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Fault Tolerant Control of Distributed System Based on Neural Network

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Abstract: Neural networks are very promising in the design and control of distributed systems due to their powerful computing power, learning and adaptive capabilities, and distributed capabilities. The purpose of this work is to study fault-tolerant control of distributed systems based on neural networks. For nonlinear systems with actuator failures, fault-tolerant control based on a small portion of the network is required. By combining error tracking and forecasting methods to build performance metrics and reduced fault-tolerant systems, this translates into a control problem. The PSO algorithm is introduced to train the judgment neural network, which avoids the selection of the initial vector and improves the training success rate to a certain extent. To mitigate the effects of actuator errors, a neural network error observer is designed to estimate and compensate for errors. Finally, the effectiveness of the proposed fault-tolerant supervisory control method is proved by an example simulation.

1. Introduction

Distributed systems have been widely used in data fusion and comparative computing, finance, traffic management, dispatch management and other fields [1-2]. Therefore, the research of error control technology of distributed system has become an important and beneficial subject in the research of modern control system. A networked control system is a distributed networked real-time feedback control system that uses a communication network to exchange information between system components (controllers, actuators, sensors, etc.) that belong to different environments. The sensors, actuators, and internal components of the system can all fail, as can the network communication links between the system nodes. Once an accident occurs, it will cause huge losses and material losses, and even lead to catastrophic accidents [3-4].

Early ensemble approaches ignored the effects of system failures, although they had a significant impact on large distributed resources [5]. Khaldi M proposed a new fault-tolerant method for task clustering, called FT-HCC, which aims to improve performance by including task creation time (makepan) and task constraints. Use real-time analytics to improve performance. The results show that the proposed method and technique are effective in fault tolerance [6]. The interaction of distributed embedded control systems (DECS) with the real world places stringent demands on real-time (RT) performance and reliability. Considering the failure of communication nodes and systems, Alvarez I explored a solution to implement FT in Ethernet-based DECS [7]. Therefore, in order to improve the stability, security and reliability of the network control system, fully and reasonably utilize network resources, and use fault-tolerant control methods to ensure that the system can still work normally and stably in the event of component failures, network failures and external disturbances. Very important theoretical significance and practical application value [8].

Now, although some system control model literatures are based on neural networks, the unreliable factors of distributed systems are not fully considered. So far, there is no comprehensive literature about the method of fault-tolerant control of distributed systems for neural network algorithms, and there is no corresponding fault-tolerant measures. This paper takes the distributed system based on the neural network algorithm as the object to carry out research. In order to improve the fault tolerance performance of the distributed model to the actuator fault, the particle swarm algorithm is proposed to optimize the training of the evaluation network, and to solve the partially unknown and completely unknown continuous The fault-tolerant control problem of nonlinear systems gives a new idea to solve the fault-tolerant control problem of distributed systems, and further improves the fault-tolerant control theory of distributed systems, which has important research significance and broad application prospects.

2. The Technology of Fault-tolerant Control of Distributed System Based on Neural Network

2.1. Distributed Estimation

Distributed estimation has wider applicability and stronger reliability than centralized and decentralized strategies. Distributed estimation is mainly used in systems measured by sensor networks, which degenerate into conventional centralized measurement systems [9-10]. Therefore, the centralized estimation strategy can be regarded as a special case of distributed estimation. The main problem faced by distributed estimation is that the measurement information of a single node may not be able to observe the state information of the entire system, so the traditional observer design method cannot be directly applied to solve the distributed estimation problem [11].

2.2. Fault Detection and Threshold Calculation Method

A complete fault-tolerant control system mainly includes two parts: fault diagnosis and fault-tolerant control. Fault diagnosis technology is an important branch in the field of automatic control. Actuator errors are the most common type of errors in practice, so there is a lot of research in the field of error diagnosis and error control. This paper first investigates fault participants [12-13]. According to the degree of failure, it can be divided into partial failure and complete failure. When the regulator fails, the actual input expression uf(t) of the control system is:

Among them, u(t) is the normal input of the system, F=diag[f1, f2,..., fnu] is the diagonal matrix, which represents the multiplication error of the actuator, uf0(t)=[uf01, uf02,..., uf0nu]T for additional compiler errors. Table 1 shows the error types corresponding to the values of parameters fi and uf0i when the ith actuator fails.

