Multi-Sensor Data Fusion Algorithm Based on BP Neural Network

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Abstract. In multi-sensor detection system, the application of multi-sensor accurate detection system parameters is limited due to the existence of measurement noise. Using multi-source data fusion technology can be more accurate, timely detection and data processing system. Data fusion is a basic function in humans and other biological systems. In this paper, in order to make the system adaptive multi-source data fusion, using the BP neural network algorithm is a good way to deal with incomplete test data and test the noise problem. In this paper, the characteristics of three levels of data fusion and the derivation process of BP neural network algorithm are introduced in detail. In order to verify the role of BP neural network algorithm in the process of detection system filtering, a MATLAB simulation experiment is carried out. The experimental results show that the BP neural network algorithm can effectively reduce the measurement error of multi-sensor detection system and improve the detection accuracy.

1. Introduction
With the development of science and the progress of society, the amount of information acquired and processed by people is increasing day by day, and the complexity of information utilization and processing is increasing. With the progress of computer communication, automation testing technology, all kinds of the complex background of application system for multisensor data, forcing people to more effectively integrate multiple sensors and different information sources, in order to improve the automation of data processing [1]. Nowadays, data fusion is widely used in industrial manufacturing system, intelligent transportation, resource exploration, weather forecast and medical diagnosis [2].

BP neural network is to simulate the human brain information processing mechanism and structure of a kind of parallel information processing model [3]. It is one of the characteristics of data fusion technology layer fusion algorithm and distributed storage and associative memory function, can resist noise, fault tolerance and robustness is good. As a result of these outstanding features, the BP neural network can complete the complicated calculation in real time and a huge number of database retrieval of image understanding, pattern recognition and data filtering process [4] showed its superiority.

Reznik et al. applied the multi-layer sensory neural network to detect the signal changes in the wireless sensor network and judge the occurrence of abnormal events. The neural network algorithm can preprocess the data of the input layer, the output layer is the detection signal needed by the sensor system [5]. Wilbert et al. combined genetic algorithm and neural network algorithm to achieve better performance in multi-task process management of monitoring system [6]. The pattern classification can be judged independently in the node, the cluster-head node collects the classification information of
other nodes, further fuses the data, and saves the communication energy. The experiment shows that the algorithm has strong data robustness [7].

This paper mainly studies the data fusion technology of multi-sensor networks and proposes a data fusion model based on neural network [8]. The sensor is the core component of the instrument and measuring system and the important link of the process control. The output characteristics of the sensor directly affect the performance of the whole system, so it is very important to improve the precision of the sensor, but the output characteristics of the sensor are affected by many environmental factors, such as temperature, magnetic field and so on [9]. In order to reduce the data communication between sensor nodes and effectively reduce the influence of measurement noise, the eigenvalues in the detection system data are extracted by using various functional functions of neurons, and then a small number of eigenvalues representing the original data are sent to the sink node. The traditional processing methods including hardware circuit compensation and various software measures are not obvious, it is difficult to achieve the expected precision. BP neural network algorithm is a new method applied in this field. This paper adopts the data fusion algorithm based on BP neural network to effectively improve the measurement accuracy of the detection system. This method is more effective and reliable in improving the performance of sensors [10].

2. Introduction of data fusion technology

In a narrow sense, data fusion is the process of processing a variety of different types of data. But in a broad sense, data fusion refers to a discipline or problem-solving tool that includes data processing. As a tool to solve problems, data fusion includes the understanding of fusion unit and the design of fusion structure. The fusion structure is easy to understand by which mode the data is fused to the system. Fusion unit refers to the process from each data processing to decision-making to execution. The data fusion process is composed of many fusion units.

Currently, data fusion is not only applied in the military field, so a more general definition of data fusion can be given [11]. The multi-source information of a target is fused to form a more accurate and complete estimation and judgment than that of a single source. The redundant or complementary data of each sensor in space or time are combined according to a certain criterion to obtain a consistent description or understanding of the object under test, so that the system has better performance than its constituent subsystems.

