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Development of Information System for Product Redesign: Evaluation of Assembly Process and Characteristics of Product Functions

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Abstract. Since product design strongly depends on the experience and ability of the designers, and a long lead time is required for the product design stage, introducing a support system related to this experience and ability is an effective technique to reduce the lead time. In this paper, an information system is developed to support the development of engineering mechanisms with the evaluation of the assembly process on the basis of the abstract functions required for new products. The developed system is based on a database system involving the following data structure: (1) a hierarchical structure related to information about the product functions, (2) the relationship between the parts and engineering functions and/or mechanisms of products, and (3) the relationship between the parts and manufacturing characteristics. The system stores the relationships between the product functions, structure of parts, and assembly characteristics. This information can then be interactively retrieved using the data structure described in (1), (2), and (3). A procedure for designing new products is proposed that involves using the information about existing products. This paper presents the characteristics of the proposed procedure and the developed information system. In addition, a case study of the redesign of a simple structured robot by using the proposed procedure is discussed.

Keywords: Product Design, Database, Hierarchical Structure, BOM, Manufacturing Process, Product Functions

1. INTRODUCTION

The diversification of customer requirements and the shortening of product lifecycles have created a need for companies to manufacture and develop various types of products in a short period. Therefore, an effective strategy is required to supply products as quickly as possible. By evaluating the manufacturing and assembly process between the product design stage and the process design stage using a sophisticated strategy, high quality products can be supplied to the marketplace. In the current production environment, concurrent engineering systems and systems that enable previewing designs help to reduce the time interval between these stages. In addition, they promote the rapid feedback of evaluation information from the manufacturing and assembly stage to the product design stage. To introduce effective operation and production for multiple items, the following issues are discussed in the product design stage: the design of modular parts, standardization of parts and modules, utilization of common parts and common manufacturing processes, etc.

One of the most significant tasks in the product design stage is the transformation of the abstract requirements for functions into concrete engineering configurations, parts, mechanisms, etc. However, this work strongly depends on the knowledge and experience of the personnel involved. Therefore, when inexperienced personnel tackle product design, an information system should be introduced to provide knowledge and decision making support. On the other hand, although product productivity is considered, as well as the mechanisms for functions and the configuration of products in the product design stage, it is difficult for inexperienced personnel to visualize the manufacturing process and the evaluation of productivity depends on their experience and knowledge.

Many companies introduce a product lifecycle management (PLM) information system. This information system is developed based on a bill of materials (BOM), and various types of BOMs are prepared to share data among different work divisions. This system can promote the interchange of information related to the various tasks to be performed by the different work divi-

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sions. However, process design and product design are not considered in the same stage in conventional techniques.

Quality function deployment (QFD) is a tool that assists with the development of concrete engineering items based on abstract function requirements. QFD supports the decision making process for engineering items to satisfy the function quality requirements of the marketplace (Salvendy, 1991). Although QFD is a significant and effective tool, collecting various types of data and analyzing the results of experiments involves considerable effort.

The data related to existing products are useful for reducing the development period and warranting the quality of parts and mechanisms in the development of new products. In addition, in the redesign and continuous improvement of products, the parts or modules of products modified for required functions can be extracted by using data related to existing products. The determination of the relationships between parts and function characteristics allows parts or modules to be used as units in the redesign and modification of existing products. When the main parts and modules of a product are related to the manufacturing and/or assembly process information, process design can be considered in the product design stage.

In recently studies there are some papers dealing with product redesign and modification of products for PLM by focusing on parts and modules. Lee *et al* proposed systematical process with regard to maintenance, repair and overhaul of products and application of the process is performed for a repair of turbine blade of aircraft as a case study (Lee, Ma, Thimm, and Verstraeten, 2008). Rangan et al presented product data management and data structure constructed by focusing on parts and modules, or functions in the process of PLM (Rangan, Rohde, Peak, Chadha, and Bliznakov, 2005). Xu *et al.* proposed data structure to evaluate cost in implementation of PLM and the process of cost evaluation (Xu, Chen, and Xie, 2006). However, the data structures presented in these papers are constructed to evaluate criteria appeared in specific works or operations. In addition, engineering functions of a product imaged from abstract concept are not discussed.

In this study, a process is developed for the design of new products by focusing on parts and modules. The relationship between the required functions and parts structures of existing products is utilized in the developed process. The proposed process involves the evaluation of the manufacturing and assembly processes related to the parts structures of products. The information system to support product design in the developed process involves the following items:

(1) Construction of a database in which the hierarchical structure of functions, sample parts to realize functions, and characteristics of functions are stored,
(2) Determination of the relationship between the structure of parts and hierarchical structure of functions.

