Title:
Optimal Design of Component Layout and Fastening Methods for the Facilitation of Reuse and Recycle

Authors:
Masakazu Kobayashi, kobayashi@toyota-ti.ac.jp, Toyota Technological Institute
Hajime Horiuchi, sd12440@toyota-ti.ac.jp, Toyota Technological Institute
Masatake Higashi, higashi@toyota-ti.ac.jp, Toyota Technological Institute

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Introduction:
Due to rise of environmental awareness and enactment of legislation in recent years, products that reach their end-of-life need to be collected, disassembled and reused / recycled. However, since it is impractical to reuse / recycle every component that makes up a product from a cost effective standpoint, only high-value components are reused / recycled and the rest of components is discarded. Therefore, there is a need to design a product in which high-value components can be removed with less disassembly cost and work for the facilitation of reuse and recycle.

For years, many researches have been done to make products to be disassembled more efficiently. Design for Disassembly (DfD) [1][7] is the guideline to design products to be easily disassembled for maintenance, repair, recovery and reuse of components/materials. Disassembly sequence planning [2-4] is the method to obtain the optimal disassembly sequence which a product is disassembled with minimum cost and work. Layout optimization considering disassemblability [5-6] is the method to explore the layout which components comprising a product can be disassembled with less cost and work. However, compared to the researches of DfD and disassembly sequence planning, layout optimization considering disassemblability has not been researched sufficiently. In this research, to improve disassemblability of a product for the facilitation of reuse and recycle, layout design during conceptual design phase is focused on and a new method of optimizing component layout and fastening methods inside a product is developed.

Main idea:
The purpose of the proposed method is to design the component layout and the fastening methods which high-value components can be removed from a product with minimum effort. "Value" means how much the component is worth recycling / reusing and how much maintenance the component requires. The component with high 2R (reuse / recycle) and maintenance value is named "high-value component". Component shape is represented by a rectangular box and three-dimensional layout of components is represented by sequence triple [8]. It is assumed that components can be removed in only one direction and one component can be removed at a time. To explore the optimal component layout and fastening methods, genetic algorithm is used. Fitness function of GA is defined by the below equation.

$$\text{Maximize} \quad f = \sum_{i=1}^{n} \left(D_{\max} - D_i\right)\cdot\left(V_{r,i} - V_{m,i}\right) - \sum_{i=1}^{m} \left\{\left(T_{fastener,i} \times k_i\right) + T_{tool,i}\right\}\cdot G_i \qquad (1)$$

Where, the former term is based on the value of components and the disassemblability of the layout whereas the latter term is the estimated time to remove fasteners used to fix high-value components.

n is the number of components and m is the number of high-value components. D_{max} is the maximum level of disassembly sequence depth, D_i is the level of disassembly sequence depth of component *i*. $V_{r,i}$ is the value of recycling / reusing component *i*. $V_{m,i}$ is the maintenance value of component *i*. $T_{fastener,i}$ is the basic time to remove one fastener used to fix component *i*. k_i is the number of fasteners of component *i*. $T_{tool,i}$ is the basic time to prepare the tool to remove the fasteners of component *i*. G_i is the difficulty of removing the fasteners of component *i*.

As for evaluation of disassemblability, "disassembly sequence" and "disassembly sequence depth" are introduced. Disassembly sequence is the sequence of components to be removed from a product. Since the purpose of the proposed method is to obtain the layout which high-value components can be easily and quickly removed from a product, the basic rule is that if more than one component can be removed at the same time, the component with highest value is removed preferentially. Disassembly sequence depth shows the number of steps required for each component to become removable from a product. The depth of the components that can be removed from the beginning is called "Level 1". The depth of the components that become removable after removing one component according to the disassembly sequence is called "Level 2". So, depth of the components that become removable after removing n components is called "Level n+1". If no new component becomes removable after removing n components, "Level n+1" becomes empty set.

As for fastener design, three design parameters are considered: The face in which fasteners are arranged (More than one face can be selected), the type of fasteners and the number of fasteners. Based on these parameters and the component layout, the time to remove fasteners can be calculated.

As for constraint condition, since each component needs to be appropriately fixed for the proper functioning of the product, fastening strength of each component is evaluated. Specific required fastening strength is configured for each component and fastening strength of each component is calculated by the type & number of fasteners.

Case study

The proposed method is applied to the design of internal devices of a laptop computer. The computer consists of 15 components. Each component has the value of recycle / reuse and the required fixation strength. It is assumed that only top 7 high-value components is reused / recycled. They are represented by green rectangles in the below figures.

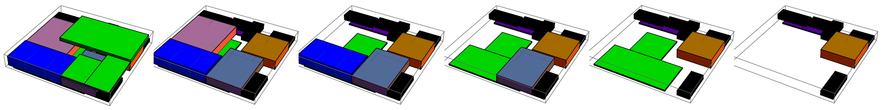

Fig. 1: Disassembly sequence of the optimal design (Green rectangles: High-value components).

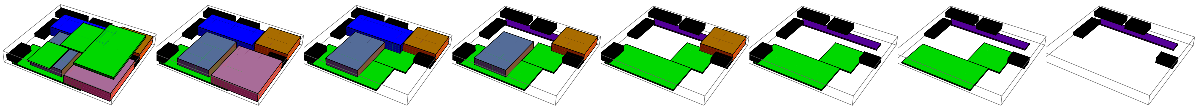

Fig. 2: Disassembly sequence of the existing laptop (Green rectangles: High-value components).

The optimal layout and its disassembly sequence are shown Fig.1. For comparison, the layout and disassembly sequence of the existing laptop are shown in Fig.2. Estimated disassembly time to remove the high-value components of the optimal design and existing design is 453.4s and 481.7s respectively.

Conclusions:

To make product disassembly more efficient for the facilitation of reuse and recycle, a new method of optimizing component layout and fastening methods between components / enclosure inside a product is developed. Using the proposed method, the component layout and the type & number of fasteners which high-value components can be removed with less disassembly work can be obtained.

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