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A General Purpose Network-Oriented Fault-Diagnose Control Architecture for MMR

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Abstract

WSN technology has strong advantages in the facet of environmental perception; node localization and path selection. The WSN technology combining with Multi Mobile Robots (MMR)can gain the ability of its self-planning, self-organization and self-adaption under the complex environment situation. The engineering record shows that the formation control of multi mobile robots is easily broken down. Even if a careful created robot formation at the great cost of manpower and material resources, it is possible breaking down when facing with unknown and complex environment. Recently, the traditional mobile robots formation also facing fault tolerance problem as well, such problems as low coupling, bad robustness and agreement diversification, especially hard to remedy the trouble when occurring the communication breakdown or damage. While WSN networks conducts a research on fault tolerant techniques, robots will show their advantages over localization, distance measuring, fault diagnosis, breakdown maintenance and formation recovery. Robots are installed WSN sensor node can perceive location between nodes by using this algorithm, the paper will proposing an algorithm based on WSN-MMR fault diagnosis through comparing the data perceived by neighbor nodes. It can ensure that the checked node situation and spread the state to other neighboring nodes in the networks. The algorithm can realize the fault diagnosis of the nodes and have a good performance, its feasibility and effectiveness can be tested.

Key words*: wireless sensor networks, fault diagnosis, fault detection, MMR; average node degree; CDR; FAR*

1. Introduction

The research on mobile robot technology (Multiple-Mobile Robots, MMR) began in 1970s, with the development of computer technology、electronic technology, control theory. The development of new materials and mechanical engineering make the multi mobile robot technology rapid developing in recent years. From the simple application to intelligent, from manual to participate in self-organization, from the application to the known environment to unknown environment, multi mobile robot formation system is developing towards a large-scale, complex direction. However, the mobile robot tasks become more and more complex; a single robot cannot completely meet the requirements of a variety of complex tasks. It must make up a robot team. Through collective cooperation to complete complex tasks, it makes mobile robot formation technology emerge to meet the times requirement. From the industrial field to the military, aerospace, industry, mining, medical and many other areas will see the figure of mobile robot formation. But when system has accident occurs, it is likely to cause casualties and property losses and disastrous consequences, so it is particularly important to improve the

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reliability and safety of the formation system of mobile robot. The study on mobile robot formation is improving mobile robot's intelligence. The research based on the wireless sensor network can helps to improve the autonomy and flexibility of the robots.

Because the WSN technology node location has strong advantages over the environment perception, path selection and node localization, WSN technology will be combined with the mobile robot formation to gain ability of self-planning, self-organization and self-adaptation in the complex environment. Therefore, the research of fault diagnosis method based on MMR wireless sensor network is very necessary.in literature [1, 2], [3-6] studied the method of node fault diagnosis in wireless sensor networks. Lynne E. at [3] proposed a control method by wireless sensor network. M.Ding *et al.,* [4] proposed fault identification algorithm, comparing the value with the neighboring nodes, to determine the fault node state. X. Luo *et al.,* [5] proposed a fault-tolerant technology for fault detection in wireless sensor networks. Jinran Chen *et al.,* [6] proposed DFD algorithm method in the diagnosis of node status with the adjacent nodes of each test. In this paper, based on a summary of the existing fault detection method, proposed the use of node data spatial similarity to achieve the node failure detection algorithm and analyzed the fault model, a comparison is made between the nodes in the network density and node failure rate, and verify the validity of the algorithm through experiments.

2. The Fault Model of Nodes

2.1. Network Model

In MMR the state of the robot can be divided into two kinds: normal or fault. The fault is a "permanent" and "static", the so-called "permanent" refers to the fault will continue until the robot fault is repaired or replaced; the so-called "static" refers to no new [7-8] fault in the robot in the process of fault diagnosis appears. Robot fault [7] MMR is divided into two categories: hard and soft fault. The so-called hard fault, a fault module leads to the robot unable to communicate with others (such as robot communication module fault, energy depletion, mobile robot, and out of the network communication range caused by other reasons not communication); the so-called soft fault, referring to a robot although failure, but still can continue to work with other robot communication (hardware and software of communication module are normal and have routing information), but the perception of the robots or transmission of data is not correct, or robot is instantaneously non-communicated.

In the fault diagnosis of MMR in wireless sensor networks, it is mainly aimed at the soft fault detection. Suppose m robots are randomly deployed in the preset area, and has the same transmission distance. P was defined as the probability of failure of all robots in the formation (including software and hardware failure), the number of MMR fault robot is*mp*; defined soft fault occurred in all probability fault in robot is *q*, the number is *mpq*, so the total number of valid robot fault diagnosis in the network is *m (1 - p) + mpq*. The new probability $p = \frac{mpq}{m(1-p)+mpq} = \frac{pq}{1-p+pq}$is defined as an important parameter of the fault diagnosis algorithm of robot.

