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Research on Fuzzy Neural Network Assisted Train Positioning Based on GSM-R

Xiuhui Diao[1], Pengfei Wang[2], Weidong Li[2]

Abstract. Rapid and high-precision train positioning is the core of train operation control system, and Global Navigation Satellite System(GNSS) can effectively assist train positioning. Due to the complicated environment of railway line, GNSS signals sometimes miss. This paper presents a train positioning scheme when GNSS fails. The scheme is based on the GSM-R network and uses the wireless transmission function of GSM-R system to make up for the missing signal of the GNSS in the blind area, and train auxiliary positioning by fuzzy control and BP neural network. Firstly, the coverage strength and transmission path loss of GSM-R network are analyzed, and the simulation model of fuzzy neural network positioning system based on GSM-R is built. Finally, through the Simulink analysis experiment, the operation effect of fuzzy neural network positioning method and BP neural network positioning method is compared, and the detailed comparison and analysis are made from the aspect of error accuracy. The experimental results show that the error precision of the fuzzy neural network positioning method is better than that of the BP neural network positioning method alone. Therefore, GSM-R aided train positioning can improve the safety and reliability of train operation.

Key words. Fuzzy neural network, BP neural network, train positioning, GSM-R.

1. Introduction

In the existing railway lines, train positioning mainly adopts track circuit positioning method. The track circuit positioning method can effectively locate the train without the need of other complex equipment. This method is simple and practical, but it is easily affected by the external environment, such as climate change, train itself and other factors. The bad climate will cause the failure of the track

[1]Department of Mechanical Engineering, Henan Institute of Technology, Xinxiang, Henan, China

[2]School of Mechanical Engineering, Dalian Jiaotong University, Dalian, Liaoning, China; e-mail: myeyunfei@163.com

circuit, which will affect the accuracy of the train positioning [1]. Therefore, more and more countries adopt Global Navigation Satellite System(GNSS) to assist train positioning.

However, the application of GNSS will be affected by many aspects, including weather, environment, satellite health status, and so on, so the existence of GNSS failure occurs. This situation affects the safe operation of the train. Therefore, railway trains need more means and methods to ensure the reliability of train positioning. With the development of intelligent control, the application of fuzzy control and neural network has become one of the two active fields. Neural network can simulate human brain thinking, and it is suitable for dealing with complex nonlinear system structure. Fuzzy control has the ability of expert knowledge learning and logical reasoning, which is suitable for dealing with structured information and realizing optimal control. If we combine the two, we can realize the powerful function of reasoning, learning, association and information processing. Applying it to train positioning based on GSM-R can better assist train control and operation.

2. The use of fuzzy control

2.1. Fuzzy control

Fuzzy control is a kind of nonlinear control. Its model is difficult to describe accurately and rigor. However, knowledge base (including data base and rule base) can be used to control the control object. The theoretical basis is fuzzy logic and fuzzy sets [2]. The essence of fuzzy control is a method that imitates the control of an expert.

The structure of fuzzy controller mainly includes fuzzification, database, rule base, inference engine, controlled object and defuzzification. As shown in Fig. 1.

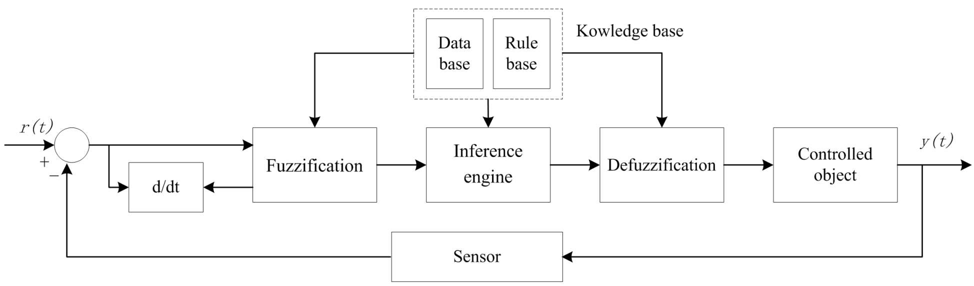

Fig. 1. Basic structure of fuzzy controller

2.2. The combination of fuzzy control and neural network

Because of the structure and function of the neural network and fuzzy control, the combination can produce new functions. For example, the neural network is used to drive the fuzzy inference; the learning ability of neural network is used to remember the fuzzy rules; and the parameters of the fuzzy controller are optimized by using neural network [3].