We discuss the redesign of a new robot system from a robot designed as an educational tool as a case study to evaluate the developed process. Here, originalities of this study are listed as follows:

(a) The data structure to refer three types of information is proposed for redesign of a product by focusing parts and modules,
(b) Evaluation of difficulty of assembly process for each part is included in the data structure,
(c) The process to redesign products is proposed with using the data structure,
(d) Information system to refer relation of functions and parts/modules is developed to design mechanism and engineering structure of parts from abstract functions for new product.
(e) The case study is performed to show effectiveness of the proposed process for redesign.

2. REDESIGN OF PRODUCTS USING RELATIONSHIP BETWEEN FUNCTIONS AND PARTS

2.1 Redesign of Products Focusing on Key Characteristics

In this study, we treat products as a set of functions and propose a procedure to design new products by modifying and exchanging the functions of existing products. This procedure is based on a transformation from the modification of functions to the modification of parts and partial mechanisms in products in the design process. The relationships between the product design information, process design information, and other information are stored in a database. When the characteristic product functions required for modification are selected, we can focus on the manufacturing and quality information related to the functions. Then, the candidates for the parts, manufacturing, and quality required for the modification can be narrowed down as "key characteristics." Ordinarily, the term key characteristics denotes the requirements for product functions and the manufacturing process used to determine the value of the products to supply to the final customers (Fine, 1998). Introducing key characteristics can connect the requirements for the characteristics of parts, functions, and manufacturing appearing from the product design stage to the manufacturing stage.

In this study, we focus on products manufactured by the assembly of parts. A structured data table is introduced to store the following information: parts structure, product functions, and manufacturing measure. This structured data table is a database connecting these three types of information and used to retrieve the required data as a unit of parts or modules. Considering the concept of key characteristics, we propose the process for the design of new products indicated in Figure 1. The concept of key characteristics is focusing on key information and retrieving the required data from different types of connected information. In the flowchart, PKCs denotes product key characteristics and indicates the characteristics of the product functions required by customers; MKCs denotes manufacturing key characteristics and indicates the characteristics of manufacturing; and AKCs denotes assembly key characteristics and indicates the assembly characteristics when considering the possibility of assembly. The flowchart shows the processes used to determine the characteristics of the parts from the requirements of customers and design concrete parts and modules from the abstract representations of functions iteratively in the product design stage. Here, the difficulty and the number of operations are considered to decide an assembly process at process (6) in Figure 1.

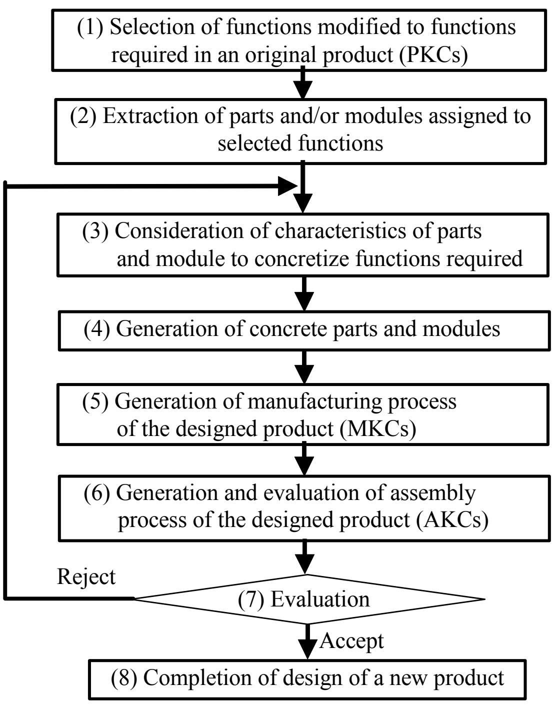


Figure 1. Schematic diagram of proposed process for redesign of new products.

2.2 Information for Parts and Modules Related to Product Functions

Next, using the measures realized in QFD, a database is developed that reflects the hierarchical structure of functions. The hierarchical structure of functions is related to the parts structure in the BOM. In addition, a procedure to redesign products effectively by using this database is developed. In the database, the parts and modules of products are narrowed down as candidates to modify using specific functions for the information relationships.