Table 1. Fault types corresponding to the parameters fi and uf0i of the ith actuator

ith executor	ufoi=	0	ufoi≠0
fi=	0.8	Normal	Offset
0<fi<	0.8	Partial failure	Partial failure
fi=	0	Complete failure	Lock up

Deep learning is one of the methods for fault finding [14]. The principle of the model-based method is to construct the redundant signal of the system by combining the input signal and output signal with the model information, and then compare it with the known signal to generate the residual signal, and then compare it with the selected threshold, and judge whether the detected system is detected by the comparison result. When a fault occurs, the principle process is shown in Figure 1.

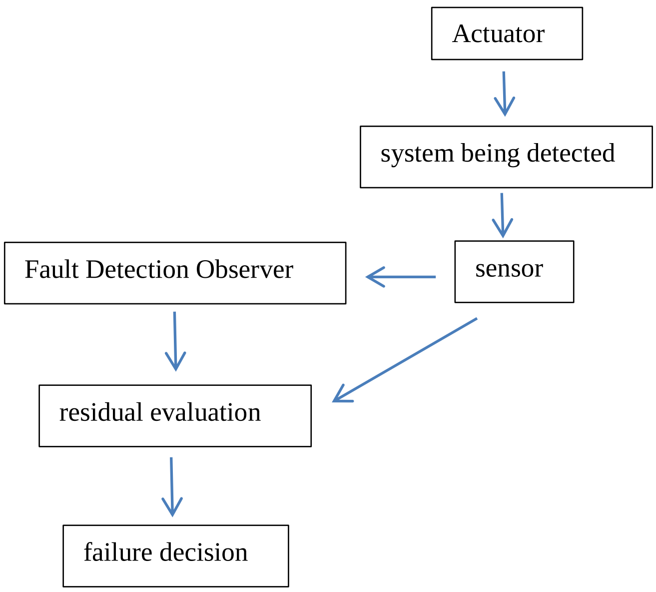

Figure 1. Block diagram of a model-based fault detection method

After the residuals are generated, an appropriate residual evaluation method needs to be selected to determine whether the system fails.

2.3. Fault-tolerant Control

Fault-tolerant control refers to the control technology that when the control system fails, its controller can compensate for the negative impact of the failure on the system in a timely and effective manner, thereby ensuring that the control system can maintain stability and specific main functions [15-16]. Early fault control techniques used a hardware redundancy design approach, which added a "spare" component that could fail to the system, but this approach was expensive, bulky, heavy equipment, and required operators with extensive experience and knowledge. It is impossible to accurately predict which components may fail [17-18]. The fault-tolerant control system is shown in Figure 2.

