooth progress of the construction, monitoring the construction environment is also very important, and in recent years, with the development of electronic technology, the sensor technology has become more and more

Article number P_2032

mature, so the environment monitoring system based on sensor in tunnel construction monitoring is particularly important. In recent years, with the development of wireless communication technology, Internet of things based on ZigBee technology has been developing rapidly, more and more shows its unique advantages, is widely used in various aspects, in tunnel construction monitoring system, especially the personnel positioning system also reflects its obvious advantages.

2. General System Design

Design of tunnel construction monitoring system based on sensor is mainly divided into two parts of the construction of environmental monitoring and personnel the system construction of positioning, mainly consists of temperature and humidity sensor, gas sensor and the dust sensor nodes in the tunnel, fixed reference node, routing node, wireless gateway, located nodes carried by the construction personnel and PC monitoring system. The system structure diagram is shown in Fig. 1.

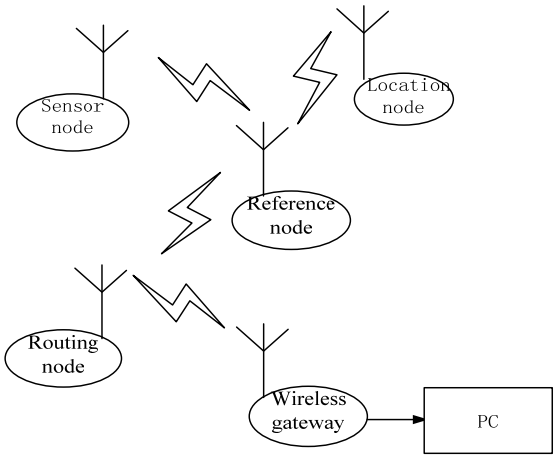

Fig. 1. System structure diagram.

Construction of the tunnel is a long and narrow, closed environment, and accident prone space, so it is necessary to ensure the safety of construction personnel by monitoring the construction environment. The corresponding data of sensor nodes will be collected and sent to PC by the reference node and wireless gateway. Then the system monitors the current construction of environmental through the analysis of data, in order to facilitate the managers of construction to make decisions when the construction environment is not conducive to the work.

Tunnel construction are always underground construction, there may be many sudden accident, so we can track the position of the construction personnel to ensure the timely rescue of sudden accident. Positioning system of construction personnel is achieved by received signal strength indication algorithm. The position of the reference node is set by management personnel, located nodes carried by the construction personnel determine our position through communication with reference node nearby and then its location is transferred to the wireless gateway, and achieves the location of the personnel positioning tracking in PC monitor system through some process.

3. System Hardware Design

The sensor nodes mainly realize data acquisition and network transmission function, so the part of the hardware includes sensors, wireless transceiver module and a micro controller. The sensor module is used to collect the monitoring region data, then the amplified data signal will be sent to the processor to process. The processor module interprets the data signal of the analog to digital conversion, and then sends out the processed data from the antenna issue.

As environmental parameters, temperature and humidity are particularly important in half-closed environment of tunnel construction, so we should choose the appropriate sensor to monitor them. Temperature and humidity sensors are SHT11 of the Swiss company Sensirion, the chip integrates temperature and humidity sensor, signal amplifier, A/D converter, calibration data storage area and the standard I2C bus circuit. The combination of the sensor and the circuit part makes its performance more excellent: first, the increasing effect of amplifier on signal enhances anti-jamming performance of the sensor, which has long term stability, and the sensitivity of sensor on the interference noise is lowered as A/D conversions are finished at the same time. Secondly, of the calibration data loaded in the sensor makes it has good interchangeability between the sensors. The I2C interface makes it easy to connect the sensor and microprocessor, simplifying the interface mode, reducing the cost of hardware. Characteristics of the sensor such as Long term stability and strong interchangeability are suitable for many data acquisition system based on sensor, and its simple Interface and direct digital output is also in line with the requirements of ZigBee wireless communication technology, so it is suitable for the construction monitoring system.