Figure 2 shows a schematic diagram of the patterns of modification of parts and modules caused by the modification of a function. However, the relationship between the function information and parts information has the structure of a single item related to numerous items. Therefore, when it is necessary to modify a specific function, the modification of plural parts is generated from the relationship. For example, function B is related to both parts Q and R. When function B is modified to function D, (a), (b), (c), (d), and (e) in Figure 2 are listed as candidates for the modification. Candidate (a) is the easiest to realize function D because it involves a simple parts exchange process. However, this candidate increases the number of parts and allows the easy imitation of products. On the other hand, candidates (d) and (e) reduce the number of parts and require the creation of an original module system involving parts and mechanisms to realize both function D and function A. Therefore, in order to extract information about function A from the information about the parts used to realize function B, it is necessary to develop an information system that includes a function to relate functions and parts to each other mutually. In addition, the system should include a function to support the creation of new mechanisms to realize a module that combines different product functions.

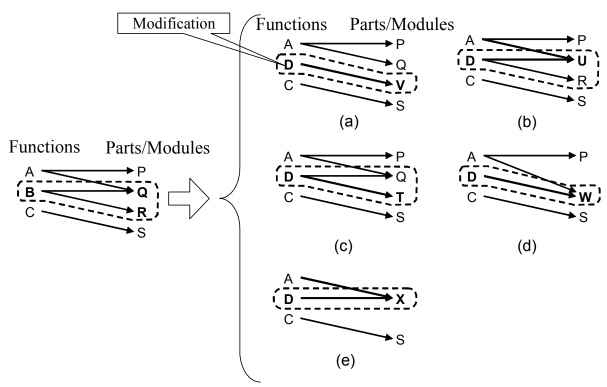


Figure 2. Schematic diagram of patterns of modification of parts and modules caused by modification of functions.

2.3 Proposed Product Design Procedure that Uses Relationship between Hierarchy Structure of Functions and Characteristics of Parts

Figure 3 shows a flowchart of the proposed product design process, focusing on the relationship between the functions required by customers and the parts of existing products. The hierarchy structure is constructed from the first label to the third label in order to analyze the functions required by customers. Then, the functions are allocated to elements of the hierarchy structure from the abstract representation to the concrete representation. This hierarchy structure corresponds to the representation constructed in QFD. In this process, the functions required by customers are translated into concrete engineering functions in the hierarchy structure. Then, the second label in the hierarchy structure or a set of plural elements with the third label is focused on to collect information about the creation of new parts, new modules, and new mechanisms.

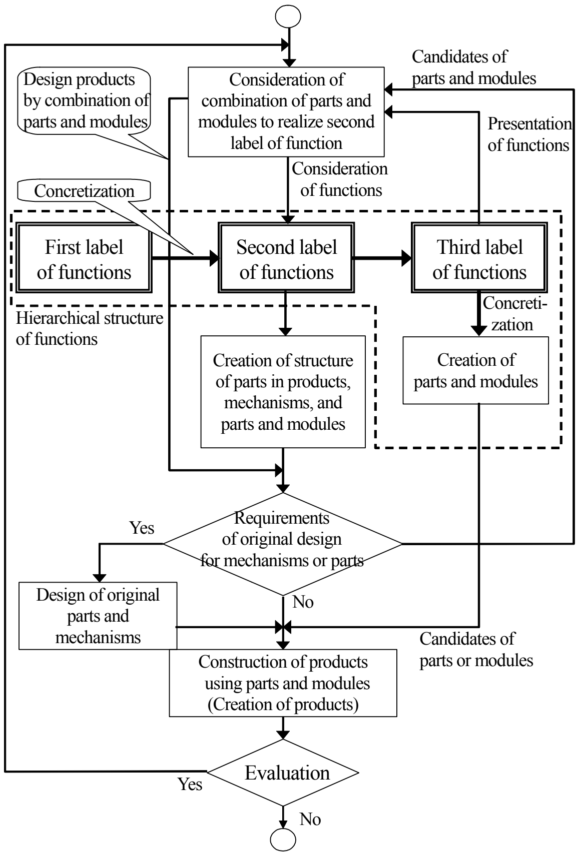


Figure 3. Flowchart of proposed process for product design focusing on relationship between hierarchical structure of required functions and parts of existing products.

A rough design can be created by combining mechanisms and parts stored in third label elements below the second label focused on. If the rough design is required to modify or create new mechanisms for engineering characteristics, third label elements are referenced and specific parts or mechanisms are extracted and modified. New products are designed by executing the proposed process iteratively. Since the parts and mechanisms of existing products are referenced to create the parts or mechanisms for new products, the proposed process is expected to reduce the period required for product development. In addition, when the data structure is related to information about the quality of parts or manufacturing, the quality of the designed products can be warranted.

