Study on the Detecting Technology of Mine Internet of Things Based on RSSI Technology

Jian Ming, Aibing Jin*, Jinhai Sun, Dongdong Hu, Yan Xia
School of Civil and Resource Engineering
University of Science and Technology Beijing
Beijing, China
mingjian.ustb@163.com

***Abstract*—Based on the theory and technology of Internet of Things(IOT) and digital mine, the Mine Internet of Things (perception Mine) is used to detect and control of the personnel, equipment and mine environment, which can improve the ability of perceiving the operation status of the personnel and the equipment and controlling risks in mining production. Field experiments of RSSI distance measurement were conducted on account of characteristics of the operational environment and engineering arrangements of the underground mine. In view of field experiments results, the RSSI-distance relation model was established. The trilateration positioning model and BP neural network positioning model were used to process and analyze the node positioning data. The mine cave-back monitoring method based on RSSI distance measurement is introduced.**

Keywords—underground mine; mine internet of things, RSSI; detecting technology

I. INTRODUCTION

There are a large number of underground metal mines in China. With the increasing depth and complexity of mining, the operational environment is deteriorating and the geotemperature is increasing, which will need the more complex engineering layout and the more difficult production management. The security threat to the mine production staffs faced increases gradually. It is of great significance to use the Internet of Things technology to obtain the distribution of underground personnel in real time for production safety in underground metal mines [1].

Many studies are conducted about the underground personnel positioning. Reference [1] proposed an instruction model which can be applied to the mine internet of things course. Reference [2] proposed the trilateration positioning model and BP neural network positioning model based on RSSI technology. Reference [3-4] analyzed advantages and disadvantages of different RSSI ranging methods and proposed the development direction of the RSSI ranging method. In order to locate sensors' coordinates more effectively and securely, reference [5] analyzed some security localization algorithms and proposed a distributed RSSI-based DPC security location algorithm. To reduce effects of roadway walls on the signal propagation, reference [6] introduced a positioning technology which combine the RSSI multiple filter and established the linear regression distance measurement model and the multilateral location method. To reduce effects of external factors, reference [7] introduced a Gaussian model based on deviation which will be used in the data acquisition stage of RSSI and a dynamic window mechanism EWMA in the ranging stage. The results shows that the contradiction between the device cost and localization accuracy was moderated. To improve the vulnerability of RSSI positioning algorithm to environmental noise, reference [8-9] proposed an adaptive Flip-Flop RSSI preprocessing algorithm based on PDR azimuth information, experimental results showed that the algorithm can improve the anti-noise interference capability of the positioning process. Reference [10-11] introduces that the concept and design of the networked smart markers based on RSSI technology.

To improve the positioning accuracy of the underground personnel positioning, the RSSI-distance relation experiment, underground positioning experiments and computer simulation experiments are conducted in this study.

II. THE POSITIONING PRINCIPLE AND TECHNIQUE

This study adapted the positioning algorithm based on RSSI. The RSSI-distance relation can be obtained through field experiments [12]. There are two types of algorithms in general. One is the range-based positioning algorithm and the other is the range-free positioning algorithm [13-15]. The trilateration positioning model and the BP neural network positioning model were established in this study. These positioning models were used to process and analyze the experimental data.

In geometry, trilateration is the process of determining absolute or relative locations of points using distances. At first, the RSSI to a distance are obtained and transformed. Then three circles whose radii are three selected effective distances will be made. Thus, coordinates of the intersection of circles will be directed. Let the coordinates of three centers of a circle be $P_1(x_1,y_1)$ 、 $P_2(x_2,y_2)$ and $P_3(x_3,y_3)$.

$$\begin{cases} r_1^2 = (C_x - x_1)^2 + (C_y - y_1)^2 \\ r_2^2 = (C_x - x_2)^2 + (C_y - y_2)^2 \\ r_3^2 = (C_x - x_3)^2 + (C_y - y_3)^2 \end{cases} \tag{1}$$

Let the position of the unknown point be T(t_x, t_y). Let the spherical center coordinates of the circle P_1 be (0,0), that of the circle P_2 be (d, 0) and that of the circle P_3 be (e, f). The radius of three circles is r_1 , r_2 and r_3 , respectively. The trilateration positioning model is shown in Fig. 1：

Authorized licensed use limited to: University of Western Macedonia. Downloaded on January 11,2023 at 18:00:17 UTC from IEEE Xplore. Restrictions apply.