In order to enhance the learning function of the neural network, the logic reasoning and operation rules of fuzzy control are introduced in the system structure. The function of BP neural network is to locate the train's current running position, match the identification points on the electronic map, and meet the real-time requirements of the system. It is difficult to control the learning rate of BP neural network. When the learning rate is large, the convergence speed of the network is relatively fast, but it will cause the network concussion; when the learning rate is small, the network is relatively stable, but the training time increases, the error convergence rate also slows down. Therefore, the idea of fuzzy control is added in this paper, and the error and error rate of change are used as input variables. Learning rate as output, the fuzzy rule is formulated according to the change of learning rate with the change of error and error rate. The fuzzy neural network controller is designed in this paper. The learning speed of BP neural network is adjusted by the fuzzy adaptive learning process, and the convergence speed is accelerated under the premise of meeting the precision requirement.

2.3. Fuzzy neural network controller

The function of fuzzy neural network controller is to improve the learning function of BP neural network, and to speed up the convergence. The input parameter is the error and error rate in the process of system operation, and the output is the learning rate of BP neural network.

The value of learning rate affects the performance of BP neural network. The learning rate determines the amount of weight change produced in each cycle of training. Large learning rates may lead to system instability. Small learning rate leads to longer training time and may slow down, but it can ensure that the error value of the network does not jump out of the error surface, and eventually tends to the minimum error value. In general, there is a tendency to select a smaller learning rate to ensure the stability of the system. So the learning rate is selected between 0.01-0.8.

3. GSM-R network

The GSM-R network maintains the original communication service, and has opened up many special services in railway application. GSM-R has added new functions, such as plane shunting, automatic train control, location addressing and function addressing, and more conforms to the four standards of reliability, availability, maintainability and safety of high-speed railway transportation [4]. In the CTCS-3 train operation control system in China, the GSM-R system has strict service quality evaluation standards [5]. When the satellite navigation signal is disturbed, the system network can be quickly restored to connect, and the connection channel between the train and the ground control center is unblocked.

In the process of data communication, when the mobile base station handover, the GSM-R network data transmission will temporarily interrupt. The transmission rate of the system is 4800bit/s, the packet is 10∼235Byte, and the handoff probability of the message transmission is less than 3%. Therefore, GSM-R network can replace GNSS and monitor the train operation status in real time when GNSS fails.

3.1. GSM-R transmission path loss

Path loss is an important factor affecting GSM-R wireless coverage. Therefore, the path loss from the base station to the mobile station should be considered in the premise of meeting the coverage requirements of the wireless network. In the process of signal transmission, the gain and loss between transmitter and receiver have a certain relationship [6] . The expression of the received power P_r is:

$$P_r = P_t - L_t + G_t - L + G_r - L_r \, , \tag{1}$$

Where L is the path loss, P_t is the transmitting power of base station, G_t is the gain of transmitting antenna, G_r is the gain of receiving antenna, L_t is the loss between transmitter and transmitting antenna, L_r is the loss between the receiver and the receiving antenna.

3.2. The influence of environment on loss

Different geographic environments have different effects on the field intensity signals received by the train, resulting in the signal fading. When trains run in plain or quasi plain areas, the main factor affecting radio wave propagation is ground reflection, but diffraction, scattering and other reflections are very weak. For the typical plain viaduct terrain, the train runs on the viaduct, and the transmission environment is better than that on the ground.

According to the terrain characteristics along Chinese railways, the Log-distance Path Loss Model is selected to predict the path loss in wireless network propagation. The model expression is shown as [7]

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10n \log(\frac{d}{d_0}) + X_\sigma \, , \tag{2}$$

Where d_0 is a near ground reference distance, d is the distance from the receiver distance to the transmitter, the X_σ is the shadow fading, and the n is the path loss index. The path loss index indicates the rate of path loss increasing with distance. The obstacles and multipath propagation in the environment will affect the value. Table 1 summarizes the path loss in different environments.

Table 1. Path loss under different environment

Communication environment	Path loss index n
Free space	2
Urban district	2.7-3.5
Be sheltered by a building	4-6
Be blocked by the factory	2-3

4. Establishment of system model

The system is mainly composed of two functional modules, fuzzy controller and BP neural network, as shown in Fig. 2. Firstly, the fuzzy variable error(e) and error rate(ec) get the learning rate(u) through fuzzy decision according to fuzzy rules. Secondly, learning rate is used as control quantity to adjust the performance of BP neural network. Finally, the output feedback of the BP neural network is compared with the input to form a closed loop control system [8-10].