Here, the difficulty and the number of operations are considered to decide an assembly process at the following processes in Figure 3: the process "Creation of structure of parts in products, mechanism, and parts and modules" in second label function and the process "Creation of parts and modules" in third label function. These include systematical process to select the appropriate design from candidates as the following process: (1) design candidates of structure of parts/modules and mechanisms to realize new functions of the product, (2) evaluate feasibility and operation difficulty of all candidates, (3) select the appropriate structure from candidates by referring value of operation difficulty.

3. DETERMINATION OF RELATIONSHIP BETWEEN PARTS INFORMATION AND MANUFACTURING INFORMATION

3.1 Preparation of BOM for Evaluation of Assembly Process

In this section, the information related to products is categorized into the "construction of parts", "functions and characteristics of products", and "procedures and characteristics of manufacturing" to manage information by units of main parts and modules. As for the information about the construction of parts, a hierarchy structure for the main parts and dummy semi-finished products is constructed in the engineering BOM. Here, the elements stored in the engineering BOM correspond to the main parts and semi-finished products. The support parts for assembly such as washers, bolts, and nuts are excluded from the structure. In addition, dummy semi-finished products are determined from the main parts as semi-finished products, which are not modules. As for information about the functions and characteristics of products, the functions required by customers are allocated to parts to realize the functions. The relationship constructed from the allocation can be used to investigate parts or mechanisms from the required functions in the database.

As for the information about the procedures and characteristics of manufacturing, the order and contents of operations are stored in the database. In addition, the contents of operations are evaluated by using the difficulty values for the assembly processes defined in the next section. In order to connect these three categorized types of information, several two-dimensional tables are introduced as multidimensional tables. Every two-dimensional table is used to connect two different kinds of categorized information.

Figure 4 shows a schematic diagram of the concept of the multidimensional tables used to connect the three different types of categorized information. When the reference of X to Y is described as X→Y, A→C uses the evaluation of the process to assemble a part or a module selected in Figure 4. On the other hand, C→A uses the evaluation of the parts or modules used in the selected assembly or manufacturing process. B→A uses the selection of parts and modules to realize the selected functions, and this reference can be used in the discussion of the modification of parts or modules for new functions.

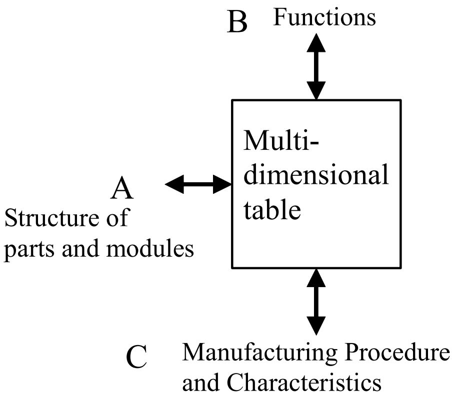


Figure 4. Schematic diagram of multidimensional tables.

3.2 Construction of Multidimensional Table

Figure 5 shows a schematic diagram of the multidimensional table proposed in this study. Figure 5 represents the concretized tables of Figure 4 and consists of six two-dimensional tables. Furthermore, Figure 5 shows the direction of reference for the data between two different types of information on different two-dimensional tables. The information for the construction of parts indicates parts and modules stored in the BOM. The data for the operations in the manufacturing process indicate information about the procedures and characteristics of manufacturing. The characteristics of the requirements, engineering functions, and factors to maintain quality indicate information about the functions and characteristics of products. These three types of information can be cross-referenced using these tables. The multidimensional table is used to select and modify parts and modules to realize specific functions in the process of product redesign. From the relationship between the procedures and characteristics of manufacturing and the construction of parts, parts and modules selected from the table can be discussed to develop an easy assembly process. From the relationship between the functions and characteristics of products and the construction of parts, new mechanisms or new modules can be created by combining the parts or modules used in existing products in order to realize functions.

Data related to the characteristics of requirements are considered as product design concepts. (1) indicates a reference to engineering characteristics and functions to concretize product design concepts. (2) indicates a reference to engineering characteristics and conditions to ensure the quality of the required functions. (3) indicates a reference to the main parts, modules, and semi-finished products modified to realize the required functions. (4) indicates a reference to the evaluation of operations to assemble parts and modules. These references can help support the design of new products by assisting with the evaluation of the assembly processes. Here, symbols A, B, and C in Figure 5 correspond to the symbols in Figure 4.

