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Reliability-Centered Maintenance Planning based on Computer-Aided FMEA

Fumihiko Kimura, Tomoyuki Hata and Noritomo Kobayashi
Department of Precision Machinery Engineering
The University of Tokyo

Abstract

For proper management of life cycle of machines and manufacturing facilities, it is important to perform appropriate maintenance operations, and to keep machine status for better reuse and recycling opportunity. For this purpose, a virtual maintenance system is very effective, where facility life cycle model is constructed in computer, and reliability and availability of machines are predicted based on usage deterioration modelling. FMEA(Failure Mode and Effect Analysis) is a powerful method to extensively investigate possible machine failure and functional deterioration, and to predict reliability. However it is very time-consuming and tedious to perform FMEA by conventional manual method. In this paper, computer aided FMEA is proposed, and its theoretical basis is discussed. An extended product model is introduced, where possible machine failure information is added to describe used machine status. By applying generic behaviour simulation to extended product models, it is possible to detect abnormal or mal-behaviour of machines under used conditions. Based on this behaviour analysis and extended product models, FMEA process can be performed by computer-aided manner, and can be very efficient to avoid laborious work and possible errors. Based on FMEA results, maintenance planning can be evaluated by simulating life cycle operations of machines and by predicting reliability during operation. For validating the proposed computer-aided FMEA method, several experiments are performed for mechatronics products.

Keywords: Maintenance, Reliability, FMEA

1 INTRODUCTION

In order to cope with the pressing issues of environmental effect due to industrial production, it is required to fundamentally reduce the environmental burden, such as resource consumption and disposal, while to keep the proper service level products can offer to customers [1,2].

It is difficult to achieve this target only by optimising individual product design towards better resource consumption and recycling performance. It is rather essential to design the total product life cycle as a whole from product planning, throughout product design and manufacturing, to product usage, maintenance and reuse/recycling/disposal. A sound strategy for product maintenance and improvement during product usage should be established, and all the life cycle processes are to be well controlled. By such approach, reuse/recycling activities are also rationalized. A whole product life cycle can be made visible and controllable. We have called such approach as Inverse Manufacturing by stressing the controllability of reuse/recycling processes, where closed product life cycles, including maintenance, are pre-planned and controlled [3].

For proper management of life cycle of machines and manufacturing facilities, as required in the above discussion, it is important to perform appropriate maintenance operations, and to keep machine status for better reuse and recycling opportunity. There are many methods for maintenance operations, such as time-based or condition-based maintenance. It is necessary to generate rational maintenance planning for optimizing total maintenance activity in terms of maintenance cost and facility availability.

It is desirable to make maintenance planning concurrently with machine design processes, and to verify the total life cycle performance before actual facility construction. For this purpose, a virtual maintenance system is very effective, where facility life cycle model is constructed in computer, and reliability and availability of machines are predicted based on usage deterioration modelling[4,5,6]. FMEA(Failure Mode and Effect Analysis) is a powerful method to extensively investigate possible machine failure and functional deterioration, and to predict reliability. However it is very time-consuming and tedious to perform FMEA by conventional manual method.

In this paper, computer aided FMEA is proposed, and its theoretical basis is discussed. For this purpose, an extended product model is introduced, where possible machine failure information is added to describe used machine status[7]. By applying generic behaviour simulation to extended product models, it is possible to detect abnormal or mal-behaviour of machines under used conditions. Based on this behaviour analysis and extended product models, FMEA process can be performed by computer-aided manner, and can be very efficient to avoid laborious work and possible errors. Based on FMEA results, maintenance planning can be evaluated by simulating life cycle operations of machines and by predicting reliability during operation. For validating the proposed computer-aided FMEA method, several experiments are performed for mechatronics products.