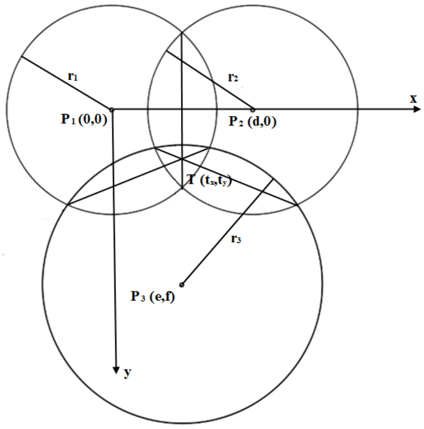

Fig. 1 The trilateration positioning model

Then:

$$\begin{cases} r_1^2 = t_x^2 + t_y^2 + \dfrac{z^2}{4} \\ r_2^2 = (t_x - d)^2 + t_y^2 + \dfrac{z^2}{4} \\ r_3^2 = (t_x - e)^2 + (t_y - f)^2 + \dfrac{z^2}{4} \end{cases} \quad (2)$$

When Z = 0, namely, three circles intersect at one point on the same plane. First, t_x can be obtained, and then t_y can be obtained:

$$\begin{cases} t_x = \dfrac{r_1^2 - r_2^2 + d^2}{2d} \\ t_y = \dfrac{r_1^2 - r_3^2 - t_x^2 + (t_x - e)^2 + f^2}{2f} \end{cases} \quad (3)$$

III. The Design of Positoning Experiments

A. The Experimental Device of Field Experiments

Different experiments were conducted in an underground metal mine. Different node layout schemes were designed on account of characteristics of the underground engineering layout.

The hardware devices of field positioning experiments included the gateway node, the reference node, the blind node and the host computer. These nodes were able to constitute a wireless positioning network. Wireless communication protocol was adapted to achieve wireless connection. Each reference node was able to communicate with gateway nodes. Gateway nodes were able to communicate with reference nodes and the host computer. The RSSI data obtained is processed using the positioning algorithm, and the position of blind nodes would be determined.

B. The RSSI-Distance Relation Experiment

Theoretically RSSI values will decrease with the increasing distance between nodes. The RSSI value can reflect the distance between nodes. Then locations of blind nodes can be obtained by means of positioning algorithms. Thus, the RSSI-distance relation model should be established first in this study. RSSI-distance relation experiments were conducted in the long straight roadway.

In the RSSI-distance relation experiment, the transmitting device was fixed at the coordinate origin of the long straight roadway, and the receiving device moved away from the transmitting device along a straight line. Measuring points are arranged along the length of experimental roadway at intervals of 0.5 m. At each measurement point, three data were obtained and recorded.

C. The Positioning Experiments

Field positioning experiments was conducted in the main ramp and the shaft station of the metal mine. In view of the data of field experiments, computer simulation experiments were conducted in laboratories. The computer simulation experiment was conducted using the BP neural network model. In the BP neural network positioning model, inputs and outputs were the data of field simulation experiments and the actual coordinate values respectively. The input vector and the desired output vector will be established respectively. The model was a three-layered neural network, namely, the number of the hidden layer was 1. The number of the input neurons is 4 and that of the output neurons was 1. Based on the number of the training samples and the results of the preparatory experiments, the hidden layer neurons' number was determined to be 4 by using the empiric formula. In view of the preparatory experimental results, the transfer functions between the input layer and the hidden layer and between the hidden layer and the output layer were determined to be 'tansig' and 'purelin' respectively. The network training function was 'trainglm'. After the experimental data was normalized and divided into training samples and testing samples, the BP neutral network would be trained and tested.