In the tunnel engineering there may be gas and other harmful gases, causing some damage to the human body, so it is necessary to take measures for detection. Gas sensor use MH-440V/D infrared gas sensor, which is a common type of micro intelligent sensor, detecting the gas volume fraction in the air using the non dispersive infrared principle. The sensor has good selectivity, and stable performance, long service life, with analog output and serial communication function, is convenient for detection. It's widely applied in environment with the presence of combustible and explosive gas,

so the sensor is useful in the gas monitoring in special environment.

In the tunnel construction process, operation such as blasting explosions will produce large amounts of dust, and high levels of dust is very harmful to the human body, so it is necessary to adopt measures to monitor dust in construction environment in order to reduce the harm of dust to the construction personnel. The type of dust sensor is GP2Y1010AU, it can measure the tiny particles larger than 0.8 microns, smoke and tobacco pollen perception generated, house dust, and it's easy to install because of it's small volume and light weight.

In the construction of underwater tunnel, pressure of tunnel is also an important environmental parameter, and it should be monitored in order to ensure the safety of underwater tunnel construction personnel. M55534B is an intelligent pressure sensor integrated with piezoresistive pressure sensor and the ADC interface of the SMD hybrid integrated circuit, with a 15 bit A/D converter with internal, which can be used for outputting the measuring pressure, and the sensor module contains 6 calibration value, used to put up high precision software compensation and result revision for the data. The MS5534B is a low voltage, low power consumption sensor, and with automatic power off function, can communicates with microprocessors etc. through synchronous serial interface.

The reference node adopts CC2430 [2], it is a kind of wireless microcontroller with classic 8051 microprocessor as the kernel, including a radio frequency transceiver and a compact and efficient 8051 micro controller, and a separate sleep mode frequency timer, which can work in international license free band, with low power consumption, ultra low cost, easy to realize miniaturization and scale of nodes. Wireless sensor node function is also realized by CC2430, the 8051 micro controller in the chip can meet the sensor node's needs of preliminary data processing and wireless communication.

Location nodes are mobile nodes carried by construction personnel, are mainly used to realize positioning function, so CC2431 containing Blind nodes engine module is needed to choose, CC2431 has included some basic functions of CC2430, besides, because it is based on CC2430 joined in the wireless location based on IEEE 802. 15. 4 standard engine [3], the Blind nodes engine supports 3-16 nodes localization operation, and it has high positioning accuracy, short positioning time, low power consumption, it is very suitable for Blind nodes system design of the system.

Routing nodes can be constituted with CC2430 and the corresponding peripheral circuits, and CC2430 is the core. In the ZigBee network, routing nodes have three main functions: allow nodes to join the network; for data routing; assist his child node communication.

Wireless gateway is existed as the network coordinator in the system communication network, so it must be fully functional equipment, and also be constituted with CC2430 as the core. The coordinator mainly works in the aspect of network building, network configuration, once the network is established, the coordinator's function is the same as function of the router.

The system hardware structure diagram is shown in Fig. 2.

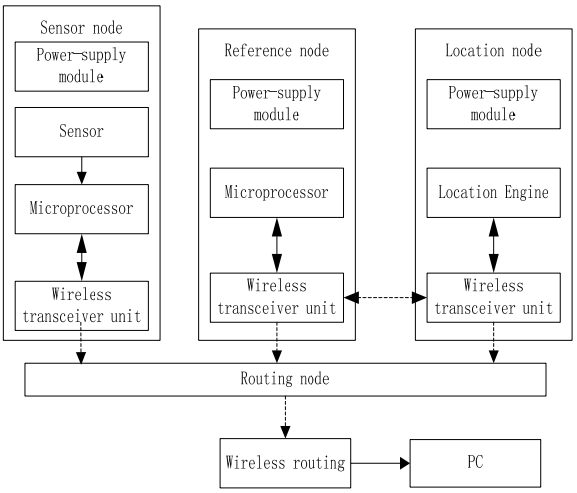

Fig. 2. System hardware structure diagram.

