Paper:

Self-diagnosis System of an Autonomous Mobile Robot Using Sensory Information

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In this paper, we describe a basic sensing system for self-diagnosing an autonomous mobile robot. In recent years, many researches on intelligent robots and systems have been done. But, when such robots and systems work in the real environment, it is important for these robots and systems to have the ability to recognize their own conditions for detecting faults. On the point of view, we should consider pay more attention to diagnose in such intelligent systems. Therefore we try to construct an internal sensing system as a self-diagnosis system on a real robot. Especially, in this paper, we discuss about motor system of an autonomous omnidirectional mobile robot, which was developed in RIKEN. The self-diagnosis system consists of multiple sensors, which are voltage, current, encoder, and magnetic sensors. We show some diagnosing experimental results using the real system. From the results, we could collect basic data for fault detection of the system.

Keywords: Self-diagnosis, Fault diagnosis, Fault detection, Autonomous mobile robot

Introduction

Most discussions on intelligent robots[1-4] assume that the system always works ideally and they do not consider how to adapt to fault situation. For example, In Robocup tournament,[5] some teams had problems under conditions differences between test running at lab. and game at the contest field. Usually It takes time to analyze such problems because they do not have measuring method. The importance of dealing with these problems has been pointed out[6] but studies were not enough. Thus, we must discuss to develop self-diagnosis system that the robot recognizes itself condition. Generally, a fault tree is introduced for diagnosing system.[7] In such case, the robot is separated into subsystems for diagnosing. S.I. Roumeliotis et al. proposed a method to extract sensor information by using a Karman filter for robot sensors' faults.[8] C. Cocca et al. and J-H Shin et al. proposed a method for recovering mechanical fault of a redundant manipulator.[9-10] However, in these method, they dealt with only mechanical fault and did not discuss faults by the other factors. In this paper, we developed a self-diagnosis system for improving reliability of the robot and confirmed its functional validity. We construct a diagnosis system on a real mobile robot and have basic experiments using it.

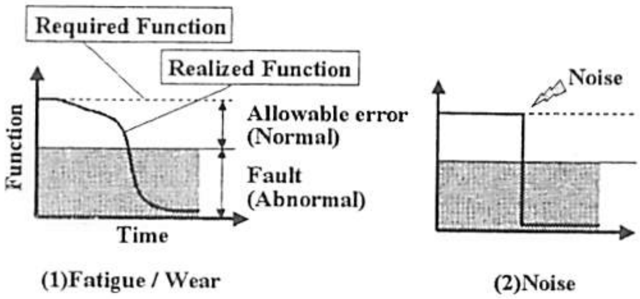

Fig. 1. Types of fault.

2. Faults

2.1. Definition of Fault

In this section, we define the fault is difference between realizable and required function. Here, realizable function means the performance that a system can actually execute and required function means the performance that a system should execute. Usually, status fluctuates while the system is working and its fluctuation are generally unpredictable. The reasons of losing realizable function by such fluctuations seems to be roughly classified into 3 categories as follow (**Fig.1**):

(1) Fatigue
(2) Effects of noise
(3) Initial failure

In case (1), realizable function gradually declines after a system working for long time. In case (2), realizable function suddenly fall down, for example, in cause of colliding to the obstacle. In case (3), the robot is already faulty before the system starting to work. This type of fault usually can be avoided by system inspection and

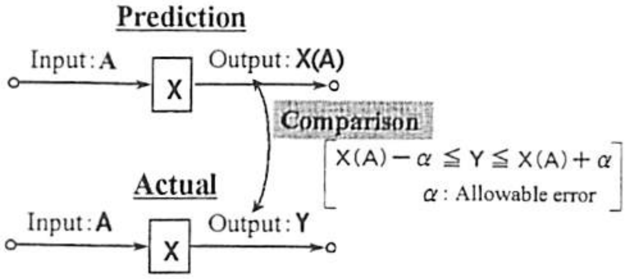

Fig. 2. Model-based fault detection.

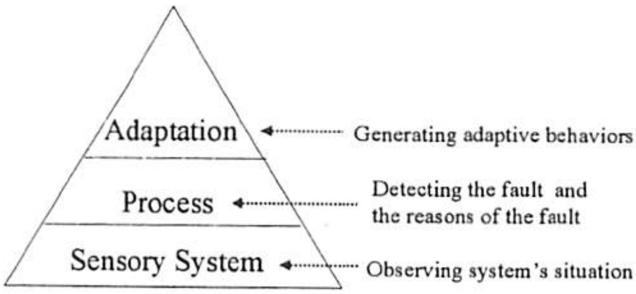

Fig. 3. Self-diagnosis system.

maintenance before startup. Therefore, we especially discuss on case (1) and (2) in this paper.

