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A Data Fusion Algorithm Based on Neural Network Research in Building Environment of Wireless Sensor Network

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Abstract

Data fusion in wireless sensor network is a effective method to reduce the network energy consumption. In order to build high performance of data fusion system, a data fusion algorithm using BP neural network to optimize fuzzy prediction and train the membership degree of collecting data is presented, which is used to determine which kind of dividing fusion mechanism is belonged for the sensor's data collected at a given moment. First the fuzzy prediction is used for acquisition of knowledge which data is simplified to remove redundant properties and samples. The BP neural network is used to process fuzzy prediction and finally the patterns of muli-sensed-data(temperature as an example) fusion distribution are formed. Two kinds of different BP neural network are proposed and compared for more precision of the fuzzy prediction result. Second data fusion based on the fuzzy prediction will be implemented to reduce the number of data transmission in the network. Simulation results show that the algorithm has good precision and applicability.

Keywords: *Data fusion; The BP neural network; Fuzzy prediction; Wireless sensor network.*

1. Introduction

Wireless sensor networks(WSNs) are composed of lots of low-cost, low-powered tiny wireless nodes and can be used for many long-term applications, such as environment monitoring, building protection and supply chain and logistics management[9,10]. For energy saving and environmental protection of the building environment, WSNs can be used to sense and collect environmental parameters such as temperature, humidity, air pressure, which can be used as the input of the automation control system of the building via Internet or industrial data bus.

Sensor nodes in wireless networks are usually powered by batteries and energy is limited. In the field of battlefield surveillance, environmental monitoring field such as forest fire monitoring, medical and health field realize remote monitoring of the human body physiological indexes under special environment, it is not realistic to supplement energy by replacing the battery which makes energy consumption to determine the lifetime of the network. In WSN wireless communication is a major consumer of energy. In the Berkeley Mote as an example, 1 bit of data transmission energy consumption can execute 800 instructions[11]. Reducing network's data transmission can effectively reduce the energy consumption of sensor networks, and the data fusion technology can be helpful to achieve the purpose of increase the network lifetime.

In a mass dense deployment of sensor networks sensed data are correlated usually. In the process of transmission, data can be combined or relevant. The main method of data fusion is to remove redundancy and low credible data, combining information from different node to reduce the amount of transmission in the network for the purpose of reducing energy consumption and prolonging the network's lifetime.

Data fusion can be implemented in different protocol layers. The network layer is mainly used for routing and data delivery, the application layer is mainly used for the query, data fusion. For a build environment monitoring system, while lots of environmental data should be sensed and transmitted for real-time acquisition, data fusion strategy in different layers can be used in the process to reduce energy consumption of WSNs, prolong the network life cycle.

Data fusion in network layer: different from the traditional network, WSNs don't care about the specific sensor on a single data, pay more attention to the multi-node cooperative information

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collected, such as: temperature monitoring. Temperature distribution are concerned about the area in a specific information, but not limited to specific node value, more is how to transmit this information through the network to gather nodes which makes in the process of data transmission to speed up the convergence of redundant data, and to choose energy efficient routing in the form of multiple hops, reduce conflict of data transmission, improve collection efficiency.

Data fusion in the application layer: application layer data fusion technology research is mostly based on query mode of data fusion technology, based on the aggregation of distributed database operation, the user sends a query request to the network using descriptive language query request in the network in a distributed manner. The query results through multiple hops routing returned to the user, handle query requests and return the query result is essentially the process of the data fusion process.