4. Equations

After initialization, the network is established with wireless gateway as a coordinator, it sends radio beacon frames and accept access request from the node as the master node. After accessing the networks from a node, sensor nodes began to collect data and upload, reference node and determine its position, blind nodes are to join the network at any time by reference nodes to calculate its own position to realize Blind nodes.

4.1. Environment Monitoring System

Environment monitoring subsystem mainly includes the sensors' data acquisition and wireless transceiver, its working process is shown in Fig. 3. In data acquisition, the sensor node processor will do some certain processing for the data obtained according to the need, including type conversion, digital to analog conversion, etc. Sensor nodes have a data preliminary processed transmitted by wireless transceiver module and wireless gateway to upper computer monitoring system, upper computer system then fuse and process the data, and compare the thresholds set, judging whether data, such as temperature, gas concentration is unusual, if there are abnormal, it will inform related staff to take corresponding measures to prevent safety accidents in a timely manner through the alarm device.

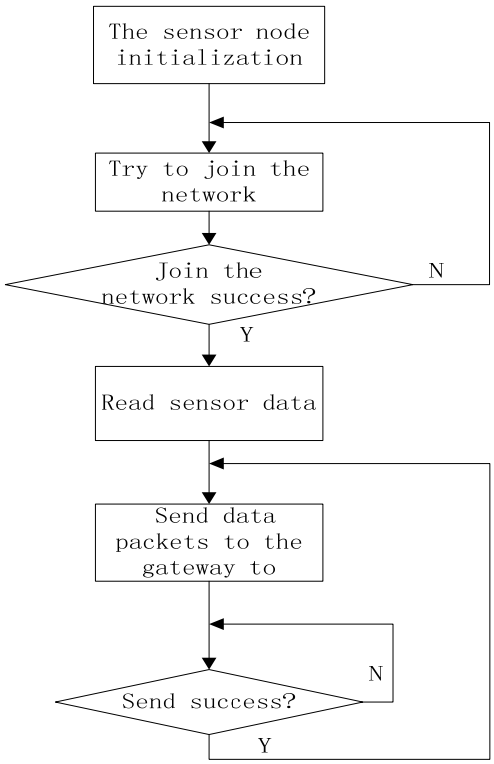

Fig. 3. Sensor nodes workflow.

4.2. Personnel Location System

Personnel location system uses RSSI algorithm to achieve by the communication between nodes and approaching the reference node to determine the positioning of the node that is the specific location of construction workers. RSSI is a wireless signal strength received by node. In RSSI-based positioning, transmitting known signal strength of the transmitting node, the receiving node calculates the propagation loss of strength of the received signal according to the signal. The use of theoretical and empirical models to transmission losses into the distance, and further use triangulation to determine the location of the node to be positioned. Signal attenuation model using the formula (1) is expressed as follows [4]:

$$p(d) = p(d_0) - 10 \cdot n \cdot \log(\frac{d}{d_0}) - \begin{cases} nW \times WAF & nW < C \\ C \times WAF & nW \geq C \end{cases} \quad (1)$$

In the formula, p(d) [dBm] and $p(d_0)$ denote the signal strength based on the distance of d and d_0, p(d) is the actual measured RSSI, n is the same exponential decay, d/d_0 indicates the ratio between the length of the path and the path loss factor, nW is the number of walls between the nodes and the base station, C denote the threshold signal that through the wall of said, WAF denote the path loss value added, nW represents signal attenuation factor through walls or obstacles.

Then using trilateration calculates the position of nodes. Fig. 4, known A, B, C, respectively, the coordinates of three nodes (x_A, y_A), (x_B, y_B), (x_C, y_C) assuming the coordinates of the positioning node O (x, y), according to the following distance formula (2) between points:

$$\begin{cases} \sqrt{(x - x_A)^2 + (y - y_A)^2} = d_A \\ \sqrt{(x - x_B)^2 + (y - y_B)^2} = d_B \\ \sqrt{(x - x_C)^2 + (y - y_C)^2} = d_C \end{cases} \quad (2)$$

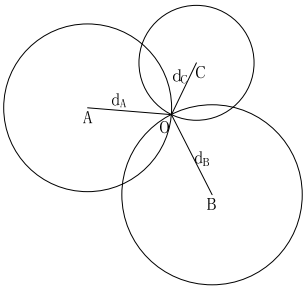

Fig. 4. Sensor nodes workflow. Schematic diagram of the three edge measurement.