The assembly process can be represented as an iterative process for a single part that is assembled for a semi-finished product. Therefore, the relationship of the main parts is constructed in the engineering BOM, while excluding support parts such as nuts and bolts. Figure 6(a) shows the construction of the conventional BOM, and Figure 6(b) shows the construction of the engineering BOM used to evaluate the assembly process. In Figure 6(b), the BOM consists of the main parts and semi-finished products. The semi-finished products include dummy products composed of main parts. The main parts and semi-finished products can be related to information about the operations used to assemble them in the assembly process. This relationship can be used to evaluate the assembly process by the units of parts and modules. The data structure for the evaluation of the assembly process is shown in the next section. Since support parts are excluded from the BOM in Figure 6(b), different tables are generated to record the support parts and contents of operations, as shown in Table 1.

From the relationships between different types of information mentioned in this paper, the data structure in the multidimensional table can be used to support the selection and design of parts and modules, the evaluation of the assembly process, and the consideration of alternative ideas for modules, parts, and mechanisms from functions by the units of parts and modules. Modules and parts are involves in the BOM. Therefore, when a relationship between the function of a product and modules can be investigated, relationship (1) and (3) successively are referenced in Figure 5.

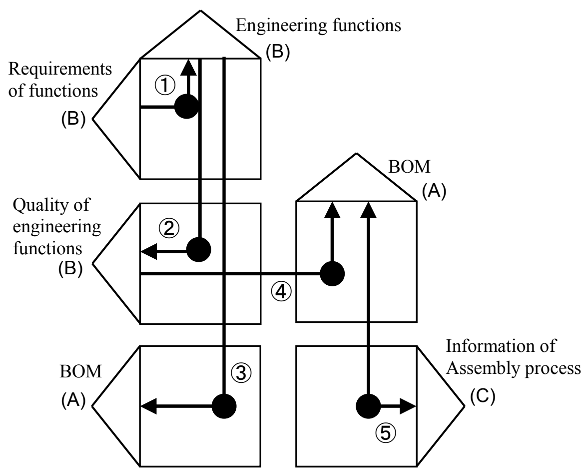
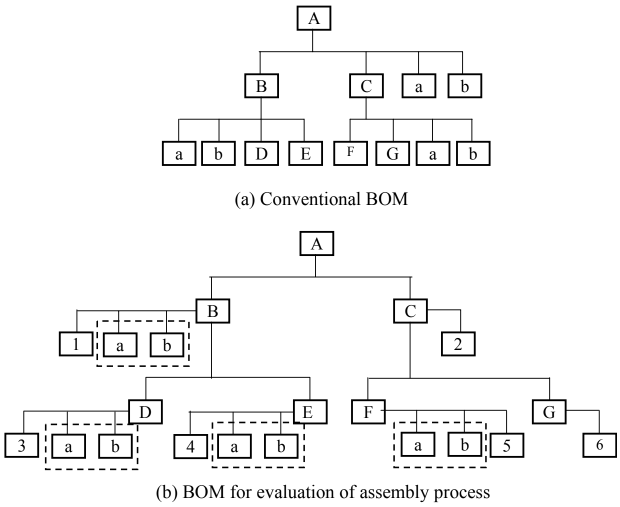


Figure 5. Schematic diagram of multidimensional table comprising different types of two-dimensional tables.



A,B,･･,F,G : Parts, semi-finished parts a, b : Support parts
1,2,･･,5,6 : Operation number
※ Data in [dashed box] is not stored in system

Figure 6. Comparison of BOM for evaluation of assembly process and conventional BOM.

Table 1. Table of operations and support parts. (#: Operation number)

#	Operation	Support parts		#	Operation	Support parts	
1	Screw	a		4	Screw	a	b
2	Insertion			5	Screw	a	b
3	Screw	a	b	6	Insertion		

3.3 Data Structure to Evaluate Assembly Process

This paper discusses products manufactured from parts. As for the information about the procedures and characteristics of manufacturing, the measures to evaluate are separated into three categories: the main parts to assemble, semi-finished products assembled from parts, and support parts used for the assembly of parts. Here, the support parts refer to washers, bolts, nuts, etc. Table 2 lists the measures introduced to evaluate the assembly process (Arakawa and Fuyuki, 2006; Arakawa, 2006). These measures denote factors causing difficulties for the assembly process. As shown in Table 2, 11 measures are introduced, with an evaluation level consisting of an integer number between zero and seven given to each. For example, the measure of “the direction to assemble a part” in the parts category can be evaluated in five levels according to the direction to assemble a part into a semi-finished product from the view of a worker. When the values for these measures are zero, they indicate that it should not be considered. Table 2 lists the categories of the different measures and the characteristics of the different levels used to evaluate them.

Table 2. Factors responsible for operation difficulty in assembly process.