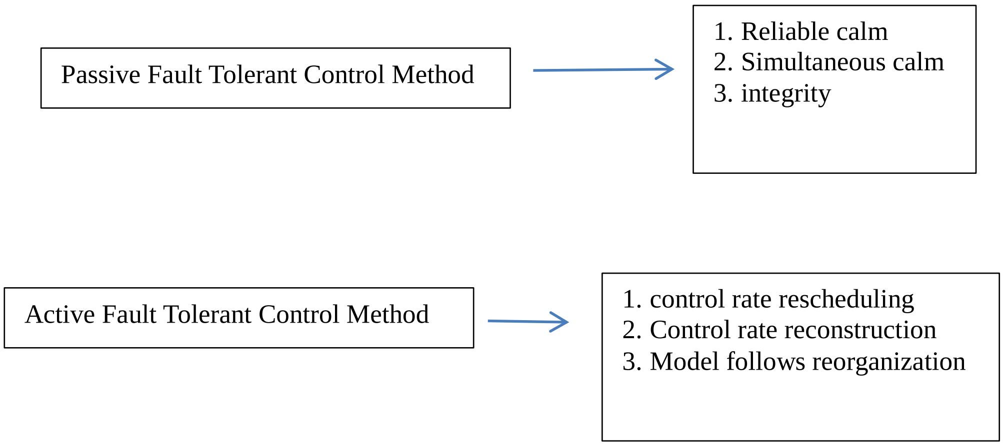

Figure 2. Fault-tolerant control method

3. Fault-tolerant Tracking Control of Distributed Systems Based on Particle Swarm Neural Network

3.1. Neural Network Implementation of Optimal Tracking Controller

In this paper, a 3-layer neural network will be used to approximate the judgment neural network. The judgment neural network can be approximated as:

$$V^*(X) = W_c^T \sigma(X) + \varepsilon_c(X) \tag{1}$$

where Lc is the number of neurons in the hidden layer.

Since the absolute weight of the neural network is unknown, the judgment of the neural network can be further approximated as:

$$\hat{V}(X) = \hat{W}_c^T \sigma(X) \tag{2}$$

3.2. Online Policy Iteration Based on Particle Swarm Optimization

This article will use the PSO algorithm to train the case network. Construct partition PK = [WK, VK], K = 1, 2, 3,..., K, k is the number of partitions. The fitness function of the selected component pk is:

$$f_{nk} = \exp(-\frac{1}{2} e_{ck}^T e_{ck}) \tag{3}$$

Therefore, the quality of the particle's position can be measured by the fitness value fnk. The larger the fnk, the better the particle's current position. On the contrary, the worse the particle's current position is. When fnk=1, that is, eck When = 0, the particle is in the optimal position.

3.3. Design of Distributed Nonlinear Observer

In this paper, a distributed nonlinear observer is designed to estimate the unknown additive fault ua of the actuator, and the influence of the actuator fault is reduced by an online compensation mechanism. The unknown actuator additional fault can be written as:

$$\dot{X} = F(X) + G(X)(u - u_a) \tag{4}$$

Because the neural network has strong nonlinear function approximation ability, the actuator fault can be approximately written as:

$$u_a = W_f^T \phi(V_f^T \hat{X}) + \varepsilon_f(\hat{X}) \tag{5}$$

Among them, lf is the number in the hidden layer, so the neural network fault observer can be designed as:

$$\dot{\hat{X}} = F(\hat{X}) + G(\hat{X})(u - \hat{u}_a) + A\varepsilon \tag{6}$$

where A is the positive definite observation gain matrix.

4. Analysis and Research of Fault-tolerant Control of Distributed System Based on Neural Network

In order to further verify the performance of the proposed fault-tolerant method, the distributed manipulator system is taken as the simulation model, and its dynamics can be expressed as:

$$I_M \ddot{q} + C_M \dot{q} + F_s \dot{q} + F_d = u - u_a \tag{7}$$

where q=[q1-q2]T is the joint angle vector.
Suppose the unknown actuator failure is:

$$ua(t) = \begin{cases} [0,0]^T, 0 \le t < 20 \\ [0, \sin(2t + \frac{\pi}{3}) + \cos(1.5t + \frac{\pi}{6})]^T, 20 \le t \le 40 \end{cases} \tag{8}$$

The selection of other control parameters is shown in Table 2.

Table 2. Control parameters

Initial weight	Wk0∈[0,0.8]
System initial state	[0.2,0.8,0.1,0]T
Observer initial state	[-0.8,0.2,-0.2,0.8]T

It can be seen from Figure 3 that even if the actuator fails at t=10s, the state estimation error oscillates in a very short time. The distributed nonlinear fault observer based on neural network can well estimate the actuator fault. The system state can be well tracked to the desired trajectory.