Data fusion is the organic combination of signals collected by sensors from various places to make the object more clearly recognized [12]. The fusion of information from multiple sensors can obtain precise features that are impossible for a single sensor. The remarkable feature of data fusion is to improve the reliability of information and the detectability of targets. By expanding the spatial search range and the instantaneous search range, reducing the inference ambiguity, improving the detection performance, increasing the dimension of the target feature vector, improving the spatial resolution, and enhancing the adaptability of the system, the performance of the whole system is improved [13].

Information fusion technology involves three processes: information processing, pattern recognition and reasoning decision [14]. According to the mathematical abstraction method of each process, information fusion can be divided into three levels: data-level fusion, feature-level fusion and decision-level fusion [15].

The data-level fusion is a direct fusion on the original data layer collected. The data synthesis and analysis of various sensor information are carried out before the pre-processing. It is the fusion process at the first level. This fusion method is simple to operate, it can observe the internal details of the multi-sensor detection system, and play a good role in data filtering. However, its disadvantages are obvious. Due to the large amount of data of the sensor for direct data fusion, it has high cost, poor anti-interference and high error correction ability for the system. Mainly used for multi-sensor image composition and image analysis.[16]

The feature-level fusion is an intermediate fusion, which firstly extracts the feature from the sensor and then comprehensively analyzes and processes the information. The advantage of feature fusion lies in the realization of considerable information compression, which is conducive to real-time
processing, and the extracted features are directly related to decision analysis. Therefore, the fusion results can give the characteristic information needed by the decision information to the greatest extent. The above fusion method plays an important role in target tracking and recognition.

Decision level convergence is the last type of convergence, and it mainly provides a role in our approach. When using this fusion method, we should first reveal the original appearance of things comprehensively and systematically according to the causal relationship of things and the preliminary results of the first two fusion methods. If the decision level fusion method is used improperly, it will directly affect the work of the judgment system. Finally, this fusion method has many advantages, which can minimize the influence of surrounding environmental factors. After considering the above situation, we can adopt the method of decision level fusion correctly. The preprocessed process costs a lot and the calculation is relatively large.

3. BP neural network

Neural network is to simulate the sensory process of human nerve endings and the information processing ability of cerebral cortex. It is an operational model made up of a number of nodes that are thought to be neurons. Each detection sensor can be regarded as the node of the neural network, and the excitation function is the output function of each node. The weighted value between two join nodes is called the weight, which represents the degree of approximation between two nodes. The output value of neural network depends on the structure of the network. Different network structures correspond to different weighting coefficients and excitation functions.

BP neural network is short for error back propagation network and has been widely used in supervisory classification. Its activation function is differentiable everywhere. Theoretically, a network with a hidden layer can approximate any continuous function with any accuracy.

Figure 1 shows the structural design of BP neural network. From the perspective of function approximation, equation (1) can be used to approximate functions of any complex form. The nonlinear function represented by equation (1) can be realized by a network containing a hidden layer with linear transfer function and unbiased value of neurons in the output layer.

$$y_i = \sum_{j=1}^{N_h} W_{kj}^2 f\left(\sum_{i=1}^{N_i} W_{ji}^1 x_i + b_j\right)$$  \hspace{1cm} (1)$$

$W_{kj}^2$ is the weight between the neurons in the second input layer, $f(x)$ is the transfer function of the hidden layer neuron, $W_{ji}^1$ is the weight between the neurons in the first input layer, $b_j$ is the bias of the neuron in the hidden layer.
Theoretically, it has been proved that BP network with a hidden layer can approximate the nonlinear function of any degree of complexity with any accuracy as long as the number of hidden layer neurons is enough.

The nonlinear transfer function of BP network neuron is usually Sigmoid function:

$$ f(x) = \frac{1}{1 + e^{-\beta x}} $$

When deducing the BP algorithm, we choose the continuous s-type function with $\beta$ as 1, namely the logsig function[17]:

$$ f(x) = \frac{1}{1 + e^{-x}} $$

Since $f(x)$ is continuously differentiable, the gradient method can be used to calculate the algorithm. A clear weight correction analytic formula is obtained.

