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Life cycle simulation of mechanical parts with part agents considering user behavior

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Abstract

To realize the effective reuse of mechanical parts for the development of a sustainable society, it is essential to effectively manage individual parts over their entire life cycle. For this purpose, we are developing a part agent system using network agents. A part agent manages all information about a part throughout its life cycle and predicts possible states of the part in the near future in order to generate appropriate recommendations for their maintenance. User behavior is important for this prediction because, in the life cycle of a part, its states are affected by the user behavior. The behavior of users is modeled using prospect theory in order to simulate its nature so as to avoid the risk of failure. This paper compares the decisions for maintenance actions in the simulations with and without applying prospect theory. The initial results are presented in a life cycle simulation of the developed part agents.

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Keywords: Prospect theory; Life cycle; User behavior.

1. Introduction

To realize the effective reuse of mechanical parts, which is a competent measure of the development of a sustainable society [1][2], it is essential to manage the individual parts over their entire life cycle. Manufacturers face difficulties in predicting the quality and quantity of the used parts that are necessary to perform reuse-based production, owing to the uncontrollable and unpredictable variation in user behavior. Product users also experience difficulties in carrying out appropriate maintenance on many and various parts in their products. Based on these considerations, we propose a scheme whereby a part "manages" itself and supports user maintenance activities, and we verify it using a life cycle simulation. Life cycle simulation has been recognized as an effective tool to design product life cycles [3]. To realize this scheme, network agents that are programmed to follow their real-life counterpart parts throughout their life cycle are being developed. These network agents are referred to as "part agents" [4] and provide users with appropriate advice on the reuse of their part and promote the circulation of reused parts.

Previous works have proposed methods of user support when using a part agent [4][5][6]; however, the user may not accept the proposed actions recommended by the part agent based on his or her preferences and requirements. For example, even when the probability of failure of a product is low, the user might want to replace it with a new product after seriously considering the risk of failure. Therefore, it is necessary to develop a user model and method that conforms to the behaviors of real users. In addition, the occurrence of failure and deterioration should be taken into consideration in the prediction made by part agents and in the life cycle simulation [7].

To deal with the replacement and purchase of parts, the exchange of information between the current part and other parts is required in order to relate the life cycles of different parts. In this paper, we describe a method developed to predict the future state of a part with a life cycle connected

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to that of other parts. Another aim of this paper is to deal with the effect of user behavior on the maintenance of the part. For this purpose, prospect theory is applied to part agents for representing user behavior, and the occurrence of failure of the parts is also simulated.

This paper describes a part agent's proposal of maintenance actions that takes into consideration the use behavior. A mechanism is proposed to incorporate the occurrence of part failure in the life cycle simulation. The results of the simulation with and without the application of prospect theory are then compared.

This paper consists of the following sections. First, the concept of a part agent is described in section 2. Thereafter, the mechanism of a part agent that provides advice on the reuse of a part is explained in section 3. Next, the representations of the life cycle of the parts and user behavior are described in section 4. In section 5, methods to represent exchange of parts in the life cycle simulation and a life cycle simulation including the replacement of parts and failure of parts are explained. In section 6, the results of the simulation to evaluate the effect of user behavior are presented. Finally, the paper is concluded in section 7.

2. Part Agent system

A part agent manages all information regarding its corresponding part throughout its life cycle. The proposal assumes the spread of networks and high-precision radio frequency identifier (RFID) technology [8]. A part agent is generated during the manufacturing phase of the core parts where an RFID tag is attached to each part. The part agent identifies the ID of the RFID tag during the life cycle of the part, tracking the part through the network. We chose an RFID tag for identification because RFIDs have a higher resistance to smudge or discoloration than printed bar codes and will last for the entire life of the part.

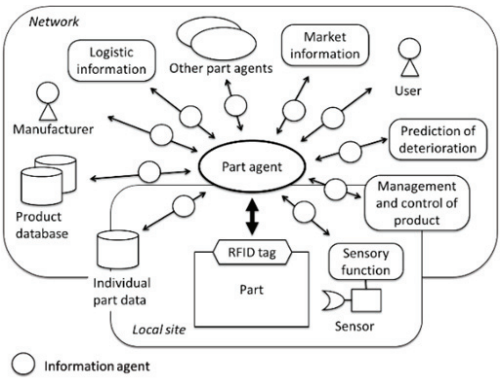

Fig. 1. Conceptual scheme of the part agent

Fig. 1 shows the conceptual scheme of the part agent. The part agent communicates with various functions within the network and collects the information required to manage its corresponding part, such as product design information, predicted deterioration of parts, logistic information, or market information. It also communicates with local functions on-site, such as sensory functions that detect the state of the part, the storage functions for individual part data, as well as the management and control functions of the product. Communication is established using information agents that are subordinate agents generated by the part agents [5].

3. Creation of advice by part agent

Fig. 2 shows a framework for a part agent to advise the user of the necessary maintenance actions based on the life cycle model of its corresponding part. At each time step, the part agent predicts the possible states of the part in the near future and evaluates those options in order to provide the user with appropriate advice [6].

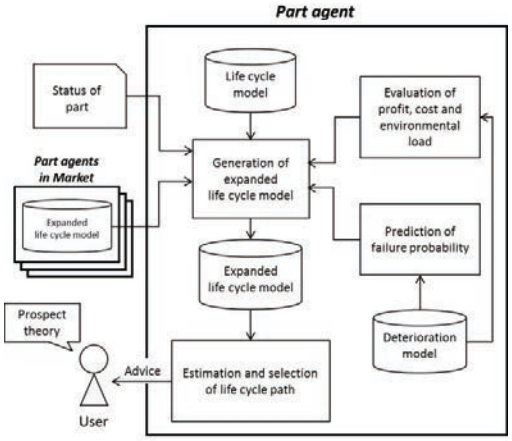

Fig. 2. Framework of part agent for advice generation

A part agent generates advice in the following order. First, the part agent expands the life cycle of the part by using the current status of the part and its evaluated values based on a deterioration model. All possible candidate paths in the life cycle are derived and estimated using a user model. The part agent obtains information on the candidate replacement parts from other agents in the market and uses it in the prediction. Based on the estimation, an appropriate action for the part is selected and recommended to the user. Details on the expansion and estimation of the life cycle of a part are described in section 5.

A variety of information is required for part agents to evaluate appropriate maintenance actions. This includes the benefit acquired from the part, the required cost for the part, and the environmental load generated in relation with the part. As these values change primarily owing to deterioration, a deterioration model that represents how the mechanical performance of the part deteriorates is required.

To deal with failures of parts, we assume that the probability of failure of a part depends on the deterioration of the part. A part agent predicts the probability of failure from a deterioration model, and estimates the probability with which stages, such as use, repair, and others, will be selected in the future. Prediction of the probability of failure and the derivation of path probability are described further in section 5 and 6.