2 RELIABILITY-CENTERED MAINTENANCE

Proper maintenance planning is a complicated task. There are many causes of machine failure, and their properties are different. Some are depending on the age of machines, and some are purely stochastic. Monitoring of machine operation is not necessarily effective. Often bad maintenability is only improved by early design changes. There are various types of maintenance, such as time-based maintenance and condition-based maintenance. It is complicated whether to adopt time-based maintenance or condition-based maintenance. Maintenance cost very much depends on required maintenance resources and facilities.

In order to achieve rational total life cycle management, it is strongly desired to realize a systematic planning method of maintenance operations. Reliability-Centered Maintenance (RCM) is one of the well-established systematic methods for selecting applicable and appropriate maintenance operation types[8]. In RCM, failure consequences and their preventive operations are systematically analysed, and feasible maintenance planning is determined. The rough process of RCM is as follows:

(1) Target products or systems of maintenance should be clearly identified, and necessary data should be collected.

(2) All the possible failures and their effect on target products or systems are systematically analysed.

(3) Preventive or corrective maintenance operations are considered. Selection of operations is done based on rational calculation of effectiveness of such operations for achieving required maintenance quality, such as reliability, cost, etc.

The above steps are repeated to realize feasible maintenance planning. Step (2) is the core of the RCM process. It is generally very tedious and time-consuming, and its contents are fundamentally the same as Failure Mode and Effect Analysis (FMEA). In the following sections, efficient and practical approach to FMEA based on computer-aided technology is explained.

3 COMPUTER-AIDED FMEA

The aim of FMEA is to systematically analyse the reliability of target systems or products based on planning or design information, and to enhance reliability by modifying target system or product design before actual production. The general procedure of FMEA is as follows:

(1) Based on the given design information about the target products or systems, a reliability diagram is created, where failure effects among components are described.

(2) Known modes of failure about individual components are applied to the reliability diagram, and failure effects are propagated up to the total functional behaviour of the products or systems.

(3) Criticality of the failure is evaluated based on the probability and severity of the failure effects.

The results of the step (3) are fed back to the original products or systems design, and they are iteratively improved. The above FMEA steps are systematic, but they are practically very tedious, especially step (2).

Here we introduce a computer-aided technology for step (2), and realize efficient FMEA, which can be performed with not much extra-effort than to use CAD systems for product design. For this purpose, a feature-based product modelling is considered, by which functional behaviour and failure effects can be automatically propagated among components. By this extended product modelling capability, all the possible mal-functions of target products or systems can be enumerated. For the evaluation of the method, it is applied to small mechatronics products. But, it can be applied for wider range of products with addition of extra feature and failure mode definitions.

4 PRODUCT MODELLING FOR FMEA

4.1 Feature modelling

For FMEA applications, two types of feature definition are required for part structure description:

(1) Part/component feature: This feature describes space occupancy or vacancy with appropriate attributes. This includes body features, such as a rigid body, a flexible body, a shaft and a flange. It also includes empty space and surfaces. It contains various attributes, such as materials.

(2) Relation feature: This feature represents semantic relations among part/component features, such as flexible deformation and rotational pair. This is described by various mechanisms, such as data, formula, logical constraints and procedures. Failure modes corresponding to parts/components and their relations are described by this type of features.

Simple example is shown in Figure 1, where a rotational relation represents transfer of rotational movement and torque between two features.