2. Related Works

Zadch L. A. [1] the United States Professor in 1965, proposed fuzzy set theory to seek a kind of processing can't accurately describe the ambiguity problem of rigorous mathematical method. Fuzzy predictive control algorithm is using fuzzy reasoning process of uncertainty information processing and decision-making to improve the performance of predictive control or fuzzy control. Zhao Yaguang [12] applied BP neural network to the data fusion and concluded the data fusion model, a detailed analysis of the basic principles of the BPNN, key issues, strengths and weaknesses as well as the application in WSN data fusion. Combining BP neural network with data fusion, get data fusion model based on the BPNN. Yuan Xia [13] used fuzzy prediction for feature extraction and optimized association of the input and output. In the work [2], BP neural network is usually adopted to solve the problem of intercross sensitivity of pressure sensor to temperature. PSO algorithm is applied to train the weights of neural multi- layer forward neural network. The results of the data fusion show that the stability and accuracy of the sensor are improved greatly. In the work[3]proposed a neural network algorithm based on BP multi-sensor data fusion method for modeling complex situations. In the work[4]A practical, general data fusion scheme was established on the basis of feature extraction and merge of data from multiple sensors. This scheme integrates artificial neural networks for high performance pattern recognition. In the work[5]BP neural network is usually adopted to solve the problem of intercross sensitivity of pressure sensor to temperature. PSO algorithm is applied to train the weights of neural multi- layer forward neural network. The results of the data fusion show that the stability and accuracy of the sensor are improved greatly. A practical, general data fusion scheme was established on the basis of feature extraction and merge of data from multiple sensors. This scheme integrates artificial neural networks for high performance pattern recognition.

In our research, the difficulties of fusing temperatures from different sensors which represent the real value partly lie in the switching of the divide state of temperatures .That is, at a given moment which kind of dividing the sensor should fuse data into. First the fuzzy prediction is used for acquisition of knowledge which is simplified for remove redundant properties and samples. The BP neural network is used to proceeding fuzzy prediction and finally the patterns of multi-data of temperature fusion distribution are formed. The model is proved experimentally to be efficient in classification and rapid in data distribution decision of sensor network.

The paper adopts fuzzy prediction to analysis the fusion node’s data, training the BP neural network prediction model. Neural network is a highly nonlinear dynamic system, it has strong nonlinear fitting ability and can look for a nonlinear function for data’s membership degree mapping relationships. Prediction not only pay attention to the target, past and present and pay attention to the target in the future, make the controlled quantity and the target amount of deviation as small as possible so as to improve the control performance of system. The advantages of fuzzy control is that it does not need accurate mathematical model of an object, simply use the prior knowledge of those who reflect system performance, according to a certain control rules to control. So to train the BP neural network for membership degree prediction according to samples, the training result is applied to data fusion of the dynamic changes of the temperature data.

3. Data Fusion Algorithm

In today's construction industry, intelligent building is the trend of The Times, which mainly involves is the problem of information collection and processing. In terms of information transmission, sensor nodes can be collected the information such as temperature, humidity and dust

quickly passed to the network center node, and a node in the case of not change the power supply can work half a year or two years. In the aspect of information processing, wireless sensor network (WSN) now reached a very high coverage, and has a high rate of communication, is a very important part in modern intelligent buildings.

Wireless sensor data fusion mainly includes the packet level and the application level. There are two ways in packet level fusion operation: nondestructive and destructive. In nondestructive fusion, all valid information will be retained, and there are a lot of redundant data. The basic principle of data reduction is to reduce the redundant information. The destructive fusion is to reduce information details or reduce the quality information method to reduce the amount of data transmission.

It needs to comprehensively consider the measurement result of each sensor node in environment with multiple wireless sensor nodes, to ensure the accuracy and reliability of the data monitoring. As the indoor temperature detection, measuring room temperature should consider the special position of the gate, the central committee and the window, synthetically get relatively reliable indoor temperature. In the process of comprehensive, multiple terminal nodes upload the data to routing nodes for data fusion after simple data proceeding. The paper mainly focuses on the secondary data fusion in the application of neural network to construct the data fusion model, reducing the amount of temperature data transmission in the network, so as the energy consumption.

Within the cluster of cluster distributed fusion rely mainly on the control strategy, the ordinary node data classification of perception, perception data were determined by fuzzy correlation functions of comprehensive support, then carries on the reliable, redundancy, the division of conflict, finally retain reliable data, dormancy redundant data, eliminating conflict many times greater than the threshold value of the data.