Objects	Categories	Factors
Parts	Positioning	(1) Direction or side from which a single part is assembled (5 levels)
		(2) Size (5 levels)
		(3) Obstacles near the parts (7 levels)
Support parts	Positioning	(4) Direction or side from which a single part is assembled (5 levels)
		(5) Size (5 levels)
		(6) Obstacles near the parts (7 levels)
	Method to assemble parts	(7) Usage of tools (3 levels)
		(8) Clearance (5 levels)
Semi-finished product	Supporting	(9) Unsteadiness (5 levels)
		(10) Unsteadiness of parts (5 levels)
	Movement	(11) Angle of rotation of semi- finished product (4 levels)

4. DEVELOPMENT OF SUPPORT SYSTEM

An information system is developed to support the proposed process for product design. This system is based on the tables that list the relationships between the information related to parts and modules, functions, and manufacturing. In this study, we focus on the development of an information system to simultaneously reference the information about the hierarchical structure of functions and parts information in the BOM.

Java is used for the development of this system. Figure 7 shows the data structure of the system by using an approximate representation of the Unified Modeling Language. In Figure 8, the structure on the left denotes the hierarchical structure of the functions and the structure on the right denotes the hierarchical structure of the parts in the BOM. Here, the elements in the hierarchical structure of the parts in the BOM correspond to the main parts or dummy semi-finished products composed of main parts. In the system, the second label for functions is related to the parts or semi-finished products in the BOM. Since the second label for functions denotes an abstract representation, this relationship is used to create many types of new mechanisms or new parts from the parts or modules under the second label for functions. Levels of factors to evaluate the difficulties of operations are described in Appendix

Figure 9 shows a schematic diagram of the information system display. Data related to a simple robot designed as an educational tool is stored in the system. The list of second labels for functions is displayed after a single element is selected from the list of first labels for functions. Then, the list of third labels for functions is displayed after a single element is selected from the list of second labels for functions. The list of measures and the list of sample parts used are displayed after a single element is selected in the list of third labels for functions. A schematic drawing of the structure and the mechanism constructed by the parts are displayed in the right area of the GUI at the same time. Here, mechanism denotes the structure of parts involving dynamic operation. On the other hand, "structure" means the static structure of parts excluding operation.

The schematic drawing supports the development of ideas for an engineering mechanism using the specific parts and modules. The elements in the list of second labels for functions are related to elements in the BOM. Therefore, the parts or semi-finished products in the BOM needed to realize the selected functions are displayed when a single element is selected in the list of second labels for functions. On the other hand, information can be referenced from elements in the BOM to the second labels for functions.

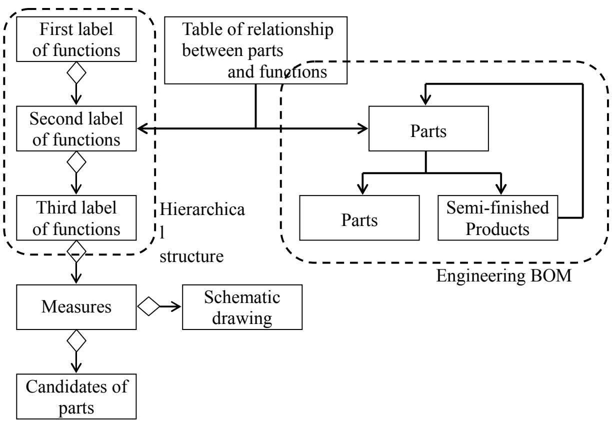


Figure 7. Data structure of developed system.

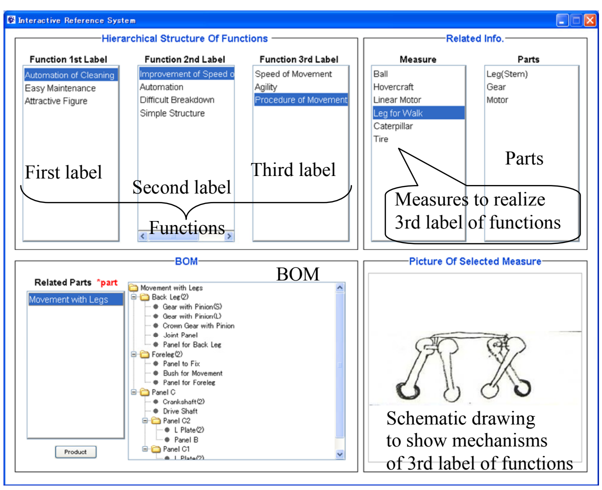


Figure 8. Schematic diagram of developed system display.

In this study, although information about the process design has not been incorporated into the developed system, the relationship between information about the process design and other information can be constructed by using the same data structure as the relationship between the BOM and functions.