This formula (3) can calculate the coordinates of the nodes:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_A - x_C) & 2(y_A - y_C) \\ 2(x_B - x_C) & 2(y_B - y_C) \end{bmatrix}^{-1} \begin{bmatrix} x_A^2 - x_C^2 + y_A^2 - y_C^2 - d_A^2 + d_C^2 \\ x_B^2 - x_C^2 + y_B^2 - y_C^2 - d_C^2 + d_B^2 \end{bmatrix} \quad (3)$$

Location system consists of reference nodes and location node. The reference node is a static node that is located in known positions. The nodes know their position and can send the position message to other reference nodes by a data packet, its work flow is shown in Fig. 5.

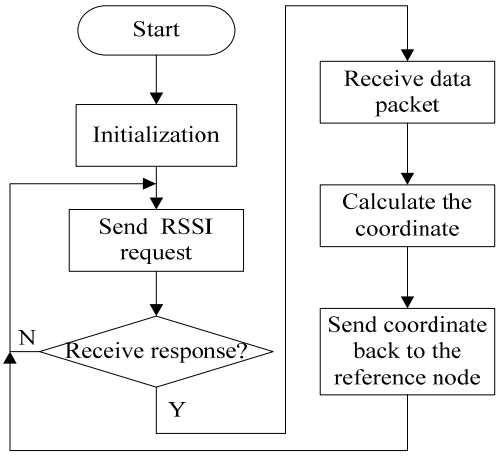

Fig. 5. Reference node work flow chart.

The location node receives the signal of data packet from the reference node, obtaining location coordinates of the reference node and the corresponding RSSI value, and sends it to the location engine, then reads out its own position calculated by the positioning engine. The position information is sent to the nearest reference node through the wireless communication module and uploaded to the PC, to track the specific location of the construction personnel. The work flow is shown in Fig. 6.

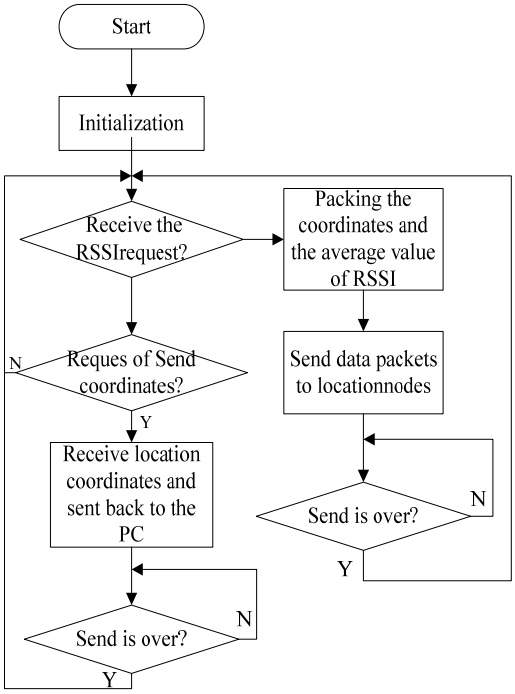

Fig. 6. Location nodes work flow chart.

4.3. Analysis of Kalman Filtering and Simulation

The location method is based on RSSI ranging technology, because the RSSI is affected by environmental noise and the measured distance may have big error, so the data need to be processed. In this paper the system use the Kalman filter to process the measured distance to minimize the error.

Kalman filter gets the best estimate data of the physical parameters through a series of the actual measurements with errors, and estimate the current value of the signal according to the previous estimate and a recent observations. Kalman filter is an effective algorithm for optimal filtering of the Gauss process. It works better when the object model is accurate enough and system state and parameter is not mutated. Therefore, combination of Kalman filtering and location method can reduce the impact of noise on the system with filter function of Kalman filter and improve the precision of orientation.