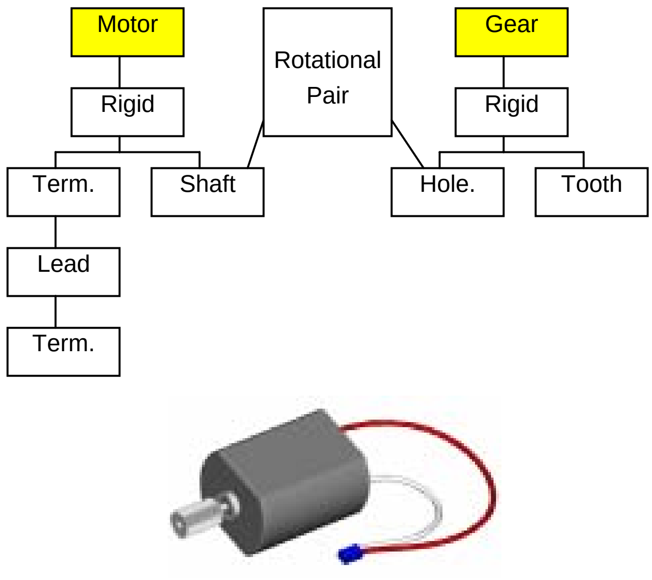


Figure 1: Feature modelling of a motor-gear pair.

4.2 Function representation

For representing functional behaviour, three levels of model description framework are introduced, as shown in Figure 2:

(1) Function structure: Targeted functions of products or systems are described from an abstract level to more concrete levels. Those functions are

connected by relations, such as dependency or decomposition. Each function is defined by its physical input-output relations.

(2) Function-dependency path: This representation is a key for failure diagnosis, and is automatically generated by comparing (1) and (3). For some functional description in (1), behaviour of physical attributes is detected, and it is related with part structure description via physical attributes. The same procedure is repeated to propagate functional dependency.

(3) Part structure: This corresponds to the feature description of part/component in section 4.1.

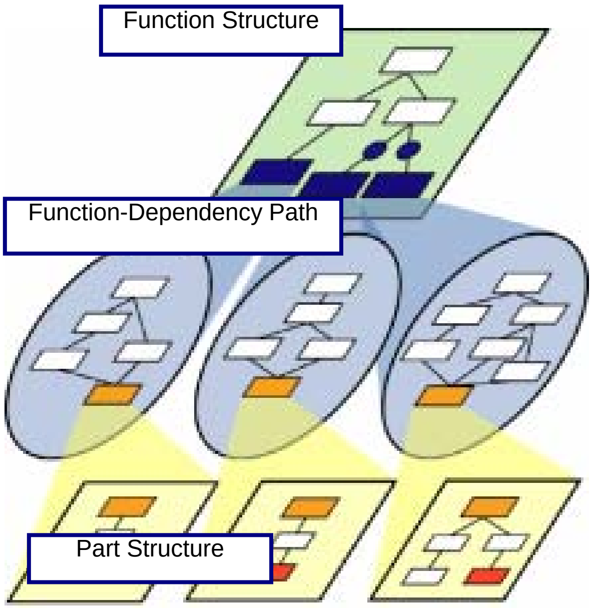


Figure 2: Function representation.

4.3 Failure analysis process

Based on the knowledge of individual component failure, possible failure reasons are assigned to respective components in part structure. There may be many failures due to environment, time, statistics, wear/fatigue, etc. As shown in Figure 3, failure phenomena are propagated by tracing function-dependency path. The results are reflected in function structure, and failure effects of individual component over total product/system behaviour can be analysed. All the results are summarized in tabular form called an FMEA table.

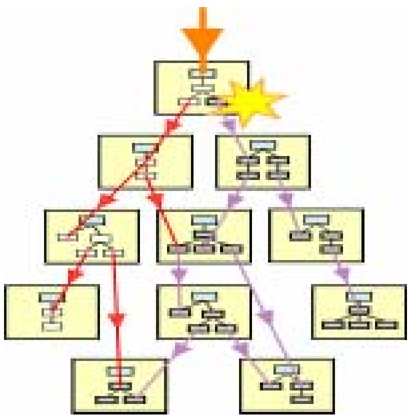


Figure 3: Propagation of failure.

In order to show the criticality of the failure, Risk Priority Number (RPN) is used. Here RPN is computed by two factors: probability of occurrence of failure and severity of failure. Those factors also can be generated by the models described in sections 4.2 and 4.3.

