Distributed Cooperative Fault Diagnosis for Internal Electrical Components of Robot System

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Robot systems have recently been studied for real-world situations such as space exploration, under water inspection, and disaster response. In extreme environments, a robot system has a probability of fault. Therefore, considering fault tolerance is important for success of missions. In prior research, we proposed a distributed cooperative fault diagnosis method for internal components of robot system. This method consists of some diagnosis devices called diagnosers' which observe the state of a electrical component. Some diagnosers execute the diagnosis independently and in parallel, and we assume that they are connected using wireless communication. In this paper, we propose a technique which involves gathering the diagnosis results. Further we confirmed that this method can detect the faults of components in simplified fault situations by conducting computer simulations.

1 Introduction

Robot systems have recently been deployed in many real world situations. Among other applications, mobile robot inspection systems for disaster-stricken areas, under water inspection, and space satellites have been developed. Those systems can contribute to decrease the risk of dangerous work and increase working efficiency. However, a robot system has a probability of fault because extreme environments are dangerous for not only humans but also robot systems.

In this context, discussion of fault tolerance is important for reliability of robot systems[1]. Fault tolerance methodology has been studied in various disciplines over the past decades. In particular, fault tolerance for robot systems have also been investigated. For example, signal based methods, model based methods, and learning methods are proposed[2]. However, their methods have the following drawbacks:

- System architecture is centralized. If main computer is broken, fault diagnosis becomes invalid as well.
- Systems need environmental models, kinematic models of the robot and real time calculation.
- It is difficult to apply to currently-operated robot systems.

In contrast, we propose a distributed cooperative fault diagnosis method. This method focuses on fault diagnosis of electrical components in the robot system's body, because ordinarily robot systems consist of various electrical components. Robot systems also have mechanical components, but in this paper we consider only electrical components, for example, embedded computers, motor controllers, and motor drivers. To realize a distributed fault diagnosis, we propose the concept that we implement a small diagnosis device called *diagnoser* to every component. The diagnoser observes the state of the component to detect its malfunction.

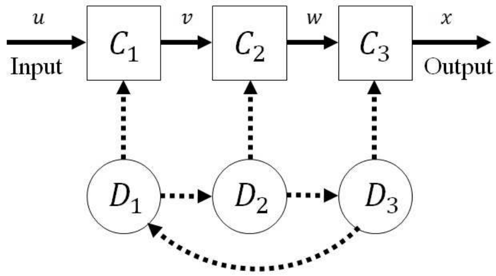

Fig. 1 This figure indicates an example architecture of electrical components and diagnosers in a robot system. C_n indicates a component, and D_n is a diagnoser. Arrow indicates correspondence relationship of fault diagnosis.

Result of diagnosis can be shared using wireless communication in each diagnoser. Finally, all diagnosers can obtain the overall diagnosis results.

2 Proposed method

As already mentioned, we proposed a distributed cooperative fault diagnosis (DCFD) method for component malfunction. In our method, we assumed a component architecture as shown in Fig. 1. In this figure, three components and three diagnosers are in the robot body, and components are connected in series. Diagnoser D_n is connected to component C_n. Before diagnosis, diagnosers learn the signals of input and output of the corresponding components using a learning algorithm. To detect the component's malfunction, a diagnoser compares the observed signal and expected output signal which is pre-calculated by learned data. If observed signal and learned data are different, component is faulty. When D_n is broken, other diagnosers (e.g. D_{n-1}, D_{n+1}) observe the state of D_n using an Adaptive-DSD (Adaptive-distributed system level diagnosis) technique[3]. To diagnose the diagnoser's malfunction, neighbor diagnoser uses signals such as heart beat of the broken diagnoser. Moreover, we call corresponding component C_n as a *Hidden component* when the diagnoser D_n is broken. We call this as a *hidden component fault diagnosis problem* (Fig. 2). Our DCFD method can estimate the state of hidden components using communication and cooperation with neighbor diagnosers. This method contributes detection of multiple faults i.e. malfunction of component and diagnoser at the same time.