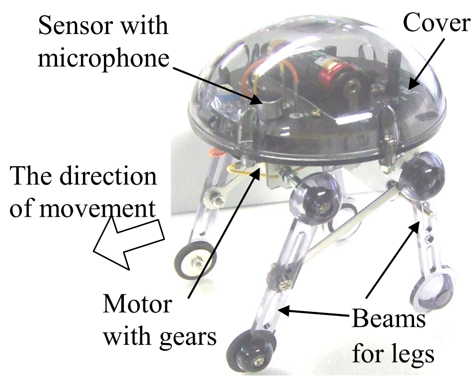


Figure 9. Product used in case study (Medusa II).

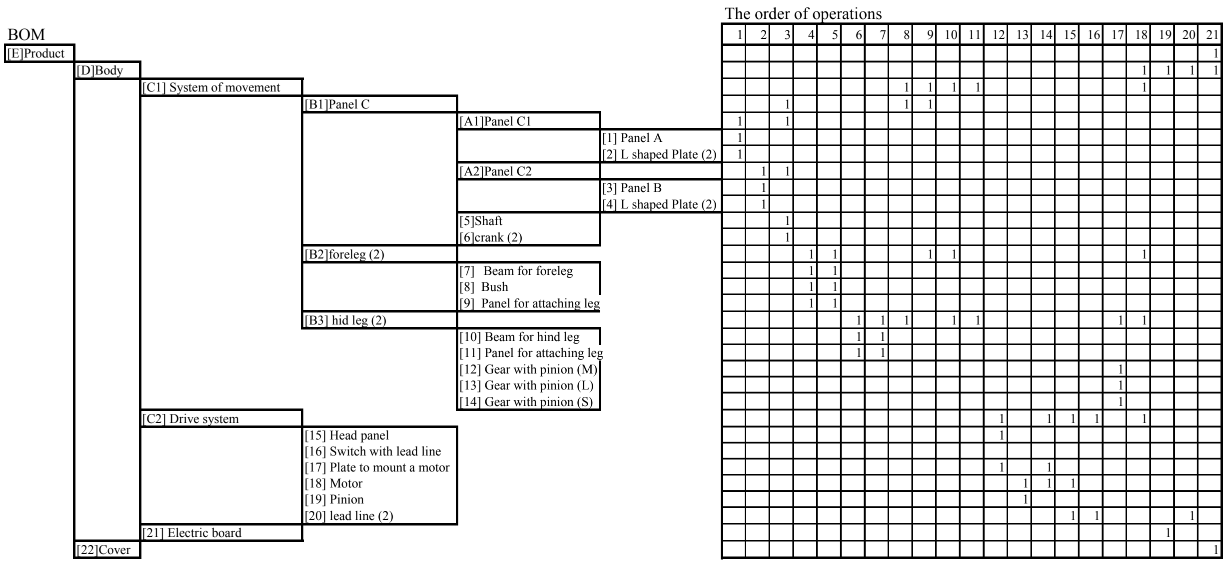
5. CASE STUDY

5.1 Characteristics of Product

In this paper, we will discuss a case study demonstrating the design of an actual product. A robot kit designed as an educational tool for students is used as the actual product in our case study. This product is called "Medusa II (MR-9592)", and is made by the ekey Japan corporation. Figure 10 shows a schematic diagram of the product. Table 3 lists its characteristics, purpose, and functions. Figure 11 shows a reference table for the relationship between the BOM and the assembly process (Figure 10 is on the final page.) In this table, operations are allocated in the columns in the order of the assembled parts. In addition, the parts and semi-finished products used in these operations are assigned to operation numbers in the rows of the table. By referencing the contents of the operations and operation numbers in this table, the difficulties in operations using parts and support parts can be investigated. The support parts are screws, washers, nuts, etc. Here, the robot used for case study is small and simple. Since relationship of parts and functions is simple in the product, the proposed process is easily applied to redesign the product by focusing parts and relationship of parts and functions

5.2 Redesign of Products from Evaluation of Assembly Process

In this section, we try to design a fast robot by modifying the functions of the original robot, Medusa II. The functions to modify are selected from the functions of the original product. Then, original parts to realize the selected functions are extracted by using the multidimensional table. When the selected functions are changed to new functions, the original parts extracted are



Operations

1	install L shaped Plate	11	install guide for hind leg
2	install L shaped Plate	12	install switch and plate to mount a motor
3	install crank	13	hit and insert pinion gear
4	assemble foreleg	14	install motor
5	assemble foreleg	15	connect lead line
6	assemble hind leg	16	Pass lead lines through holes
7	assemble hind leg	17	install gear
8	install hind leg	18	install head panel
9	install foreleg	19	install electric board
10	fix Panel for attaching leg	20	wiring lead lines
		21	install cover

Figure 10. Reference table showing relationship between BOM and assembly process.

modified or new parts are assigned to replace the original parts.