5 FMEA EXAMPLES

In order to show the feasibility of the method, mechatronics products are selected: a computer mouse and a portable CD player. Figure 4 shows an example mouse. Its part structure is shown in Figure 5. A part of its function structure is described as in Figure 6, and its function-dependency path is generated as shown in Figure 7. A part of a resultant FMEA table is shown in Figure 8. This example is simple, but almost exhaustive enumeration of possible failures can be realized, which includes rather unusual phenomena.

Figure 4: A computer mouse.

As a more complicated example, a portable CD player, as shown in Figure 9, is successfully analysed. The proposed method is basically feasible for such types of products. However for the comprehensive analysis of all types of mechanical/electrical analysis, substantial extension of feature description is necessary.

Figure 9: A portable CD player.

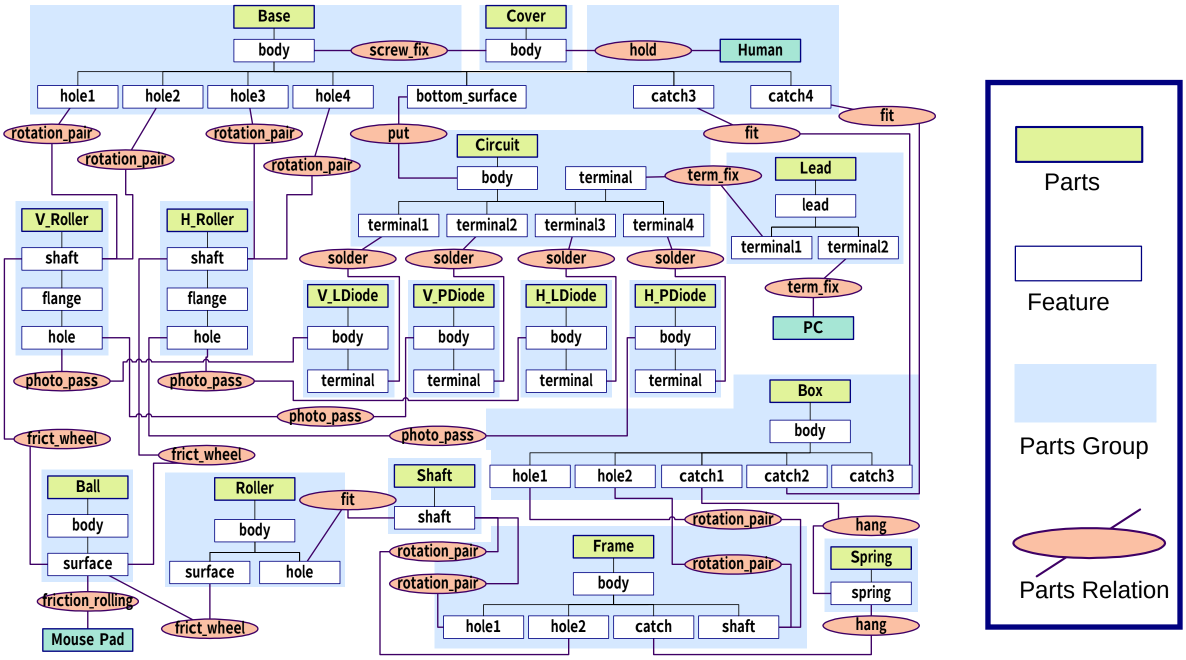


Figure 5: Part structure of a computer mouse.