The structure of BP neural network is shown in figure 1, with a total of $M$ layers. The number of nodes in layer $l$ is the output of node $k$ in layer $l$, which can be represented by the following equation:

$$ y_k^{(l)} = W_k^{(l)} y_{k-1}^{(l-1)} + \sum_{j=1}^{n_l} W_{kj}^{(l)} y_j^{(l-1)} $$

Given the sample pattern $(X,Y)$, we can adjust the weights of the neural network and minimize the following functions:

$$ E(W) = \frac{1}{2} \| Y - \hat{Y} \|^2 = \frac{1}{2} \sum_{k=1}^{n_u} (y_k - \hat{y}_k)^2 $$

Where, $\hat{y}$ is the output of the network. According to the gradient descent method, the correction quantity of weight vector can be obtained from the following equation:

$$ \Delta W_i^l = -\alpha \frac{\partial E}{\partial W_i^l} = \alpha \sigma_i^{(l)} y^{(l-1)} $$

Here, for the output layer, there is:

$$ \sigma_i^{(l)} = (Y_i - Y_i^{(M)}) f'(\hat{Y}_i^{(M)}) $$

For other layers, there are:

$$ \sigma_i^{(l)} = \sum_{j=1}^{n_k} W_{ij}^{(l)} \sigma_j^{(l+1)} f'(\hat{Y}_j^{(l+1)}), l = 1, 2, ..., M - 1 $$

For a given sample library, the weight of the network is adjusted repeatedly according to the above process, so that the output of the network is close to the expected output. Each BP network should always have enough hidden layers and hidden nodes. BP network can approximate arbitrary nonlinear mapping relation and has better generalization ability. Therefore, BP network is very effective in practice.

4. Multi-sensor data simulation

Multi-sensor detection system includes voltage sensor, current sensor and resistance sensor. The detection value of the sensor is not only related to the measured object, but also to the working temperature and the fluctuation of the power supply. $\omega = f(p, q, r)$, $\omega$ is the output signal of the sensor, $p$ is temperature fluctuation, $q$ is power fluctuation, and $r$ is input signal disturbance. For the same standard input, the value of the sensor output fluctuates with the temperature and power fluctuation. The maximum absolute error of the sensor output is $\Delta y$, and $y_F$ is the full range.
output of the sensor. The output of the sensor is greatly affected by non-target factors, so compensation should be made to eliminate the influence.

In the simulation experiment, BP neural network is used as the feature layer fusion algorithm, and the voltage, current and resistance detection values are chosen as the input signal of the neural network by using the three layer network structure. In the experiment, the expected output value of the neural network and real value corresponding to the three parameters are shown in the following figure.

Figure 2, Figure 3 and Figure 4 respectively represent the comparison between the predicted value and the true value of BP neural network for voltage, current and resistance. Figure 5 shows the training errors of the three sensors. We can see that after the BP neural network treatment, under the interference of operating temperature and power supply fluctuation, the predicted value curves of the three sensor parameters are very close to the real value, the sensor stability is strengthened, and the detection accuracy of the multi-sensor detection system is greatly improved.

5. Conclusion
The neural network method is especially suitable for solving the data fusion problem of multi-sensor system because of its good nonlinear mapping ability, generalization ability, anti-interference ability, real-time computing ability, ability to distinguish the cause of failure and high efficiency of data utilization. In this paper, we introduce the concept and characteristics of data fusion technology, and the theoretical knowledge of BP neural network is explained and derived in detail. BP neural network is used to compensate the output characteristics of the multi-sensor system, and the simulation results
show that the detection characteristics are greatly improved after the neural network compensation. The effective application of the data fusion approach in the detection system can guarantee a more comprehensive and accurate detection information. In practice, many sensors are affected by a variety of factors. This method has obvious effect on solving such problems and provides a basis for the further development of sensor data detection.

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