Experimental environment is that on the basis of the wireless sensor network's time synchronization, routing node R will receive the temperature information from three terminal nodes A, B, C sending. $T_{R(t-1)}, T_{A(t)}, T_{B(t)}, T_{C(t)}$ respectively means fusion node R uploaded terminal data last time and nodes A,B,C transmitting the terminal data to the fusion node this time. We can define $\Delta_1 = \left|T_{A(t)} - T_{R(t-1)}\right|$, $\Delta_2 = \left|T_{B(t)} - T_{R(t-1)}\right|$, $\Delta_3 = \left|T_{C(t)} - T_{R(t-1)}\right|$, $\Delta = \max\left\{\left|T_{A(t)} - T_{R(t)}\right|, \left|T_{B(t)} - T_{R(t)}\right|, \left|T_{C(t)} - T_{R(t)}\right|\right\} \left|T_{B(t)} - T_{R(t-1)}\right|$, and set $\Delta_1, \Delta_2, \Delta_3, \Delta$ as the known training samples. Using the trained samples forecast data classification at the data fusion moment, the corresponding data fusion model is generated.

After BP neural network's fuzzy prediction, we should select sensor temperature data fusion strategy according to the training result : when $\Delta_1, \Delta_2, \Delta_3 \leq$ M, the collecting temperatures of sensors A, B, C are basically same as the last collecting cycle, fusion node R will continue to use $T_{R(t-1)}$ after the judgment, choosing not retransmission the temperature of sensors A, B, C at this collecting cycle .When M< $\Delta_1, \Delta_2, \Delta_3$ <N, the temperature acquisition of sensors A, B, C has a relatively large gap with the last time, fusion node R will choose the retransmission at this time after judgment, and calculate the average temperature $T_{R(t-1)} + (\Delta_1 + \Delta_2 + \Delta_3)/3$ according to uploaded temperature of sensors A, B, C ;When $\Delta_1, \Delta_2, \Delta_3 \geq$ N, the collecting temperature of sensors A, B, C have very big difference with the fusion node's data last time, it should use the emergency transmission path to transmit the drastic change of environment to the controller in a hurry; When a sensor node's data has severe changes $\Delta > k$ while other node is almost the same, this node almost be not working, it will eliminate the node's data, and report to the controller the problems. The values of M, N, k are conducted according to the actual range of sensor acquisition .There are 61 groups of sensor temperature in the training samples.

Table 1. Simulation Data (i = 1, 2, 3)

Δ_i	Δ	Binary output			
$\leq M$	$\Delta \leq K$	0	0	0	1
$M < \Delta_i < N$	$\Delta \leq K$	0	0	1	0
$\geq N$	$\Delta \leq K$	0	1	0	0
	$\Delta > K$	1	0	0	0

The point of establishing the BP neural network is to build a network structure and the choice of learning algorithm.

3.1 Network Structure's Establishment

The BP neural network is a kind of multilayer feed forward neural network, the network main characteristic is to pass before the signal, the error back propagation. In the forward pass, the input signal from the input layer through the hidden layer can handle step by step, until the output layer. Each layer of neurons state affects only the next layer of neurons state. If the output layer is not expected output, into the back propagation, according to the prediction error adjust the network weights and thresholds, so that the BP neural network to predict the output looming expected output.

The number of input and output layer neurons of BP network is determined by the dimensions of the input and output vector. The dimensions of the input vector, that is, the number of factors. As there are 3 child nodes of fusion node to transmit data, so the number of input layer neurons is 3. According to the result of without retransmission, needing to recalculate the retransmission, large temperature variation needing urgent transport in data fusion node and at least one node is not working, there are four levels (0001), (0010), (0100), (1000),corresponding to the target output mode, and the number of neurons in the output layer is 4. Practice shows that the increasing of the number of hidden layer can improve the nonlinear mapping ability of BP neural network, but the number of hidden layer exceeding a certain value, the network performance will be reduced. The choice of hidden layer neurons number is selected by experience[7,14], this paper set the number of hidden layer neurons to 20. On Matlab2012 simulation platform, 3-20-4 structure model was adopted, namely the input layer 3 neurons, 20 hidden neurons, 4 output neurons. Neural network structure is as follows:

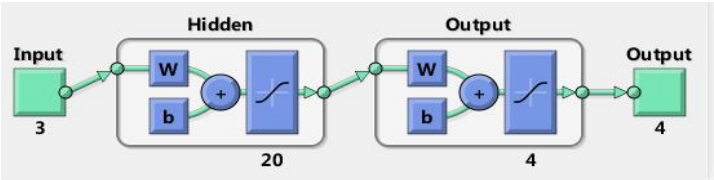

Figure 1. Neural Network

3.2 The Network Learning Algorithm

BP neural network prediction model use three layers of neural network structure. Most of the actual data correlation is a nonlinear relationship, less than three layer structure is unable to approximate the nonlinear curve. When more than three layers, of course, can also close to the curve, but it will increase the complexity of the calculation. For the BP neural network, the model of three layers structure can approximate any form of curve. The three layer structure is the input layer, hidden layer and output layer.

The BP neural network usually is the multi-layer forward neural network based on BP neural structure form. In the network structure of BP neural network, the most important is to determine the network layers and the number of neurons in each layer. Number of input and output layer neurons is usually determined according to the dimensions of the input and output data. The structure of the hidden layer is larger influence on the performance of the entire network. Each layer of neurons is according to the specific application. The second is the design of the network learning algorithm. Fundamental learning rule of the BP neural network is error back propagation algorithm, but there were some defects of conventional BP algorithm. In order to improve the BP algorithm, Levenberg-Marquardt (L-M) algorithm based on gradient descent and gauss Newton method combining is a kind of commonly used numerical optimization algorithm. It is very suitable for function fitting problems, and applied to neural network to nonlinear learning, fast convergence and small error. The BP neural network using L-M algorithm local optimization is very appropriate. The biggest advantage of artificial neural network (ANN) is that can approximate any complex nonlinear relations, fully has the strong learning ability and fault tolerance, be able to handle the quantitative and qualitative data at the same time, use the connection structure combined with other control methods and artificial intelligence [6].

The training sample input model can be trained to network to establish the BP neural network using of random weights and thresholds. The prediction data input training prediction model can forecast through the comparison, and the actual analysis to predict the degree of accuracy and availability of the model. Input and output variables will first be normalized processing between the interval [0, 1] Which is the data range after normalization [8]. Supposing x is the current data values, $X_{\max}$ is the maximum x in the overall data, $X_{\min}$ is the minimum value of the overall data, adopted the equation $X_{\max} - x_{\min}$. This method is simple, small error, and the program is simple.

Patternnet (hiddenSizes, trainFcn) takes a row vector of N hidden layer sizes and a back propagation training function and returns an N+1 layer pattern recognition network.

The transfer function of hidden layer neurons as the Sigmoid type tangent function ‘tansig’. As the result of the output vector elements for a value of 0 and 1, the transfer function of neurons in the output layer is ‘purelin’. A network training function ‘trainlm’ updates weight and bias values according to Levenberg-Marquardt optimization which based on gradient descent and gauss-newton method combined with optimization method (Levenberg- Marquardt) fast learning algorithm of BP neural network, it is suitable for the function fitting, has a fast convergence and the advantages of small error, is often the fastest back propagation algorithm in the toolbox, and is highly recommended as a first-choice supervised algorithm, although it does require more memory than other algorithms. Therefore ‘trainlm’ function is chosen as the learning algorithm. Learning accuracy of target error is also an important parameter of the network, the scope of the study is to determine the error of precision to decide at the end of the training [15]. It is the most widely used nonlinear least squares algorithm. It is the use of gradient algorithm for maximum (small) of the image, belongs to a kind of "climbing" method. It also has the advantage that the gradient method and Newton method. When lambda is very small, step length is equal to the Newton's method step, when lambda big step, the step length of approximately equal to the gradient descent method.