2.2. Sort of Fault

Generally, the system hardware, which do not include sensors, consists of multiple functional modules and devices. The condition of each module is detected by equipped sensors and faults can be detected. Faults in the system are roughly classified into (a) module(hardware) fault and (b) sensor fault. When a module becomes faulty status, the modules connected to such faulty module cannot be expected to work correctly. When a sensor becomes faulty status, the module (hardware) can response correctly to the command but the sensing result is not accurate. Therefore the whole system cannot be controlled. According to conventional studies, sensory information is utilized for only control. When the system becomes faulty status, it is difficult to determine which part is fault and the cause of fault. We try to promote a system to find the cause of fault using sensory information of plural modules.

3. Self-Diagnosis System

3.1. Diagnosis Method

The model-based diagnosing method is typically applied to diagnosis system.[11-13] According to this method, the system has a model, which represent the performance of a system. Then, this model is utilized to compare with observed condition (**Fig.2**). This method requires much time to get its own model but it is suitable for flexible diagnosing to deal with unexpected faults. In other words, the fault part is detected quickly by monitoring input/output performance at each module.

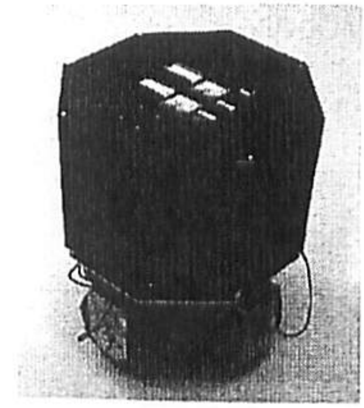

Fig. 4. Omnidirectional mobile robot.

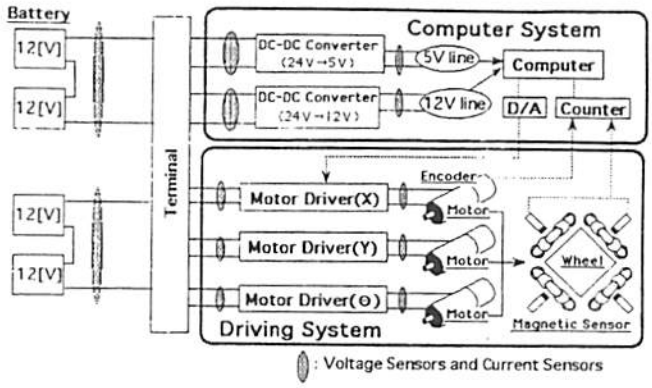

Fig. 5. Overview of system.

In this study, we also utilize a model-based diagnostic algorithm for each module. Here, self-diagnosing processes bring the information for determining to change or suspend original work plan after fault occurrence, not location of the fault itself. The whole process consists of internal sensing, diagnosing, and adaptive behavior generation (**Fig.3**). at first, the system must measure the condition of each module using the sensors. Detected fault part then is analyzed to specify the reason using diagnosing process. Also the system must behave adaptively according to fault level. Actual procedures for an actual robot would be discussed later in this paper.

3.2. System Configuration

Generally, it needs to understand its current conditions to detect fault. In this section, we describe to construct an internal sensor system for detecting conditions using plural modules.

3.2.1. Omnidirectonal Mobile Robot: ZEN

Figure 4 shows an omnidirectional mobile robot: ZEN, which is developed by RIKEN. The robot has special designed driving mechanism, which realizes omnidirectional motion using 4 wheels driven by 3 DC-motors.[14] Also, ZEN has rotary encoders on each DC motor and gyroscope sensor for control, and a PC/AT

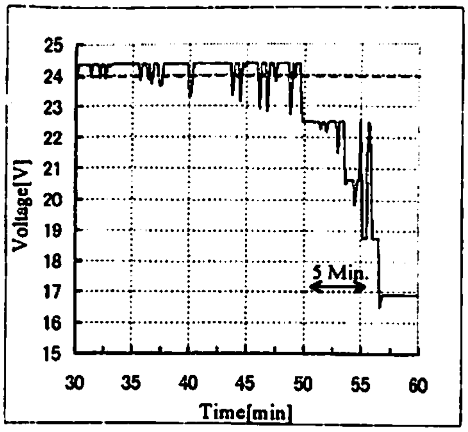

Fig. 6. Experimental result (voltage level).

