INTEGRATED OPTIMIZATION OF FUNCTIONAL AND LAYOUT DESIGNS BASED ON GENETIC ALGORITHM

Consideration of Carbon Emission troughout Product's Lifecycle

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Abstract: In our previous research, the integrated optimization of functional / layout designs based on genetic algorithm was developed for supporting conceptual design phase. This method can optimize a functional structure and a parts layout simultaneously by evaluating performance, cost and size. In this paper, we now focus on consideration of lifecycle characteristics in response to rise of environmental awareness in recent years and combine our previous integrated method with lifecycle assessment (LCA) in order to enable creation of product concepts that balance various characteristics including lifecycle ones at a higher level. This paper also shows an application of the proposed method to a personal computer design and discusses the effect of consideration of lifecycle characteristics during conceptual optimization.

1 INTRODUCTION

Due to rise of environmental awareness in recent years, companies are required to assess and improve various product lifecycle characteristics such as carbon emission. To evaluate them, ISO14040 series, which describe the principles and framework for LCA, were established and various commercial LCA software such as GaBi, SimaPro and JEMAI LCA pro was developed. However, since not only lifecycle characteristics but also product's primary ones such as performance, cost and size need to be simultaneously considered for creating an attractive product, designers are forced to take a great deal of time and effort to balance them at a higher level.

Based on the above background, this paper proposes a new integrated optimization method for creating product concepts that balance various characteristics including lifecycle ones at a higher level, based on our integrated optimization method (Kobayashi, Suzuki and Higashi, 2009). Our previous method is the integration of functional / layout optimization based on genetic algorithm for supporting a conceptual design phase. During a conceptual design phase, since there are various decision-makings, designers are asked to make optimal decisions to create great product concepts by considering various valuation characteristics such as performance, cost and size. However, since functional / layout designs, which are main two tasks of a conceptual design phase, are very different tasks, their design problems are highly hierarchized and their solution spaces are vast, it is extremely difficult for designers to build up great concepts only with their own decision makings. To overcome such difficulty, functional / layout optimization are combined and executed cooperatively in our method. Using this method, both a functional structure and a parts layout that satisfy various characteristics at a high level can be obtained. The method proposed in this paper is based on our previous method and LCA, which combination enables a design of a product concept with consideration of various characteristics including lifecycle ones.

2 INTEGRATED OPTIMIZATION METHOD

2.1 Overview

This paper proposes an integrated method for optimizing a functional structure and a parts layout by considering various characteristics including

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lifecycle ones, based on our previous method. Improved point is to integrate lifecycle assessment in order to consider its results as one of valuation characteristics of the integrated optimization.

Figure 1 shows the overview of the proposed integrated optimization method. As shown in this figure, this method consists of functional / layout optimization plus LCA. Functional optimization is the main part of the proposed method and executed just one time. Functional optimization is based on the hierarchical genetic algorithm (HGA) (Yoshimura and Izui, 2002) in order to consider hierarchical nature of a functional structure. In the proposed method, performance, cost, total area and total carbon emission are considered as valuation characteristics of the functional optimization. Any of them can be configured as an objective function and the rest of them are configured as constraint conditions. The proposed method assumes that performance and cost can be calculated by simply summing up the values associated with each part, whereas total area and total carbon emission can not be calculated by simple summation. Therefore, layout optimization and LCA are repeatedly invoked from the functional optimization to obtain the layout with minimum area and total carbon emissions respectively for every design proposal and for every generation of the functional optimization. Layout optimization is based on the traditional genetic algorithm and the sequence-pair representation (Murata, Fujiyoshi, Nakatake, and Kajitani, 1996).

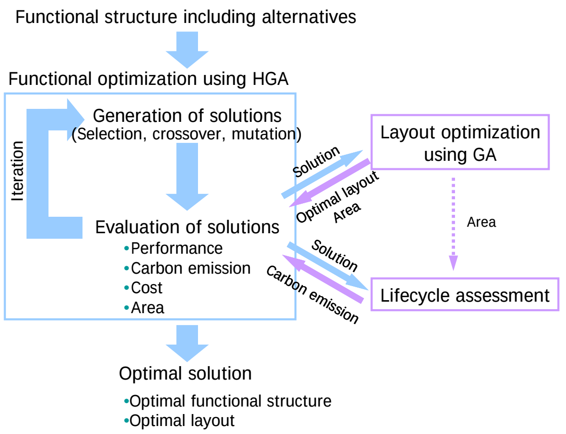

Figure 1: Overview of the integrated optimization.

Due to space limitation, the following section only describes the part of LCA. See the reference (Kobayashi, Suzuki and Higashi, 2009) for the details of functional / layout optimization and their integration.

