Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 61 (2017) 293 – 298

www.elsevier.com/locate/procedia

The 24th CIRP Conference on Life Cycle Engineering

Continuous improvement of criteria for condition-based maintenance by means of effects evaluation of treatments

Akihiro Morimoto[a], Yusuke Sato[a], Shozo Takata[a]

[a]*Department of Business Design and Management, School of Creative Science and Engineering, Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan*

* Corresponding author. Tel.: +81-3-5286-3299; Fax: +81-3-3202-2543. *E-mail address:* m.akihiro1228@fuji.waseda.jp

Abstract

With the advancement of sensor and network technologies, condition-based maintenance (CBM) is applied to various industrial equipment. In particular, mechatronics systems are suitable for CBM because of the sensors equipped in the systems. However, criteria for executing preventive maintenance should be properly determined by considering the tradeoff relations between false detections and oversights of symptoms, because the data from the sensors does not directly represent the component deterioration. In our previous paper, we proposed a method for determining the optimal criteria based on operation and maintenance data before applying CBM. This paper proposes a method to improve the criteria based on the data obtained while CBM is implemented. The method is applied to automatic ticket gates for verifying its effectiveness.

Keywords: Condition-based maintenance; Effect evaluation; Improvement of the criteria; Mechatronics system; Automatic ticket gate

1. Introduction

With the recent advancement of sensor and network technologies related with Internet of Things (IoT), it has become easy to collect data regarding machine conditions remotely. This has enabled the introduction of condition-based maintenance (CBM), in which preventive maintenance (PM) is executed based on the deterioration or failure symptoms identified by the sensors, in various fields [1-3]. For example, CBM is applied to power generation plants, chemical plants, and industrial equipment. For the successful implementation of CBM, it is necessary to set the proper criteria for executing PM, considering sensing performance. In setting the criteria, we should take into account the false detections and oversights of symptoms because of the inaccuracy of sensors or the noise included in the sensing data [4-6].

Mechatronics equipment, such as copiers and air conditioners, are considered to be suitable for CBM, because they are usually equipped with a number of sensors, which can be used for monitoring and diagnosis of their conditions [3]. However, such sensors are mainly equipped for control purposes, and error messages generated from the sensor signals do not directly represent the component deterioration and failures but the malfunctions of operational states. Therefore, we need to consider the uncertainty in the relations between error generations and the physical conditions of the equipment in conducting CBM based on the errors generated by the sensors. Moreover, we need to consider the disturbances that also lead to errors, such as improper input fed into the equipment. Owing to the abovementioned reasons, it is not necessarily easy to apply CBM to mechatronics equipment effectively.

To solve these problems, we have previously proposed a method to relate the error messages with the deterioration and failures of the equipment by integrating their structural and functional analysis with the statistical analysis of the history data, and to determine the proper criteria for executing PM [7]. This method was applied to automatic ticket gates (ATGs) for verifying its effectiveness. It should be noted that this method assumes that there is sufficient data when only breakdown

doi:10.1016/j.procir.2016.11.266

maintenance (BM) is applied to the equipment before implementing CBM. However, such an assumption is not realistic for the mechatronics equipment, which will be installed from now on.

Therefore, we propose a method to check the validity of PM executions and to improve the criteria continuously during operation. By using this method, we can apply CBM even before accumulating sufficient data for identifying the optimal criteria for PM executions.

The rest of this paper is organized as follows. In Section 2, the difficulties in applying CBM to mechatronics systems are identified. Then, the algorithm for improving the criteria is described in detail in Section 3. In Section 4, the proposed method is applied to ATGs for verifying its effectiveness. Section 5 presents the conclusions of this study.

2. Condition-based maintenance applied to mechatronics systems

The maintenance policy is broadly categorized into BM and PM. PM is further divided into time-based maintenance (TBM) and CBM. Because PM has less effects, such as the cost for maintenance and losses caused by stoppage of equipment, than BM, it is desirable to apply PM to prevent BM as much as possible [2]. In particular, CBM is more effective than TBM when the life spans of components change significantly depending on various factors, such as operational and environmental conditions. However, CBM requires ways to identify the conditions of the equipment. This occasionally causes implementation of CBM to be difficult economically or technologically. In this view, mechatronics equipment such as copiers and ATGs, which are electronically controlled using many sensors, are suitable for CBM, because the sensing data generated by sensors can be collected online and used for monitoring and diagnosis of their conditions.

However, sensors in the mechatronics equipment are mainly used for control purposes. The equipment controller uses the sensor data to identify the operational states of the equipment and generates error messages when any malfunction is detected in the operational states. Although deterioration and failures of the components affect the operational states, and the progress of deterioration could lead to an increase in error generation, this does not necessarily represent the condition of the components. The error messages may be generated by disturbances like improper input. For example, in the case of ATGs, wet or bent tickets could cause a malfunction of the equipment and thereby result in generation of errors. In contrast, there could be cases where the deterioration and failures do not generate errors. For example, ATGs have inbuilt mechanisms for aligning the tickets inserted in the equipment. However, no error is generated when the orientation of a ticket satisfies the required conditions and does not need to be aligned, even though the mechanism fails.

In order to implement CBM in mechatronics equipment by using error messages, we need to determine the criteria for PM executions taking into account false detection as well as oversight of symptoms because of the abovementioned problems. Assume that the PM is executed when the number of the error messages exceeds the criterion. Then, higher the criterion is set, fewer the number of PM executions required. In this case, the number of false detections decreases but the number of oversights increases. On the other hand, when the criterion is set lower, the opposite occurs. False detection of symptoms leads to the unnecessary execution of PM, while oversight results in BM. Since the effect of PM is usually lower than BM, for determining the criterion a tradeoff between the number of false detections and oversights should be considered.

Numerous studies on CBM applied to mechatronics systems are reported in the literature. Most of them discuss the improvement of the performance of diagnosis and prognosis in terms of the percentage of correct diagnoses by means of various techniques such as model based decision and multi sensor fusion [8-10]. However, there are few studies that deal with the tradeoff issue between false detections and oversights of the symptoms quantitatively. Besides, most of existing studies assume that the relations between error generations induced by the sensor data and the failure modes are known in advance, although, in many cases, the relations are not known because of the complexity of the relationships as explained above.

With respect to these problems, we have previously proposed a method to relate the errors with the deteriorations and failures by integrating the structural and functional analysis with the analysis of the history data. We have also formulated a method to determine the optimum criteria for PM executions of mechatronics systems considering the influence of false detections and oversights of the symptoms based on the simulation using history data [7].

However, the abovementioned proposed methods need the history data when PM is not executed. This assumption is valid if CBM is implemented in existing systems that have been operated without applying PM for a certain period of time. The recent mechatronics systems, however, have shorter life cycles owing to the rapid technological development and the change in the customer needs. Therefore, in this paper, we propose a method to improve the criteria, based on the data obtained during the operation in which CBM is applied, while initial criteria are determined empirically when the equipment is put into operation.

3. The method of effect evaluation of treatment and improvement of the criteria

3.1. Procedure to improve the criteria for PM execution

In this study, we consider the problem of determining the criteria for PM executions based on the errors generated. As shown in Figure 1, PM is executed when the number of error generations during the period of time T_c exceeds the threshold N_e. We define the combination of N_e and T_c as the criteria for PM execution. Such criteria are determined for each type of error messages, because each type of error messages has a specific relation with a specific component deterioration or failure. (The method of identifying such relations has been discussed in our previous study [7].) This implies that the PM is executed in a different way depending on the type of error messages that triggered it. In this study, the execution of PM and BM involves application of actions to recover from the