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Part agent that proposes replacement of a part considering its life cycle using a Bayesian network

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Abstract

Managing information on individual parts throughout their life cycle is a requisite to promoting their reuse. To do so, we have been developing a part agent system that uses network agents and RFID technology. A part agent proposes appropriate maintenance actions for a part based on information about its life cycle. This paper describes a method for a part agent to predict possible states of the corresponding part and to select an appropriate action by using a Bayesian network based on information collected on the state of the part, consumer preferences with regard to maintenance, and its usage.

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Keywords: Part Agent; Life Cycle of Parts; Bayesian Network; Reuse

1. Introduction

The effective reuse of mechanical parts is important for the development of a sustainable society [1]. To realize effective part reuse, managing individual parts over their entire life cycle is essential because each individual part has a different reuse history.

For reuse-based production, manufacturers need to capture the quantity and quality of the parts returned for reuse. However, it is difficult for manufacturers to predict such information because of the uncontrollable and unpredictable diversity of user behavior. On the other hand, it is difficult for product users to manage and carry out appropriate maintenance on the large number and variety of parts in the products they own.

Therefore, we propose a scheme whereby a part “manages” itself and supports user maintenance activities. For this purpose, we are developing a management system that includes network agents. Each agent is programmed to follow its real-life counterpart throughout its life cycle. We refer to this network agent as a “part agent” [2].

The part agent advises users on the reuse of parts and promotes the circulation of reused parts. Using this mechanism, consumers can also learn about environmentally friendly product uses and predicted product failures.

We previously proposed a framework of part agents [3] that advises the consumer on the ecologically responsible use of parts based on an evaluation of their possible states in the near future. In this paper, we introduce a part agent function to the framework that estimates the failure probability of the corresponding part by using a Bayesian network to represent the probabilistic causal relationships among the failures and user operations of the part.

To evaluate the effectiveness of the method, we developed a prototype function that evaluates reused parts for replacement by calculating their expected future cost based on their failure probability as estimated by the Bayesian network.

The concept of part agents is explained in section 2. The fundamental theory of Bayesian estimation is briefly introduced in section 3. The part agent function under development is described in section 4. The prototype simulation developed for evaluation of the Bayesian network is described with the results in section 5. Section 6 concludes the paper.

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2. Conceptual scheme of part agent

A part agent manages all information about its corresponding part throughout its life cycle. The scheme assumes the spread of networks and high-precision RFID technology [4].

A part agent is generated at the manufacturing phase of core parts when an RFID tag is attached to its corresponding part. The part agent identifies the ID of the RFID tag during the part's life cycle and tracks the part through the network. We used RFID tags as a method of identification because they have a higher resistance to smudges or discoloration than printed bar codes, which is important over long life cycles.

In related research, the product embedded identifier (PEID) [5] involves a small computing chip, an RFID tag, and sensors to support the middle and end of the product life. In contrast to the PEID system, our system aims to promote multiple reuses of individual parts that may go beyond the manufacturer's management. This requires a "lightweight" system that can be used repeatedly without maintenance of sophisticated hardware.

Fig. 1 shows the conceptual scheme of the part agent. The part agent communicates with various functions within the network and collects the information needed to manage its corresponding part, such as product design information, the predicted deterioration, logistic information, and market information. It also communicates with local functions on-site, such as sensory functions that detect the state of the part, storage functions for data of individual parts, and management and control functions of the product. Communication is established by using subordinate information agents generated by the part agents.

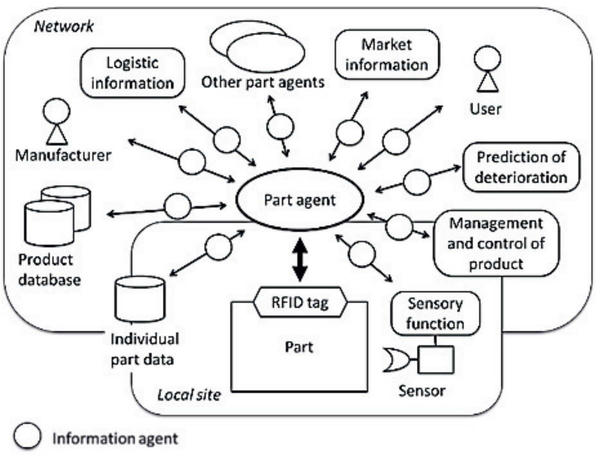


Fig. 1 Conceptual scheme of part agent.

3. Estimation of part failure using Bayesian network

Predicting failure is an important function of a part agent to support the effective reuse of the part. However, doing so is difficult because of the probabilistic nature of failure and its dependency on the level of usage by the consumer and on the environmental conditions. To deal with this problem, we applied an estimation method based on a Bayesian network.

A Bayesian network is a directed acyclic graph that represents causal relationships among events with a conditional probability table for each event node. It is a probabilistic model that is used for predicting uncertain events, decision-making, and failure diagnostics. Node probabilities are calculated by giving information to observable nodes and by propagating probabilities via the network structure based on the conditional tables of the nodes [6].

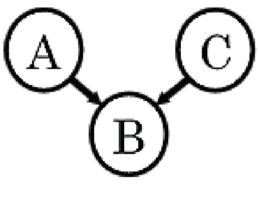
Fig. 2 shows a simple example of a causal network with conditional probability tables. The graphic on the left side of the figure depicts the probabilities that events A and C affect event B. The probability of event B varying with the occurrence (shown as 0 and 1 in the table) of events A and C is called the conditional probability, and this is summarized in the conditional probability table on the right side of Fig. 2.

The probability that event A occurs after event B is obtained by Bayes' theorem in equation (1):

$$\mathrm{P}(A|B) = \frac{P(B|A)P(A)}{P(B)} \tag{1}$$

where P(A) is the prior probability of the occurrence of event A before event B and P(A|B) is the posterior probability of the occurrence of event A after event B has occurred. The probability of the occurrence of event A can be estimated when event B is known to have occurred based on the prior probability of event A, or P(A), and the conditional probability P(B|A).

We represent probabilistic causal relationships between part failures and their factors by using this Bayesian network in order to obtain the failure probabilities.



A	C	P(B|A,C)	
		0	1
0	0	p11	p21
0	1	p12	p22
1	0	p13	p23
1	1	p14	p24

Fig. 2 Example of Bayesian network with conditional probability table.

4. Agent advice based on life cycle information using Bayesian network

In a previous paper [3], we proposed a basic framework for a part agent to advise a user based on the life cycle model of a part. At each time step, the part agent predicts possible states of the part in the near future and evaluates those options in order to advise the user.

A part agent expands the life cycle to evaluate each optional expanded life cycle path for several time steps in the future. The states of the part, including its environmental load, value, and cost, are estimated for every life cycle stage in the near future by using the current status of the part and information about its deterioration and failure.

In the previously proposed framework, models representing the deterioration, value, cost, and environmental load were simplified and not elaborated. We consider the deterioration model to be the most important as the