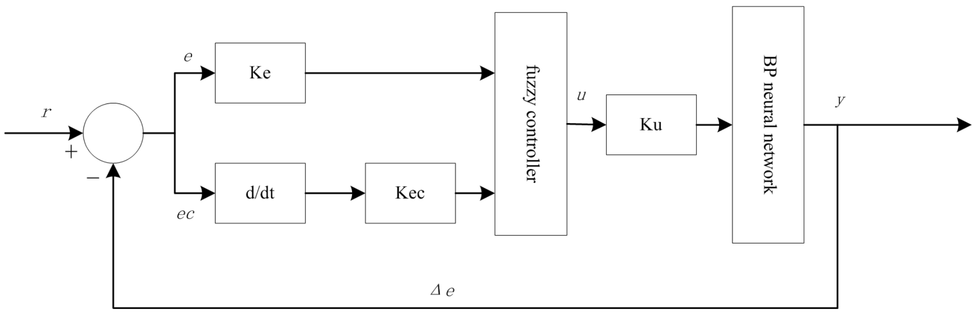

Fig. 2. Positioning system structure of fuzzy neural network based on GSM-R

The function of the fuzzy neural network function module is to carry out the BP neural network training based on fuzzy control and the BP neural network training separately, and the training results are stored in the work space through the output module.

5. Simulation analysis based on Simulink

In this paper, the GSM-R data and rail mark points are simulated and analyzed. Whether the system can meet the requirements of the satellite navigation blind spot train positioning can be judged from the error accuracy.

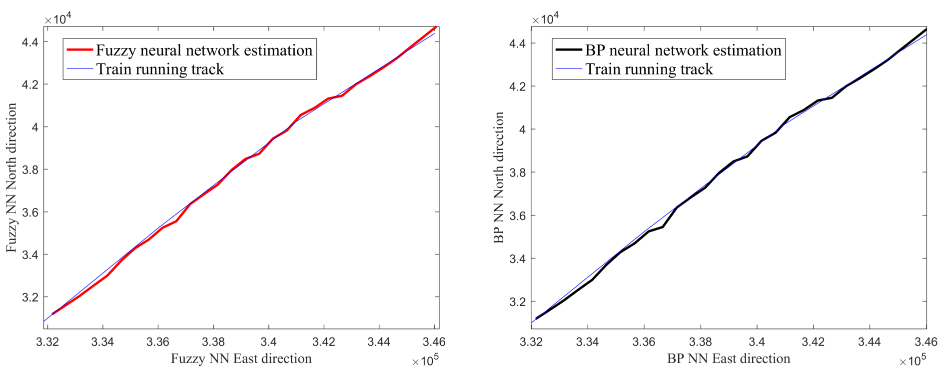

Fig. 3. Estimation effect of Fuzzy neural network and BP neural network

Precision represents the accurate location of the train, the accuracy in this paper refers to the actual measured value and fitted value deviation. The fitting results of the fuzzy neural network positioning method and the BP neural network positioning method are shown in Fig. 3. The purpose of satisfying the principle of accuracy is to ensure the safe operation of the train, and provide an accurate position identification mechanism for the train positioning system.

Through analysis and comparison, both the fuzzy neural network estimation method or the BP neural network estimation method can coincide with the actual running track of the train. However, the learning performance and generalization ability of the BP neural network with fuzzy adaptive adjustment are obviously better than that of the BP neural network alone. The fitting curve of the fuzzy neural network is more consistent with the change trend of the actual railway line, and the accuracy is higher, which can truly reflect the detailed characteristics of the train running track.

The positioning error of the fuzzy neural network positioning method in each direction is shown in Fig. 4. The positioning error range of the east direction is between -12.3 m~13.8 m, and the positioning error range of the north is between -11.5 m~12.5 m, which can meet the requirements of the satellite positioning blind zone train positioning.

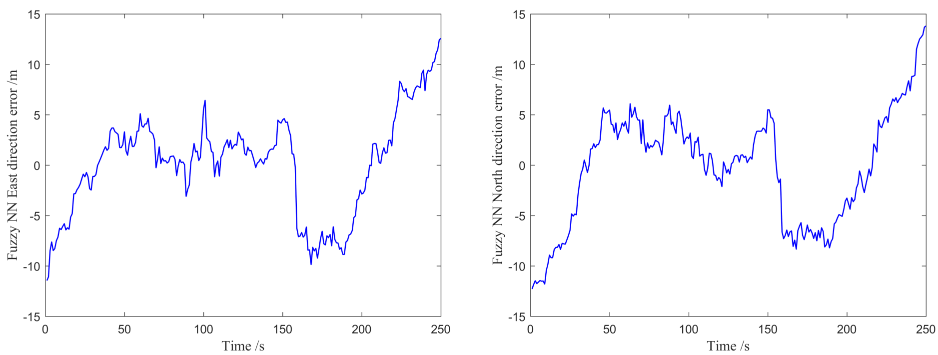

Fig. 4. Fuzzy neural network east error and north error

But the positioning error of the BP neural network positioning method in each direction is shown in Fig. 5. The positioning error range of the east direction is between -12.9 m~15.2 m, and the positioning error range of the north is between -10.5 m~17.8 m. Obviously, the precision of the fuzzy neural network positioning method are better than those of the BP neural network positioning method alone.