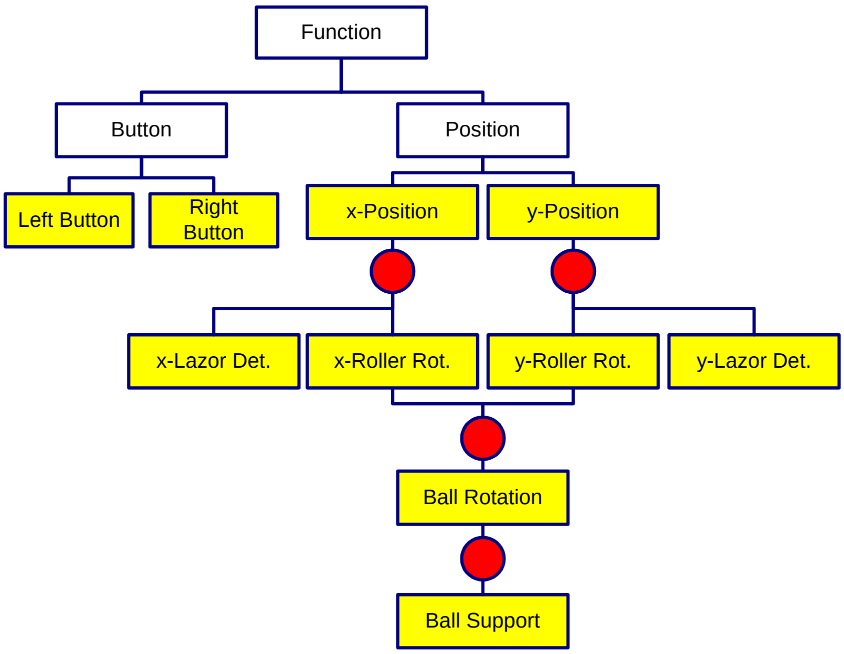


Figure 6: Function structure of a computer mouse.