LM algorithm between Newton method and gradient descent method is a kind of nonlinear optimization method, is not sensitive for a parameterized problem, dealing with redundant parameters effectively, make the cost function will minimize the chance to fall into local minimum value, these features make LM algorithm is widely used in the field of computer vision, etc.

Training process is shown in Figure 2:

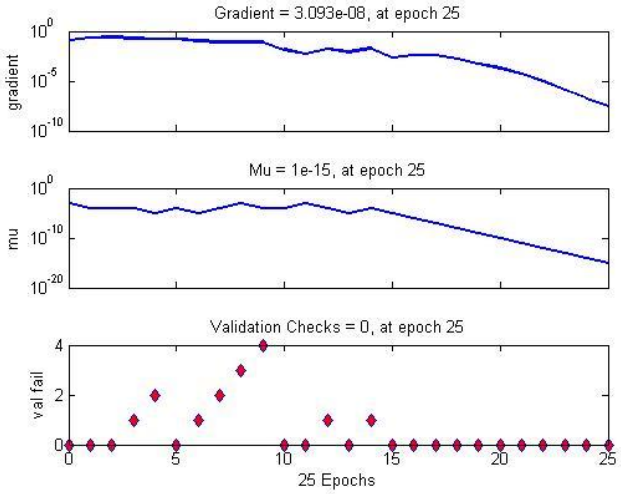

Figure 2. Training Process

Simulation algorithm has two steps: first step, Import the training samples for training results, observe the iterative steps to compare convergence speed. Supposing the simulation values are M=0.6, N=2.2 K=1.2. The second step, import validation sample then validation results are obtained. Third step, import samples for forecasting error curve and run as a result, the observation of the oscillation of the forecast error curve and operation result shows that the prediction error values, to compare the accuracy of forecasting model [16]. Get the corresponding error histogram graph as follows:

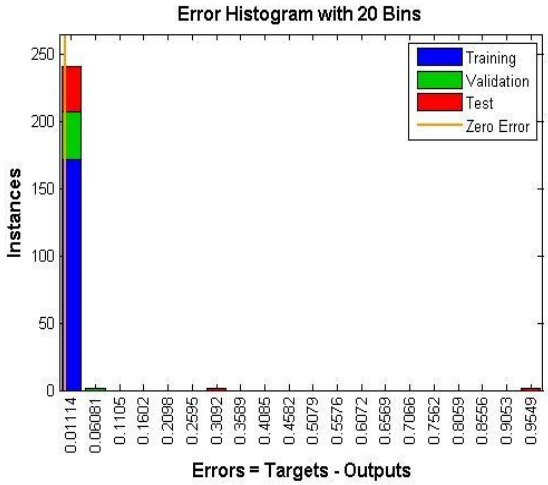

Figure 3. Error Histogram Graph

Importing sensor temperatures as the training sample data, training, validation, and projections is processed for the network. The BP neural network can achieve error requirement after many training requirements, namely the convergence. Mean square error (MSE) is shown in Figure 4 after the network training:

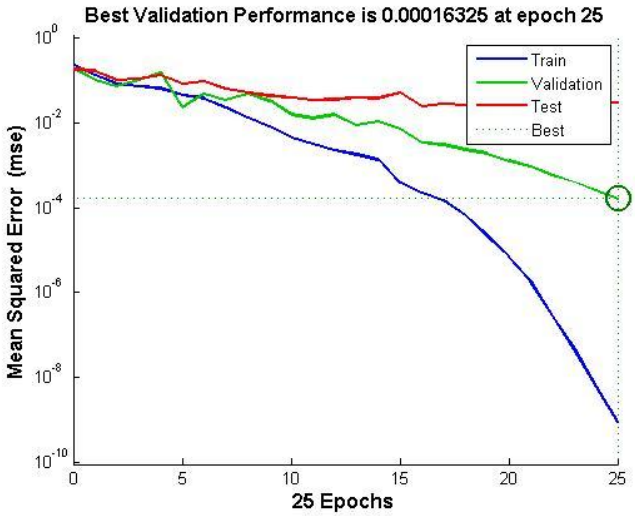

Figure 4. Mean Square Error (MSE)

We can judge temperatures of sensors A, B, C belonging to (0001), (0010), (0100), (1000) after many times training. As shown in Figure 5, the accuracy can be as high as 100%.