IV. Results Discussion of Positioning Experiments

RSSI signal values obtained from the RSSI-distance relation experiment was read out from the RSSI status register. These values were converted to the decimal number. Then the relationship between RSSI and distance was obtained through the mathematical analysis. The relationship between RSSI value and distance is shown in Fig. 2:

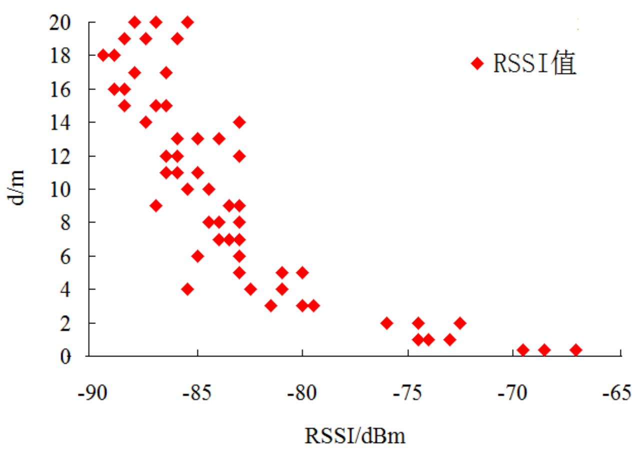

Fig. 2 The relationship between RSSI value and distance

The study found that the distribution of data is not linear. The curve fit analysis is carried out. Comparing the decision coefficients R^2 and comparing the generated

Authorized licensed use limited to: University of Western Macedonia. Downloaded on January 11,2023 at 18:00:17 UTC from IEEE Xplore. Restrictions apply.

graphs, the best model is Growth model, namely, $y=e^{C+b_1x}$ or $ln\, y = C + b_1 x$. The model summary shows that: R^2 =0.876, F=424.730, Sign if F =0.000. The parameter estimates shows that the constant of regression equation is -15.357 and b_1 is -0.208. The non-linear regression equation of the model is as follows:

$$y = e^{-15.357-0.208x} \tag{5}$$

In the field experimental environment, the wireless data transmission was interfered by a lot of environmental factors. The data transmission of long distance was easily disturbed, which reduces the positioning accuracy of the positioning devices.

The experimental results showed that there was a certain degree of fluctuation in positioning accuracy, but the attenuation of the signal had obvious regularity. The signal fluctuation and attenuation were obvious in a relatively short distance. The RSSI-distance relation fitting curve was obtained and was used as the characteristic curve of the positioning signal on account of the field experimental data.

The positioning accuracy analysis of trilateration positioning experiments showed that the positioning accuracy of the model was relatively low and the distribution of abnormal values was irregular.

The result analysis of BP neural network positioning experiments showed that the determination coefficient of the fitting result could meet the experimental requirements.

The calculation results of the X direction and the Y direction obtained through the BP neural network positioning model were more accurate than that obtained through the trilateration positioning model. The BP neural network positioning model can reduce the effect of the effect of the ranging error on the positioning accuracy.

The RSSI technology is also used in other study fields of mines, such as monitoring methods for the mine cave-back.

V. WIRELESS MONITORING METHOD FOR THE MINE CAVE-BACK

A. The Cave-back Monitoring Methods

Traditional monitoring methods for the mine cave-back include the micro-seismic monitoring system, time domain reflectometers and extensometers. The cable in the monitoring hole is used to collect data in these monitoring methods. If the cable is cut because of ground movement, these monitoring methods will be useless.