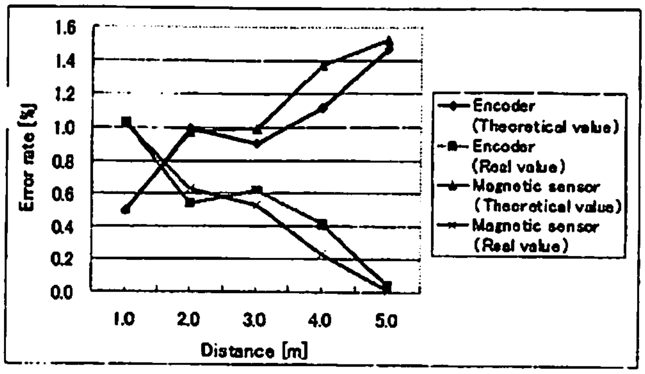

Fig. 7. Experimental result (driving the wheel).

type computer for getting sensory information and moving autonomously.

3.2.2. Internal Sensory System

Here, we discuss an internal sensory system for driv-g mechanism and power supply. ZEN does not equip the sensors to electrical power lines. For this study, we set new sensors on ZEN to detect condition of each power line. Current and voltage sensors are installed to each electrical power line for monitoring electrical input/output. Each motor equips a rotary encoder and gyrosensor is utilized to detect rotational motion of robot's body. For measuring wheel motion directly, a magnetic sensor is also installed with a slit-processed disk on each wheel as an encoder. Thus, the system can observe both of input value from each motor and output value through gears using 2 encoders (**Fig.5**). Sensors are provided at both input and output of modules.

4. Diagnosing Robot Conditions

We had basic experiments using real system. As for the power system, its condition is monitored using voltage and current intensity at each module. **Figure 6** shows

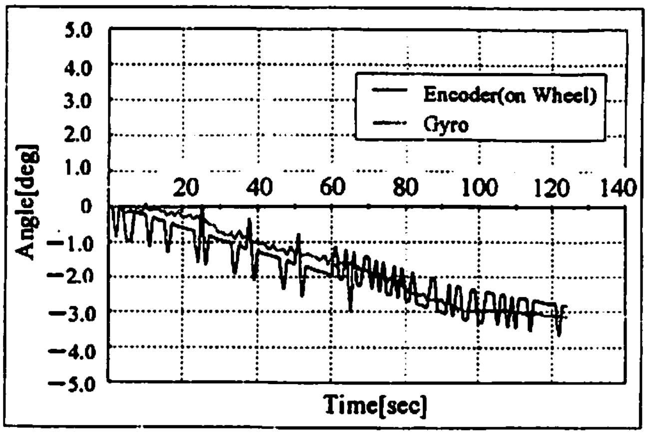

Fig. 8. Experimental result (driving the wheel).

		Condition (A Faulty Point)											
			System Fault						Sensor Fault				
		Normal	Slip of Wheel	Gear, Axle Fault	Motor Fault	Motor Driver Fault	Power Line Fault	Low of Battery Level	Encoder Fault (on Motor)	Encoder Fault (on Wheel)	Current Sensor Fault (on Motor Driver)	Current, Voltage Sensor Fault (on Power Line)	Current, Voltage Sensor Fault (on Battery)
Sensor Output	Gyro Sensor	O	×	×	×	×	×	×	O	O	O	O	O
	Encoder(on Wheel)	O	O	×	×	×	×	×	×	O	O	O	O
	Encoder(on Motor)	O	O	O	×	×	×	×	O	×	O	O	O
	Current Sensor (on Motor Driver)	O	O	O	O	×	×	×	O	O	×	O	O
	Current, Voltage Sensor (on Power Line)	O	O	O	O	O	×	×	O	O	O	×	O
	Current, Voltage Sensor (on Battery)	O	O	O	O	O	O	×	O	O	O	O	×

O : Normal Output × : Abnormal Output

Fig. 9. System condition-sensor output.

actual measured voltage at each module in case of no-load and constant-velocity running. As the result, ZEN can not work when the battery's voltage becomes 17[V]. Also, The robot thus stops completely 5 minutes after battery's voltage value starting to drop. Thus the robot must charge its own battery practically when voltage drops below the threshold value.