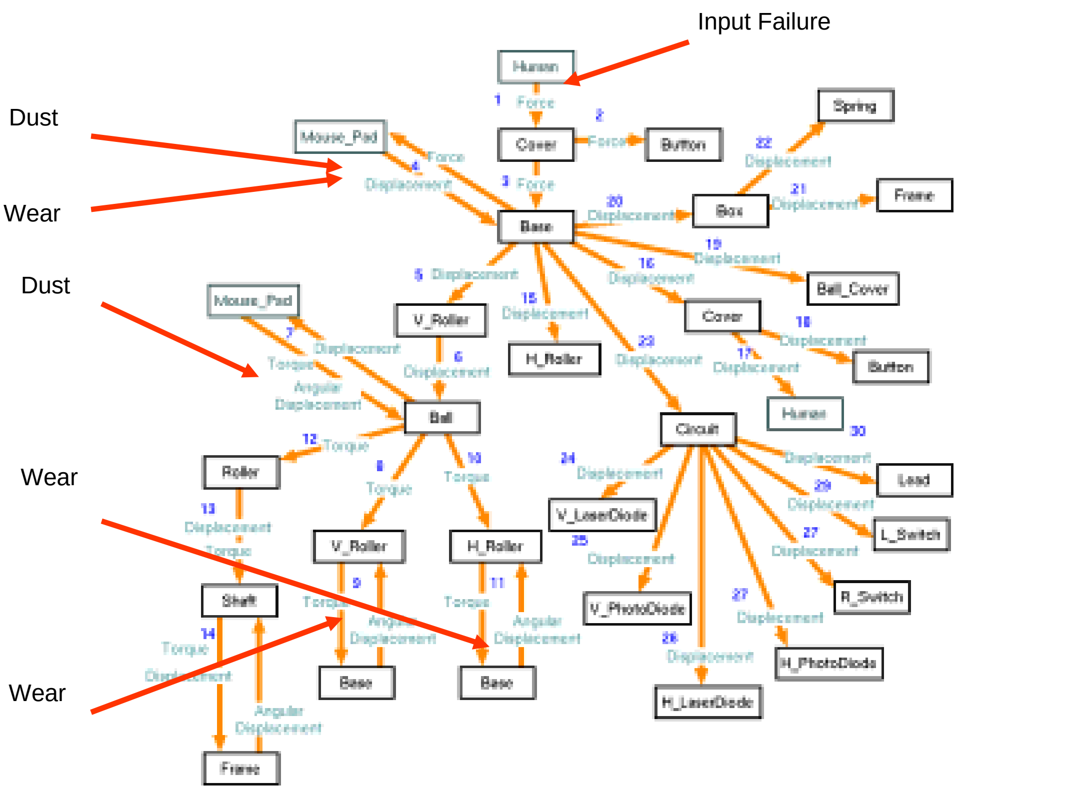
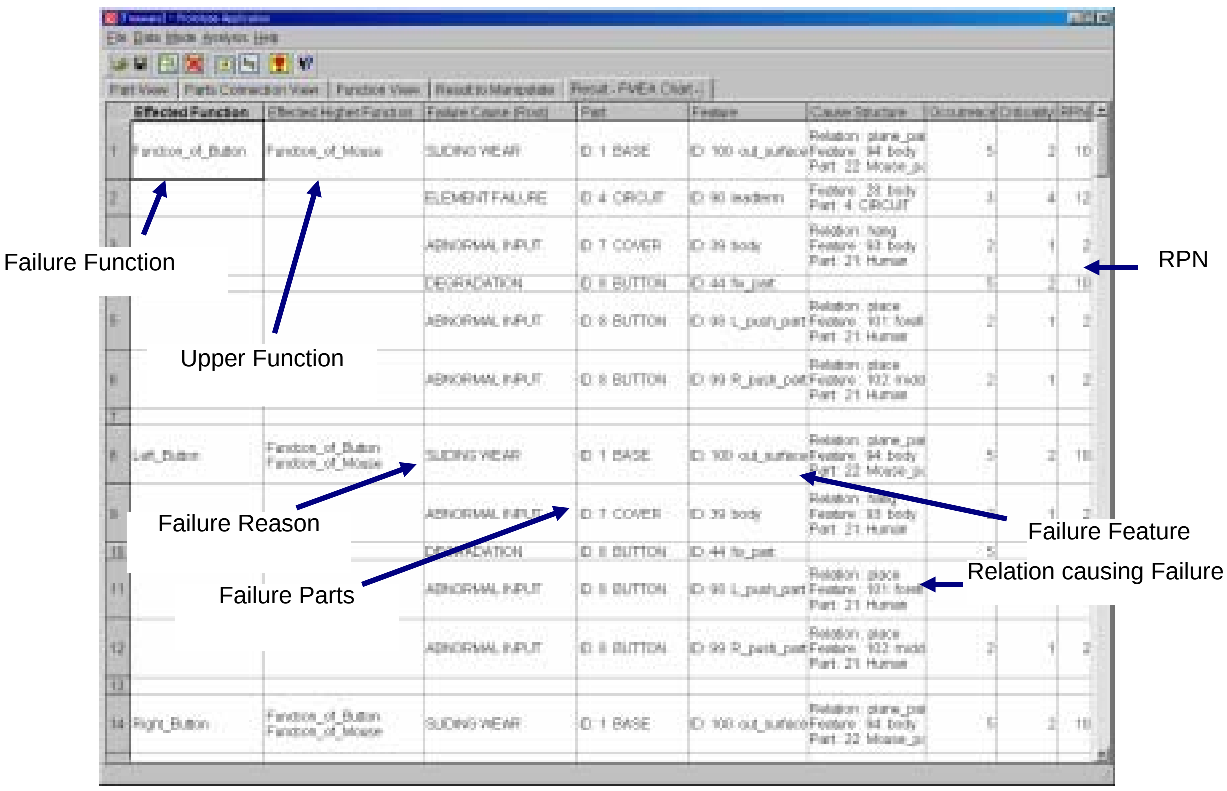


Figure 7: Failure analysis based on function-dependency path.



Figutre 8: FMEA table for a computer mouse.

6 CONCLUSION

As a basis for systematic computer support for RCM planning and FMEA, a feature-based product modelling is introduced, by which semantic description and analysis of product behaviour is realized. By applying various failure phenomena of individual component to product representation, total malfunctions and functional defects are predicted. FMEA is a core part of RCM, and computer-aided FMEA is expected to be very effective for total maintenance planning throughout the whole life cycle of target products and systems.

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