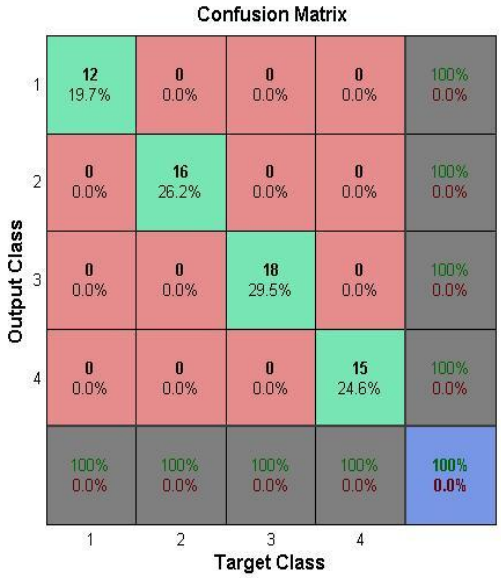

Figure 5. Correlation Results of Temperatures

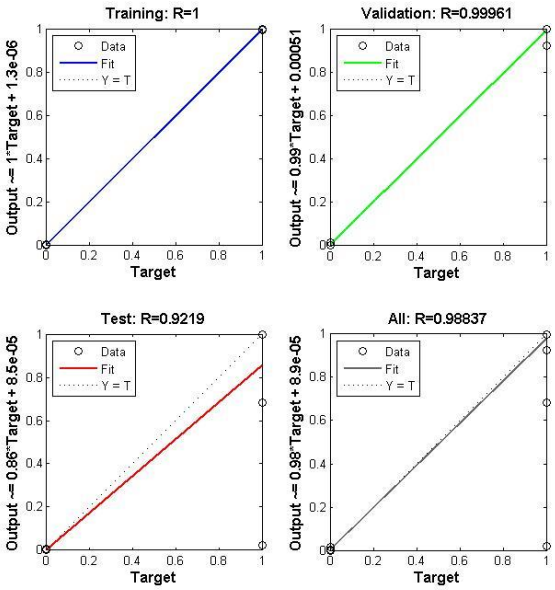

Figure 6. Contrast of Training and Actual Results

All training data's accuracy is as high as 0.98837 in Figure 6, completely meets the accuracy requirement of indoor temperature' monitoring of the wireless sensor network.

Algorithm's shortcoming is when the occurrence of multiple terminal node failures, the situation may not be accurate judgment, needing more training samples for testing, at the same time, each adding child nodes of the fusion node means an index increased training samples, so to eliminate failure nodes temperature data before using neural network is helpful. We define $C_1 = |\Delta_1 - \Delta_2|, C_2 = |\Delta_1 - \Delta_3|, \Delta = |C_1 - C_2|$ in eliminating algorithm before data fusion of three terminal nodes. If the difference of the three terminal node data's temperature is bigger, then at least one node is function failure. M is used to limit the value of Δ which is the interpolation of inputs for BP neural network. In the case of the sensor node failure, sorting the value of C_1, C_2, the larger one can be ruled out and send the failure report directly to the controller. If it is normal conversely, the algorithm will continue to neural network data fusion strategy.

We can get the 100% accuracy rate from the train results' classification, but the real train result is not the expected data 0 or 1, they are infinitely near the points. As we know more approach to the expected value, the BP neural network's training performance is better. Therefore, we search for a more accurate training network. In another BP neural network, choosing 'newff' to building the net and using different parameters from the last training experiment. Compared from the results of different BP neural network, we can get more precision of the fuzzy prediction.

'Newff' create a feed-forward back propagation network. The maximum epoch is set as 1000, the objective error is set to 0.01. The result of last training is show in the Table 2.