For a MMR formation given communication distance, another important parameter of average node degree of the d robot is studied in this paper and the diagnosis process. The average node degree of the network is the average number of neighboring nodes have, whose number depends on the effective formation of the *n* robot. When the network appears a failure robot, the average node degree is required to recalculate.

2.2. Data Model

In the MMR formation, with the similarity distance between robots, namely the normal adjacent robots have the same or similar value measurement. So it can pass through the adjacent robot perception data to diagnose the current state of the robot. Robots *Vi* and *Vj* mutually adjacent robot and fault free, *Xj* and *Xi* were measured values of the two robots, the robot should meet $|xi - xj| \leq \xi$, and$0 \leq \xi \leq 1$, the threshold ξ depends on the different application fields of MMR.

3. Fault Diagnoses Method

3.1. The Network Communication Diagram and Node State Definition

This paper introduces a general framework of fault detection and control method based on WSN network (General Purpose Network-Oriented Fault-Diagnose Control Architecture) is applied to the MMR fault detection method in robot. The definition of *G (V, E)* for wireless sensor networks deployed in the communication graph in MMR, where V is the collection of all sensor nodes, E is the collection of all adjacent nodes edges. In sensor networks, when the distance between adjacent nodes *Vi* and *Vj*. Define distance *D (Xi, Xj)*is smaller than the radius of communication network, two adjacent nodes in the communication graph *G (V, E)* is connected to the side. In wireless sensor network *G (V, E)*, $vi \in V$ and $1 \leq i \leq n$, a collection of adjacent *Vi* node can be expressed as: $N(Vi) = \{vj \in (VI, Vj) \in E)\}$.

In the process of fault diagnosis for node Vi, Fi indicates the state of the node, and $Fi = 0$ means *Vi* nodes without fault, while $Fi = 1$that means node *Vi*is fault. According to the adjacent node measurements of spatial similarity principle, the measurement of Vi values are compared to the results of the comparison, given the two adjacent nodes $(Vi, Vj) \in E$, $Vj \in N(Vi)$, *C (Vi, Vi)*.in order to compare the function of *Vi* and its neighboring nodes, denoted by *Cij, is:*

$$Cij = C(v\,i,\ \ vj) = \begin{cases} 0 & if\ |xi - xj| \leq \xi \\ 1 & otherwise \end{cases} \tag{1}$$

When the *Vi* and its adjacent node is similar to the result, the result is returned as 0, otherwise it returns 1. *Ci* is the number of all adjacent nodes in the $Cij = 0$,$if 0 \leq |Ci| \leq |N(vi)|$,$0 \leq |Ci| \leq |N(vi)|$,*Ci* reflects the node Vi and the degree of similarity between neighboring nodes; if$|Ci| \geq \theta$ (θ is a preset threshold), *Vi* can be diagnosed of fault free nodes, and the $Fi = 0$.

3.2. Node Fault Diagnosis Algorithm

The process of fault diagnosis is proposed, is divided into two stages. The first stage is the threshold test stage, for the given threshold. The threshold test, for each sensor node *Vi*; when $|Ci| \geq \theta$, let $Fi = 0$; if $|Ci| \leq \theta$, $|Ci| \leq \theta$. that means node failed to pass the threshold test, do nothing, and then exit threshold test. The second stage is the stage of fault free node state diffusion, for fault free node *Vi* passing through threshold test

($Fi = 0$), if the neighbor node *VJ* $Cji = Cij = 0$, $Fj = 0$ is made, until the node state spread to all of the neighboring nodes. Node failure detection algorithm steps are as follows:

Step1 TO each VI sensor nodes was detected in step 1, generate the neighbor nodes of the collection *N (Vi)*, and initialize Fi=0, initialize the threshold;

Step 2 While $j=1$ *to* $|N(Vi)$ {Calculate thereturn value of $Cij=C\,|\,(Vi, Vj)$;}

The statistical values of *Ci*;

When $(|Ci| \geq \theta)$ { Fi=0；

While j=1 to $|N(Vi)|$

{When (*Cji*=*Cij*=0) Fj=0；}}
Step 3 for the rest of the untreated node *V1* = *V* -{*vi*|*vi Fi* = 0} V
While every *Vk*belong *V1*
If (*Cki*=*Cik*=0 and *Fi*=0 and *Fk*=1)
{*Fk*=0; let *Fk*=0 spread to the adjacent node;}
Step 4 mark all *Fk*=1 nodes for the fault node