3 Experiment

3.1 Experimental setup

We set the components, diagnosers, and their connections as shown in Fig. 1. In this experiment, we assume that each diagnoser obtains the knowledge of the input-output signal pairs from learning before the experiment. In the initial state

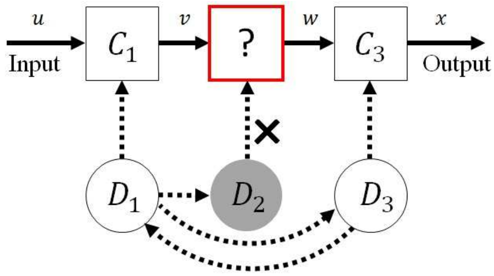

Fig. 2 This figure is state of hidden component fault diagnosis problem.

of experiment, all components and diagnosers are fault-free. Experimental procedure is as follows:

1. All components and diagnosers run with DCFD
2. After 60 seconds, D_2 breaks down
3. After that happens, we confirm that D_1 can detect fault of D_2 using DCFD.
4. After 120 seconds, C_2 breaks down, this situation becomes a hidden component fault diagnosis problem.
5. We confirm that D_3 can estimate the fault of C_2
6. Finally, we confirm that the DCFD method can estimate multiple faults

Until the end of the operation, our proposed system executes the diagnosis and representation of results. A component outputs the same value when it obtains an input signal. Input signal $u = \{0, 1\}$ alternates randomly every 0.5[sec]. Each diagnoser diagnoses the state of the component once a every second.

In this experimental setup, diagnosis result is not deterministic with one diagnosis because when input signal of component is '0', then output signal is '0' regardless of whether the component is broken or not. In other word, a diagnoser can detect the fault of components when input signal is '1'. In response to this problem, we adopt likelihood of faults to increase accuracy of fault diagnosis. Likelihood is given by n/N. The n is number of observed fault, and N is number of diagnoses performed. Here, N is set to 50.

3.2 Result and discussion

The result for the diagnosis is shown in Fig. 3. Likelihood of D_2 increases and converges to '1' in 60 seconds. This result means that D_1 can detect faults of D_3 when D_2 is broken. In Fig. 3, the likelihood of C_2 increases from 120 seconds, however, this result doesn't indicate convergence compare with the likelihood of D_2. Main cause of this phenomenon is that sometimes a diagnoser can detect a fault-free of state of C_2 as a fault regardless of whether C_2 is broken or not. However, these results indicate effectiveness for solving the hidden component diagnosis problem by using a suitable threshold value.

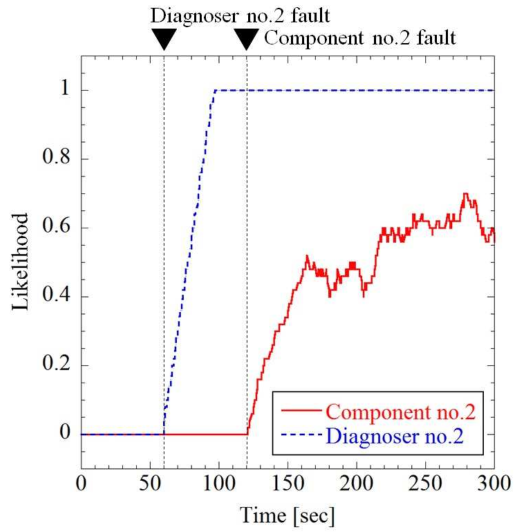

Fig. 3 Comparison of change of fault likelihood of diagnoser no.2 and component no.2.

4 Concluding remarks

We propose a DCFD method to diagnose the state of internal electrical components of a robot system. We also carried out simulation experiments under simplified conditions. The experimental results suggest that the proposed method can diagnose the diagnoser's malfunction and hidden component's malfunction. This result exhibits that the DCFD method has a probability of solving of the hidden component fault diagnosis problem.

In future work, we plan to demonstrate the effectiveness in more complex and various dynamic situations. In the simulations, components, diagnosers are in a simplified experimental model. It seems hard to apply actual robot systems. We intend to extend this method to real components in actual robot systems.

Acknowledgment

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References

[1] J. Carlson and R. R. Murphy, "How UGVs physically fail in the field", *IEEE Transaction on Robotcs*, Vol. 21, No. 3, pp. 423–437, 2005.

[2] Z. Gao, C. Cecati, and S. X. Ding, "A Survey of Fault Diagnosis and Fault-Tolerant Techniques − Part I : Fault Diagnosis With Model-Based and Signal-Based Approaches", *IEEE Transactions on Industrial Electronics*, Vol. 62, No. 6, pp. 3757–3767, 2015.

[3] R. P. Bianchini Jr and R. W. Buskens, "Implementation of online distributed system-level diagnosis theory", *IEEE Transactions on Computers*, Vol.41, No.5, pp.616–626, 1992.