2.2 Lifecycle Assessment

In the practical LCA, there are various valuation characteristics such as emissions of CO2, SOx and NOx throughout entire product's lifecycle, usage rate of renewable material and reuse / recycle rate. This paper adopts carbon emission as a valuation characteristic of the propsoed method, because CO_2 reduction is one of most interested problems in order to fight global warming in recent years. Total carbon emission of each design proposal obtained during functional optimization processes is calculated by the following concepts.

(a) Value of carbon emissions is evaluated and configurated for each part by executing LCA.

(b) All parts can be classified into two types. One has the fixed value of carbon emissions and the other has the value of carbon emissions per unit area. Most parts belong to the former type, whereas an electronic substrate, for example, belongs to the latter type. Actual value of carbon emissions of the latter type is calculated by multiplying unit carbon emissions by the area calculated by layout optimization.

(c) Total carbon emission of a design proposal GHG_{total} is defined by the below equation.

$$GHG_{total} = \sum_{i=1}^{m} GHG_i + \sum_{j=1}^{n} Area_j \times uGHG_j \qquad (1)$$

Where GHG_i is the fixed value of carbon emissions of part i, whereas, $uGHG_j$ is the value of carbon emissions per unit area of part j. $Area_j$ is the value of area of part j.

3 CASE STUDY

3.1 Problem Description

In the case study, internal devices of a personal computer are designed using the proposed method . "Internal devices" means that input devices, a display and an enclosure are not included.

A computer consists of the following 5 components: motherboard, HDD, cooling system, power supply and auxiliary storage. Motherboard, cooling system and power supply can be decomposed into more than one part, whereas HDD and auxiliary storage can not be decomposed any more. Table 1 shows an example of their alternatives. Prices and sizes are configured by surveying their retail price and measuring their size. Performances

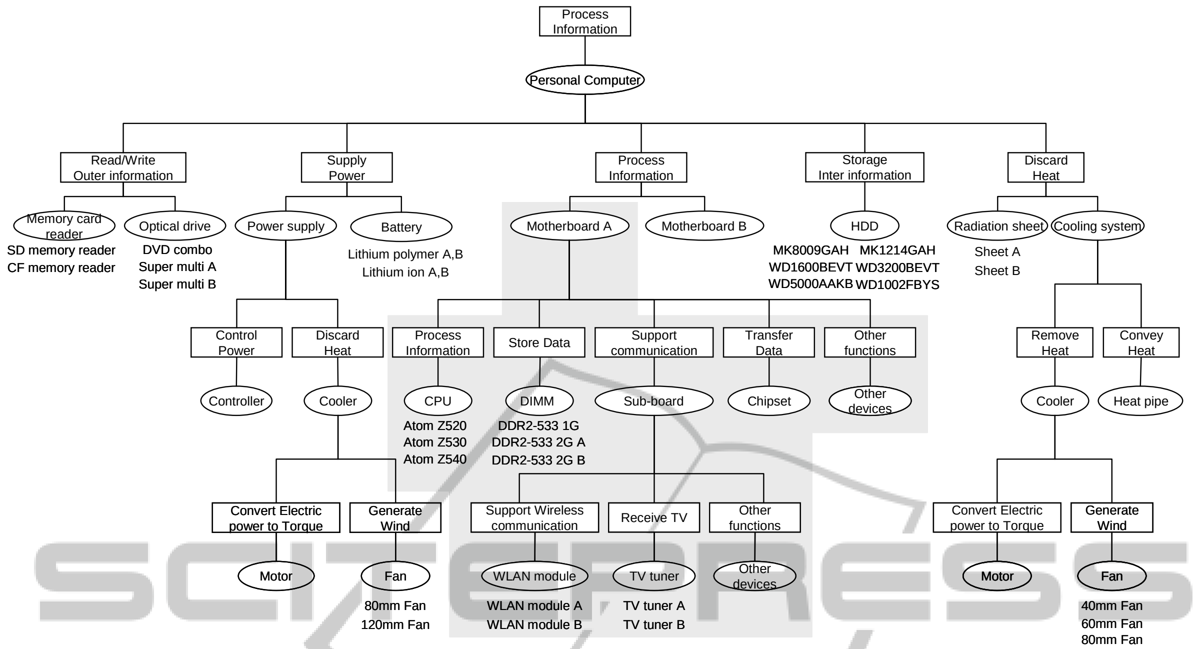

Figure 2: Functional structure designed in the case study.

are subjectively and intuitively configured. Carbon emissions are configured by surveying the reference (Japan Environmental Management Association For Industry, 2007). Figure 2 shows the functional structure of a personal computer used here. Note that, due to space limitation, the lower functional structure of Motherboard B is not described here. Motherboard B is similar to Motherboard A, but has powerful CPU, more Memory and discrete graphic card.