6. Conclusion

In this paper, through the use of global navigation satellite systems, a fuzzy neural network positioning method based on GSM-R is proposed. Firstly, the coverage strength and transmission path loss of GSM-R network are analyzed, and the related

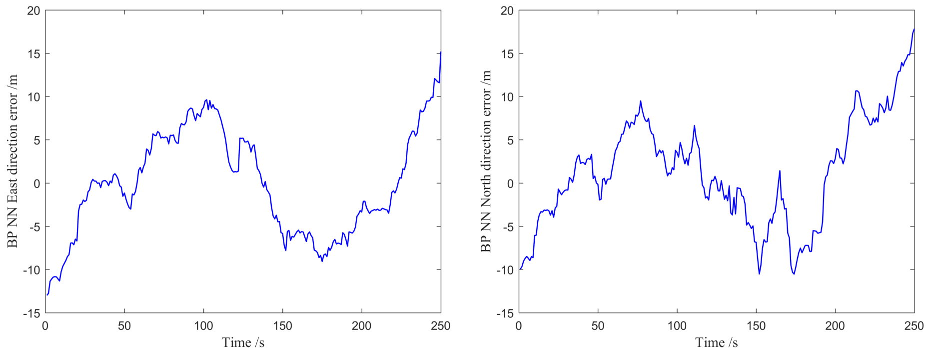

Fig. 5. BP neural network east error and north error

data are collected and calculated. Secondly, the simulation model of fuzzy neural network positioning system based on GSM-R is built. Finally, through the Simulink analysis experiment, the effect of fuzzy neural network positioning method and BP neural network positioning method is compared, and the detailed comparison and analysis are made from the aspect of error accuracy.

The experimental results show that the error precision of the fuzzy neural network positioning method is better than that of the BP neural network positioning method alone. In the case of GNSS failure, GSM-R aided train positioning can improve the safety and reliability of train operation.

References

[1] W. D. LI, L. H. Hou: *A Study on the Train Positioning Method Based on Cubic B-spline Curve Fitting*. Control Engineering of China *24* (2017), No. 3, 135–140.

[2] C. L. P.Chen, Y. J. Liu, G. X. Wen: *Fuzzy neural network-based adaptive control for a class of uncertain nonlinear stochastic systems*. IEEE Transactions on Cybernetics *44* (2014), No. 5, 583–593.

[3] P. C. Chang, C. Y. Fan, J. J. Lin: *Monthly electricity demand forecasting based on a weighted evolving fuzzy neural network approach*. International Journal of Electrical Power & Energy Systems *33* (2011), No. 1, 17–27.

[4] S. Deng: *Discussion on frequency allocation of GSM-R system*. Railway Signalling & Communication Engineering *62* (2009), No. 4, 1212–1220.

[5] F. Huang: *Analysis of communication quality of GSM-R carrying CTCS-3 service*. Zhejiang University, China (2010).

[6] Z. Zhang, J. Xu, W. Lian: *Scenario classification and path loss index estimation of radio wave propagation in GSM-R system of high speed railway*. Railway Signalling & Communication *50* (2014), No. 9, 52–56.

[7] W. Hong: *Study on large scale model and handover optimization of high speed railway wave propagation*. Beijing Jiaotong University, China (2012).

[8] H. Y. Dong, L. Yang, L. I. Xin, J Yan: *Study on high-speed train atp based on fuzzy neural network predictive control*. Journal of the China Railway Society *35* (2013), No. 8, 58–62.

[9] L. S. Wang, H. Z. Xu, H. Y. Luo: *An intelligent cruise controller for high-speed train*

operation based on fuzzy neural network theory. Applied Mechanics & Materials *300-301* (2013), 1405–1411.

[10] X. H. Yan, B. G. Cai, J. Wang, W Shangguan: *Research on fuzzy neural network based fault-tolerant control for deeply gps and sins integrated train positioning system.* Journal of the China Railway Society *37*, (2015), No. 4, 51–60.

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