4. Simulation Results and Analysis

By using MATLAB software, node fault detection algorithm for wireless sensor network is simulated. We operate an analysis on its performance. In the analysis, the accuracy under different average node degree in network, the Correct Detection Rate (Correct Detection Rate, CDR) and false alarm rate (False Alarm Rate, FAR) changes, and then we can determine the average node degree and the threshold of CDR and FAR. When the probability of fault occurrence of nodes in wireless sensor networks is p, the precision of fault diagnosis can be used to representα/np, where np is the number of nodes in the network for all faults, a number of nodes are the correct diagnosis of faulty nodes in all represented by α; similarly, the false alarm rate can be used for fault diagnosis of β *(1 - /[n P)]* to represent, in which $n (1 - p)$ is the number of fault free nodes in the network, the β for fault free nodes are falsely detected as fault nodes. Obviously, in order to improve the performance of node failure detection algorithm, we must improve the rate of fault diagnosis, at the same time we should put the false alarm rate under control in the lower range.

In the simulation experiment, the 20 sensor nodes are randomly deployed in the 256*256regions; all sensor nodes have the same transmission distance. To simulate network node failure rate of p was 0.1, 0.2, 0.3, 0.4, and 0.5, in season point's detection. Figure 1 and Figure 2 reflects the average degree of nodes in wireless sensor networks d approached to0.16, as the rate of p and threshold theta changes, we got the sensor fault diagnosis accuracy and the false alarm rate.

From Figure 1 and Figure 2 we can see that fault detection, correct detection rate (CDR) and false alarm rate (FAR) increased with the increase of threshold, setting reasonable threshold can make the detection accuracy and false alarm rate to achieve a better balance. The average node degree is given d » *0.16*, with the increase of node failure rate of p, in order to make the fault detection to achieve a better performance, the threshold Rate should be increased.

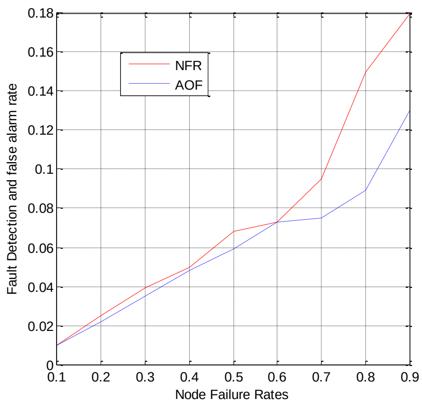

Figure 1. Fault Detection and False Alarm

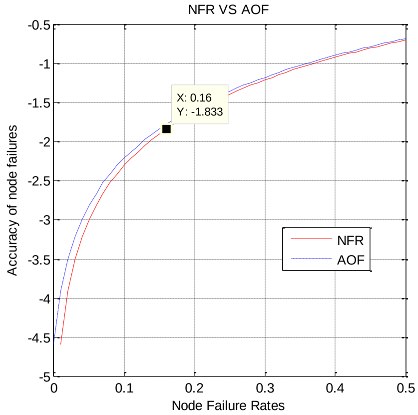

Figure 2 Accuracy of Node Failure

So in the process of the fault diagnosis, when the high failure rate is high, *d* should be set high, and detection performance can be satisfactory; similarly, low failure rate corresponds to low threshold. In the experimental process, it can also be found that when the average node degree is relatively low, with the increase of node failure rate, no matter how to regulate threshold, the effect is in a sharp decline. This is because the average node degree of *d* decreased, resulting in sensor networks is not easy to generate the graph nodes, nodes in the diffusion function detection algorithm are hard to realize. So when *p* is high and *d* is low, we can increase the number of nodes in a sensor network and improve the communication distance of nodes, thus improving the average node degree *d*.

In order to analyze the network average node degree of *d* how affects threshold and detection performance, we change the average node degree in the experiment, and analyze the condition d » 0.3 and d » 0.8 corresponding to the detection accuracy and false alarm rate. From them we can find, when the average node degree of *d* is relatively high, the node fault detection network has a very high CDR and low FAR. At the same time, with the increase of the average node degree, the scope of threshold selection is also increased. For example, the average node degree of d » 0.8, Therefore in the fault diagnosis of the node, when the average node degree is high, the node failure rate has a little effect on CDR and FAR, the value is always in the range of very low FAR; and for CDR, we can through the control of threshold to reach the optimal value, the experimental results show that when θ » d, the result is the most satisfying.

5. Conclusion

This paper introduces a method of fault diagnosis of the MMR in a wireless sensor network According to the similarity principle, each mobile robot as a node in the network can through the comparison of the sensor data of adjacent node perception, so as to determine the robot state, and the test state process spreads to other neighbor nodes in the network. This paper analyzes the average node degree and relation between node failure rate and threshold. The experimental results show that the algorithm is simple, with good performance in the process of fault diagnosis. This algorithm can improve the accuracy of fault diagnosis and control false alarm rate at.

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