In the case study, performance is handled as an objective function, whereas cost, total area and total carbon emission are handled as constraint conditions.

Table 1: Examples of parts specifications.

	Cost (USD)	Dimension (cm)	Perfor mance	CO_2 (kg)
SD memory reader	25	2.4*3.2	3	0.13
CF memory reader	130	4.3*3.6	2	0.27
CD-R/RW/DVD combo	80	12.8*13.0	7	2.87
Super multi drive A	130	12.8*13.0	8	2.87
Super multi drive B	260	12.8*13.0	10	2.87

3.2 Results

Figure 3 shows the results from the use of our previous method that does not consider carbon emission. In this case, optimizations ars executed 12 times under 12 various cost constraints from 550 USD to 2550 USD and constant area constraint (Area < 1200 cm^2). Parameters of HGA and GA are shown in Tabel 2. The optimal layouts of the design solutions denoted by two stars in Figure 3 are shown in Figure 4. Whereas, Figure 5 shows the result from the use of the proposed method that considers carbon emission. In this case, optimizations are also executed 12 times under 12 various constraints of carbon emission from 5 kg to 50 kg and constant constraints (Cost < 3000 USD and Area < 1500 cm^2). Parameters of HGA and GA shown in Table 2 are also used in this case.

Table 2: Parameters of HGA and GA.

	HGA	GA
Population	100	60
Crossover rate	1	1
Mutation rate	0.05	0.01
Generation gap	0.9	0.5
Terminal generation	200	50

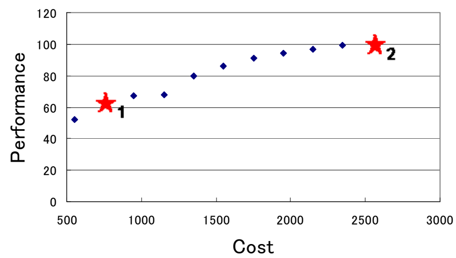

Figure 3: Relationships between performance and cost of obtained solutions.

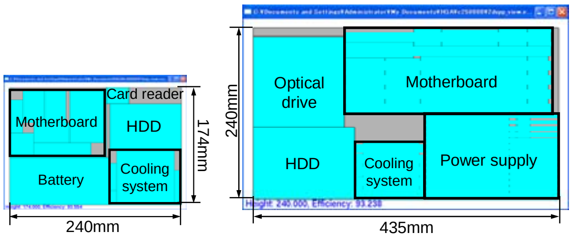

Figure 4: Optimal layouts (Left: Star 1, Right: Star 2).

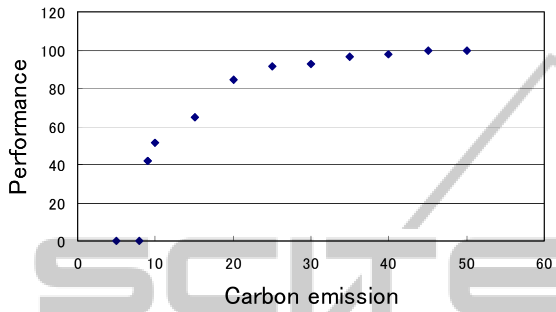

Figure 5: Relationships between performance and carbon emission of obtained solutions.

A Comparison between two results shows that a constraint of carbon emission makes it difficult to design a high performance PC even if constraints of cost and area are sufficiently relaxed. This is because high performance parts used in the case study have a tendency to emit a lot of CO_2 throughout their lifecycle. These results show that the proposed method can obtain a optimal product concept with consideration of various characteristics including carbon emission.

4 CONCLUSIONS

To create optimum product concepts that balance product primary characteristics such as performance and cost and product lifecycle ones such as carbon emissions at a higher level in response to rise of environmental awareness in recent years, this paper combines LCA with our previous method that integrates functional / layout optimization. Using the proposed method, optimal functional structure and parts layout can be obtained by considering various characteristics including lifecycle ones. Although consideration of lifecycle characteristics are indispensable in recent product development, not only lifecycle characteristics but also product's primary ones such as performance and cost need to be simultaneously considered and balanced at a higher level for creating an attractive product. This is why the proposed method is quite useful.

In the case study, the proposed method is applied to a design of a personal computer and the results show the effect of consideration of lifecycle characteristics during conceptual design phase.

As for future works, we are planning to improve the following points.

(1) For practical products, since connections between components or parts have crucial roles such as force transmission and object transport, their consideration is the first issue to be settled.

(2) For practical products, since parts have many different appearances and are placed in 3D space, consideration of a three-dimensional layout with arbitrary part shape is required to extend the range of application of the proposed method.

(3) In the proposed method, only carbon emission is considered. Consideration of lifecycle characteristics in addition to carbon emission will improve the effectiveness of the proposed method.

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