In the driving part, the fault is detected in gears and axles by monitoring motor rotation and wheel rotation. When ZEN try to go straight movement, error increases due to the effects of slip of wheel and backrush of gears for power transmission (**Fig.7**). For example, if the rotation velocity of left and right wheel are not equal, the robot's postural angle changes although the robot tries to move straight (**Fig.8**).

In these way, we can judge whether the module is normal or fault status using allowable error in each module.

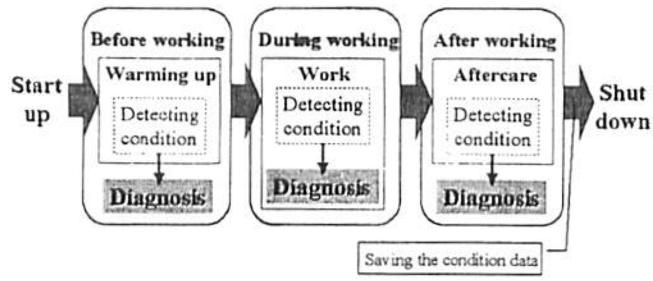

Fig. 10. Diagnosis process flow.

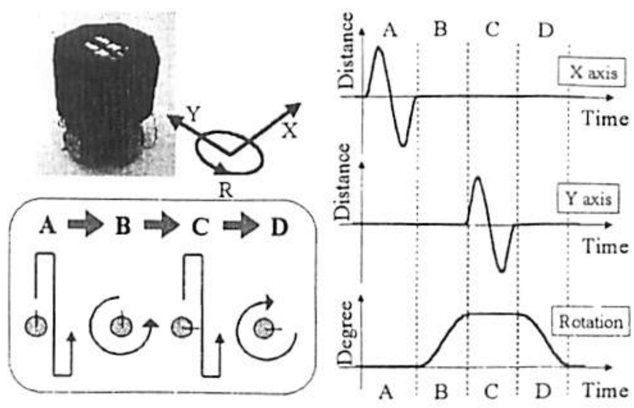

Fig. 11. Example motions for diagnosis.

5. Diagnosis Experiment

Figure 9 shows experimental result, for comparing the conditions of modules of ZEN. "O" indicates normal output -- a state in which output of each module is normal for the input command. "X" indicates abnormal state -- a state in which the module or sensor becomes fault. Sometimes we take a wrong decision of fault part in system. So it is desirable to determine faulty part from the sensory information. If the motor is fault, a motor or wheel would stop rotation naturally. On the other hand, if the encoder on the motor is fault, a wheel would rotate normally but we recognize the motor to be faulty because motor output cannot be read accurately. In such cases, it is possible to expect the influence on the robot by arrange and classify each module's condition.

We introduce a diagnostic series -- processes of understanding current conditions of the robot before, during, and after working (**Fig.10**). Diagnosing before working is useful to (1) change original work plan according to the condition of the robot and (2) determine whether the robot can work intentionally. Diagnosing during working monitors with sudden faults. Diagnosing after working is useful (1) determine whether maintenance is needed or not and (2) collect data for pre-estimated conditions of the robot at next startup. For diagnosing of before and after working, the robot would execute planed motion and collects internal information of each module. Thus before and after work warming up and cooling down motion must be done. It is required, for example, to detect its condition by moving on a 2-dimensional plane using all 3 D.O.F. (**Fig.11**). During working, the robot monitors internal information according to task actions.

6. Conclusion

In this paper, we discuss self-diagnosis system of an autonomous robot for monitoring its own condition and basic consideration of self-diagnosis system construction. At first, we defined the fault and classify the fault into 3 categories. We propose a paradigm in which a model-based diagnosing algorithm is applied to each module in the system. Also, we install additional sensors on an omnidirectional mobile robot : ZEN and construct a self-diagnosis system using them. As an example, we discuss experiments on the robot's driving and power system. For efficient diagnosing, we consider to classify diagnosis process into the following 3 stages : before, during, and after working.

In future work, using developed system, we will collect data related to input/output value of each module when the robot's condition is normal. Based on these process, we would have indexes of the standards and procedures for judging condition of module. The diagnosing then should be executed in detail on each stage. Also, we focused on such system information to improve performance of whole system. For working in real environments, environment information is important and we will try to introduce external sensors.

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