Table 2. Training Parameters in Simulation

item / BP training	Transfun (hidden layer)	Transfun(output layer)	Training fun	Performance (err)
patternnet	tansig	purelin	trainlm	0.0098
newff	tansig	logsig	trainlm	0.0087

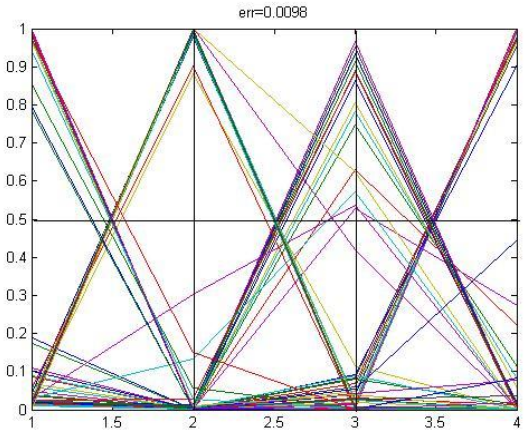

Figure 7. Training Results of Patternnet

From the result of performance(err) shown in Table 2 ,We can see that 'newff' BP neural network training result 0.0087 is closer than 0.0098 of 'patternnet' to the expected output values 0 or 1. The fuzzy prediction and membership of the outputs is shown in Figure 7 and Figure 8, and Figure 9 is the expected outputs result.

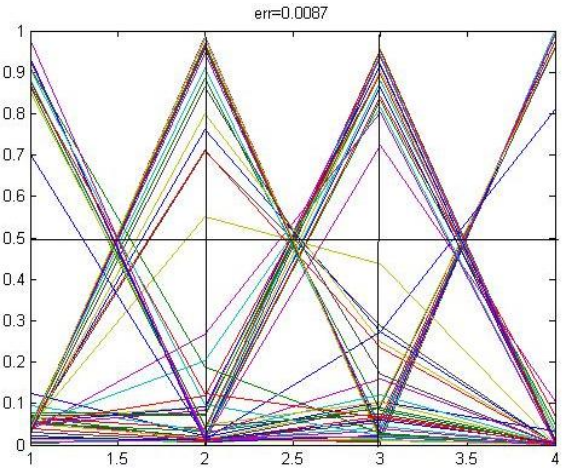

Figure 8. Training Results of Newff

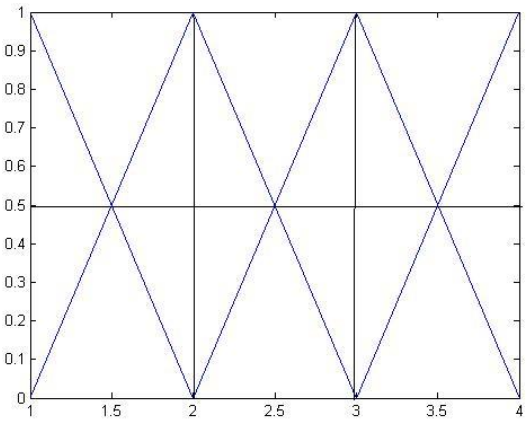

Figure 9. The Expected Training Results

As for one input temperature sets, the expected outputs are column vector such as [0 0 0 1], which is meaning we should get a 0 or a 1 at the Abscissa 1, Abscissa 2, Abscissa 3, Abscissa 4 of the x-coordinate. In Figure 7, we can see the output is approach the middle of 0-1 at Abscissa 3 which is not a good training result. While in Figure 8, the training result is apparently superior to the Figure 7. Figure 9 shows the ideal training result.

4. Conclusion

In the paper, training the temperature of the wireless sensor network based on the theory of fuzzy correlation classification, through BP neural network, to get the membership degree of training data and complete the data fusion. Through simulation, training model can accurately estimate the membership degree of the node's temperature according to the above fusion algorithm fusion. If indoor environment is in the same situation, the algorithm will reduce fusion nodes' uploading data compared with fusion node's data in the acquisition cycle. The next work is to use genetic algorithm to optimize neural network' weights and threshold, get the optimal prediction of membership, then the BP neural network was used to optimize fuzzy prediction data fusion and further improve the accuracy of data fusion.

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