For example, Open holes is the most useful monitoring method. The monitoring devices such as cameras are lowered into the hole and into the cave, which can get the best direct data for interpreting positions and profiles of the cave. These monitoring methods are easily affected by collapse and dislocations of boreholes. The stable borehole is very important to the effectiveness of these methods.

In these monitoring methods, the cables which are along the length of monitoring borehole are used to transfer data and power.

The small displacements of the hole wall may cut the cables, making the monitoring system do not work normally.

B. The Design of the Wireless Monitoring System

In order to solve these problems, some companies developed the networked marker systems. These systems are more robust and effective compared with traditional methods for monitoring cave propagation. The collected data is transmitted wirelessly through rock, which eliminates some problems encountered by traditional monitoring methods. After the traditional method has failed, these systems can collect the location information of the cave back. All this information can provide benefits for future caving operations.

The objective of developing such monitoring systems is mainly to resolve the following problems: The data on when and where the deformation develops, the nature and scale of the deformation, the pore pressure change caused by the deformation can be provided and transmitted wirelessly to the host computer in real time.

C. The Concept and Operation of System

The RSSI value is used to indicate the distance change between markers. The destination marker issues a radio broadcast. The markers which can receive signals will respond to the issuing marker. A number representing the RSSI value and the responding marker will be recorded and propagated back to the receiving device.

Several holes with different lengths will be drilled downwards into the orebody from a monitoring drive. The markers will be installed into the holes. The receiving devices will be installed in a location which will not be affected by caving and blasting.

Experiments showed that the effective communication range through rock was around 6 m. In order to make the fail marker skipped in the chain, the markers are arranged along the length of monitoring borehole at intervals of 2 m, which improves the monitoring system redundancy and provides high availably.

At a close distance, the signal that transmitted through rock will saturate the measuring ability of the receiving device, which means that a maximum RSSI will be showed within this distance. Beyond this distance, a difference in the RSSI can be measured.

If a maker did not respond to queries, it probably dislocated or traveled to the extraction, which indicates the location of the deformation or the cave.

These marks also act as tracker markers, which means that they will be detected by readers installed on the extraction level. The cave material flow is tracked using these electronic markers. They are installed into the orebody. After these markers travel through the cave and are extracted through the draw points, their identity will be detected and recorded by the readers which installed in the haulage drift.

VI. CONCLUSIONS

(1) based on the theory and technology of Internet of Things(IOT), the RSSI ranging method was adopted to perceive the operation status of the personnel and the equipment in the underground mine.

(2) The RSSI-distance relation fitting curve was obtained on account of the data of laboratory experiments and field experiments.

(3) The trilateration positioning model and BP neural network positioning model were established, which could

Authorized licensed use limited to: University of Western Macedonia. Downloaded on January 11,2023 at 18:00:17 UTC from IEEE Xplore. Restrictions apply.

process and analyze the node positioning data. The experimental results showed that the positioning accuracy obtained through the latter was higher than that obtained through the former.

(4) The mine cave-back monitoring method based on RSSI distance measurement is introduced.

ACKNOWLEDGMENT

Supported by "Fundamental Research Funds for the Central Universities (Grant No. FRF-TP-14-077A2)".

REFERENCES

[1] Sun Jinhai, Ming Jian, Guo Yingwei, et al., "Exploration and practice on expriment teaching of mine Internet of Things", Laboratory Science, vol. 21, no.4, pp. 41-44, 2018.

[2] Ming Jian, Hu Nailian, Niu Xiangshan, et al., "Study on the personnel localization algorithm of the underground mine based on ZigBee technology", 2017 the 9th IEEE International Conference on Communication software and networks proceedings, vol. 1, pp. 408-411, 2017.

[3] Wang Huanhuan, Hu Aina, "Ranging method based on the mapping between RSSI and distance scope", Journal of University of Electronic Science and Technology of China, vol. 41, no.4, pp. 522-526, 2012.