Workflow of Kalman filter includes two stages: prediction and update [5]. In the prediction stage, estimation filter estimate the current state by the estimate of last state. In the update stage, filter optimizes predictions obtained in the prediction stage by observation in the current state, in order to obtain a more accurate estimate.

The paper gives a simulation example based on distance measurement: the observed is the distance data obtained from simulation mixed with white noise, then process the value in the MatLab with the Kalman filter. The number of sampling points is limited to 50, and the simulation results are shown in Fig. 7.

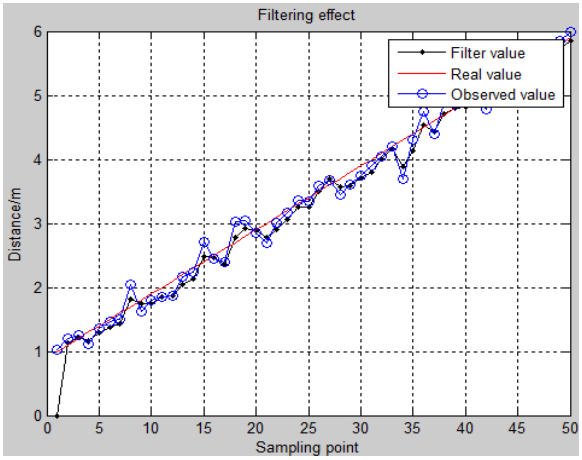

Fig. 7. The simulation result.

It can be seen from Fig. 7, the fluctuation of data curve is relatively smaller after the Kalman filter. It is more close to the real data curve, and data error is smaller, so it can give more precise location data in the location system.

5. Conclusions

The combination of Sensor technology and wireless communication technology not only reduces the complexity of the environmental monitoring system, and increase scope of the monitoring system, makes the monitoring more comprehensive. The technical characteristics of ZigBee such as low power consumption, automatic networking, dynamic routing, high reliability provides reliable, stable wireless communication base for monitoring system, to reduce the cost of the system and expand the monitoring region. The algorithm of Kalman filter is based on most simple algorithm, it improves the positioning accuracy, has high utility and market value. The ZigBee wireless communication technology solves the wiring trouble of traditional wired monitoring equipment and the inconvenience to expand. The system can effectively monitor comprehensive environment condition in tunnel

construction process, it can also control the specific distribution of Dispersed construction personnel.

Acknowledgements

The research paper is funded by the Innovation Fund of Shaanxi University of Science and Technology Graduate. In addition, the fund consists of the following: scientific research project by the Shaanxi Provincial Department of Education in 2012 (No. 12JK0521), Shaanxi Province Weiyang Technology Bureau projects in Xi'an, in 2012 (No. 201203), Shaanxi Province Yulin Technology Bureau projects in Xi'an, in 2011 (No. 2011kj-06, No. 2011kj-29), Shaanxi Province Weiyang Technology Bureau projects in Xi'an, in 2011 (No. 2011K07-11), Shaanxi Province Technology Bureau projects in Xi'an, in 2013 (No. CXY1343(6).

References

[1]. Wang Ying, Traffic standardization construction safety of the tunnel monitoring system based on Internet of things technology, *The Analysis*, 10, 2013, pp. 138-142.
[2]. Wang Xiaoqiang, Ouyang Jun, Huang Ning, Lin, ZigBee design and implementation of wireless sensor network, *Chemical Industry Press*, Beijing, 2012.
[3]. Li Wenzhong, Section alarm system based on ZigBee wireless network technology introduction and actual, *Beihang University Press*, Beijing, 2007.
[4]. Zhang Canming, Zhou Mengran, Chen Junlan, ZigBee positioning technology in gas monitoring system in the application, *Coal Technology*, 30, 3, 2011, pp. 105-106.
[5]. Jin Rencheng, Zhao Wei, Shi Xiaopei, Research on EKF-Based Localization Technology in Wireless Sensor Networks, *Chinese Journal of Sensors and Actuators*, Issue 12, 2010, pp. 1810-1814.