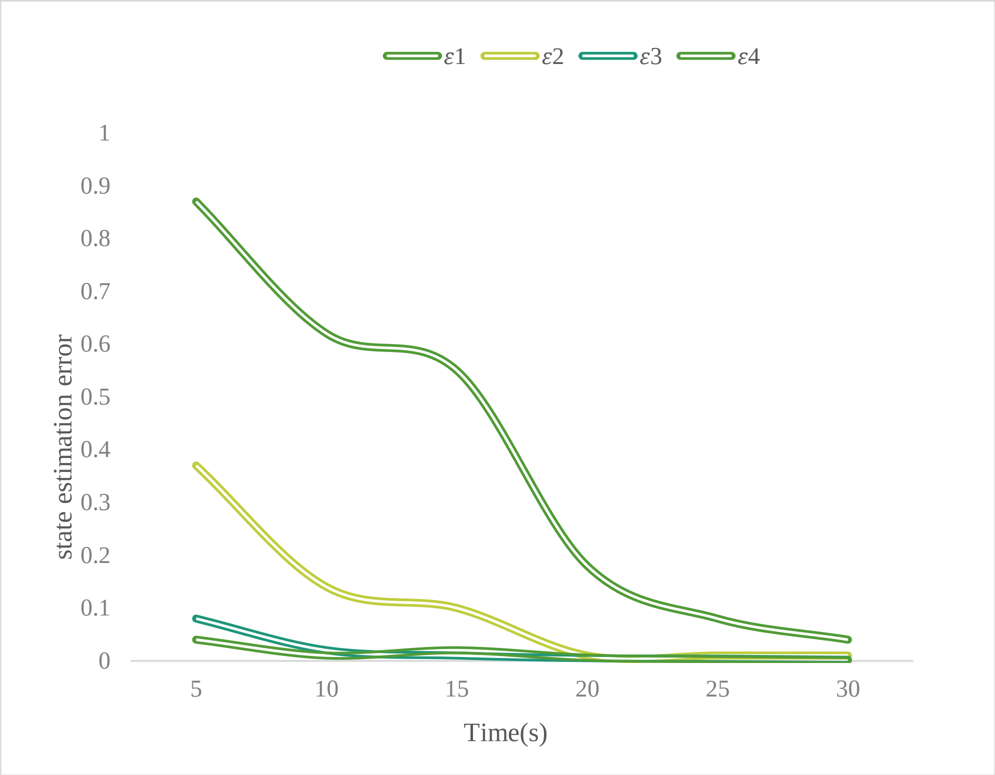

Figure 3. System state observation error

Table 3 lists the success rates of the PSO and the BP training the judgment network for 80 times. It can be seen that compared with the BP algorithm, the PSO algorithm has a higher success rate in training the judgment network, which means that the proposed fault-tolerant tracking control scheme is more suitable for the actual system to some extent.

Table 3. Comparison of the success rate of 80 comparative experiments

Training algorithm	BP	PSO
80 experiments success rate	62%	94%

5. Conclusion

Distributed systems widely exist in industrial engineering. Such large-scale systems put forward new requirements for reliability and fault tolerance. At present, there are few research results in distributed fault and control. Therefore, the research on faults based on distributed systems control have important significance and extensive needs. On the one hand, it can promote the development of distributed system control theory, and on the other hand, it can enrich the research content of fault diagnosis technology. The purpose of this paper is to study the method of distributed systems, and to conduct research on distributed fault diagnosis and fault-tolerant control of linear systems based on particle swarm neural network. The research on fault-tolerant control of distributed systems has achieved some results, but there are still problems that need to be further explored. In this paper, the fault-tolerant control technology of particle swarm neural network is used to solve some problems that occur during the operation of the system. In addition to in-depth research on fault-tolerant control technology, more precise control methods should be developed to ensure the reliability and stability of the system. It can be used safely in engineering. Due to the limited spectrum resources, time-varying channel gain and interference, etc., the research on the fault-tolerant control of the wireless network control system is more difficult. Therefore, further theoretical and practical research work is needed to address the above problems.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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