[4] Wang Huanhuan, Shao Kaili, "Study on ranging technology based on RSSI in wirless sensor networks", Microcomputer Information, vol. 28, no.10, pp. 346-348, 2012.

[5] Zhan Jie, Liu Hongli, Liu Dawei, et al., "Research on secure DPC localization algorithm of WSN", Journal on Communications, vol.32, no.12, pp. 8-17, 2011.

[6] Cui Lizhen, Li lei, Gao Lili, et al., "Research and implementation of location technology based on improved RSSI algorithm in coal mines ", Mining Safety & Environmental Protection, vol. 40, no.4, pp. 35-42, 2013.

[7] Xu Jiuqiang, Liu Wei, Zhang Yuanyuan, et al., "RSSI-based anti-interference WSN positioning algorithm", Journal of Northeastern University(Natural Science), vol. 31, no.5, pp. 647-650, 2010.

[8] Hu Hong, Li Xuemei, Qin Liyuan, et al., "Indoor PDR algorithm based on RSSI ranging positioning", Computer and Modernization, no.253, pp. 87-90, 2016.

[9] Zheng Xueli, Fu Jingqi, " Study on PDR and RSSI based indoor localization algorithm", Chinese Journal of Scientific Instrument, vol. 36, no.5, pp. 1178-1185, 2015.

[10] S Steffen, J Poulsen, A Van As,, et al.,"Wirless system for monitoring cave-back propagation" , 7th International Conference & Exhibition on Mass Mining proceedings, pp. 251-256, 2016.

[11] G R Power, A D Campbell, A Van As,, et al.,"Modelling of real-time marker data to improve operational recovery in sublevel caving mines" , 7th International Conference & Exhibition on Mass Mining proceedings, pp. 105-109, 2016.

[12] Zhu Jian, Zhao Hai, Sun Peigang, et al., "Equilateral triangle localization algorithm based on average RSSI", Journal of Northeastern University(Natural Science), vol. 28, no.8, pp. 1094-1097, 2007.

[13] Li Huaying, Wang Zhen, "Analysis of transmission model of WSN for mine environment monitoring", Coal Technology , vol. 37, no. 10, pp. 271-274, 2018.

[14] Zhao Zhao, Chen Xiaohui, " An improved localization algorithm based on RSSI in WSN", Chinese Journal of Scientific Instrument, vol. 22, no. 3, pp. 391-394, 2009.

[15] Pan Zhoujin, Zhao Mingyue, Luo Zhen, et al., "Detection and simulation of WSN wormhole attack node based on RSSI localization", Computer simulation, vol. 36, no. 1, pp. 387-391, 2019.

[16] Duplancic, P and Brady, B H, "Characterization of caving mechanisms by analysis of seismicity and rock stress", 9th International Congress on Rock Mechanics proceedings, pp.1049-1053,1999.

[17] Ming Jian, Zang Lingling, Sun Jinhai, et al., "Analysis models of technical and economic data of mining enterprises based on big data analysis", 3rd IEEE International Conference on Cloud Computing and Big Data Analysis proceedings, vol. 1, pp. 224-227, 2018.

[18] Ming Jian, Hu Nailian, Sun Jinhai, "Study on modeling and scheduling optimization algorithm of mining-excavation planning", 9th international Symposium on Computational Intelligence and Design, vol. 2, pp. 22-25, 2016.

[19] J Mass-Sanches, E Ruiz-lbarra, J Cortez-Gonzalez, et al., "Weighted Hyperbolic DV-Hop Positioning Node Localization Algorithm in WSNs", Wireless Personal Communications, pp. 1-23, 2016.

[20] Wang Fubao, Shi Long, Ren Fengyuan, "Self-localiation systems and algorithms for wireless sensor networks", Journal of Software, vol. 16, no.5, pp. 857-868, 2005.

Authorized licensed use limited to: University of Western Macedonia. Downloaded on January 11,2023 at 18:00:17 UTC from IEEE Xplore. Restrictions apply.