Table 3. Characteristics of original product used in case study.

Purpose	Robot functions learned by students
Functions	(1) Movement: four legs with link
	(2) Non-contact and sensitive switch: sensor for switch reacting to sound
	(3) Protect circuit board
Characteristics of structure	Number of parts: 110 Height: 130 mm Width: 100 mm Weight: 170g Methods of assembly Screw: 13 Insertion: 1

Table 4 lists the main functions and parts used to realize the functions in the original robot. In order to realize the "movement" function (function (1)), a motor with gears and four stems with links are combined and installed in the product. On the other hand, in order to realize the "non-contact and sensitive switch" function (function (2)), a sensor with a microphone is installed in the product to switch the motor. Table 4 is obtained by extracting information about the parts related to the functions from the two-dimensional table representing the relationship between functions and parts.

Table 4. Relationship between functions and parts used for functions in original product.

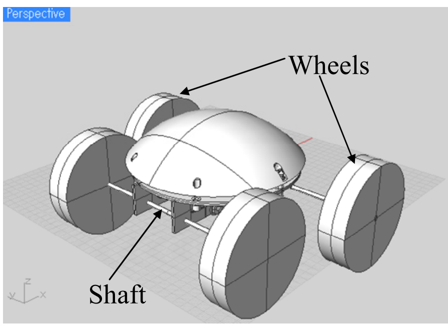
Functions	Characteristics	Parts
(1) Movement	Four legs	Foreleg, Back leg, Plate to guide movement of hind leg
	Link structure	Foreleg, Back leg, Panel to connect legs, Plate to guide movement of back leg, crank
	Power drive	Motor, Gear, Shaft
(2) Non-contact and sensitive switch	Switch reacting to sound	Sensor with microphone, Circuit board
(3) Protect of electric board		Sphere-shaped cover

In this case study, function (1) is changed to a "rapid movement" function to redesign the original product. From the two-dimensional table, the following parts are extracted as parts to realize function (1): beams with links for forelegs, beams with links for hind legs, a panel to connect the legs, a plate to guide the movement of the hind legs, and cranks. These parts are removed from the original product for redesign. To realize the "rapid movement" function, the following characteristics of the function are considered: (a) simple structure,

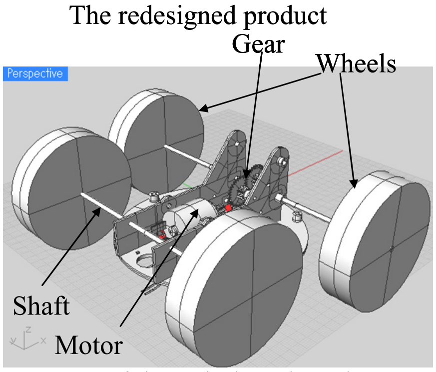
(b) stability of the product in the moving process, and (c) reduction of the number of parts.

Table 5. Comparison of difficulties of operation process for every factor between the designed product and the original product: the numbers in round blankets indicate the factors of the difficulties and correspond to the factor numbers in Table 2.

Factors for operation difficulty	All operations		Operations related to modified parts	
	Original Product	Designed Product	Original Product	Designed Product
(1)	0.75	0.58	0.87	0.40
(2)	0.48	0.45	0.47	0.52
(3)	0.47	0.51	0.19	0.14
(4)	0.58	0.41	0.79	0.00
(5)	0.66	0.65	0.69	0.00
(6)	0.39	0.40	0.38	0.00
(7)	0.43	0.41	0.41	0.33
(8)	0.35	0.38	0.30	0.36
(9)	0.32	0.27	0.39	0.20
(10)	0.46	0.38	0.51	0.25
(11)	0.68	0.62	0.78	0.00



The redesigned product



A part of the redesigned product

Figure 11. Schematic diagram of product redesigned by evaluating assembly process.

A wheel drive function is adopted to satisfy these characteristics in this redesign. Therefore, four wheels are introduced and shafts are used to connect the wheels. Figure 12 shows a schematic diagram of the redesigned product. The shafts and the motor with gears are used in the redesigned product, which are parts used in the original product. This redesign causes a reduction in the number of operations from 21 to 17. Table 5 shows a comparison of the resultant levels for the difficulty of operations in categorized factors between the original product and the redesigned product. These values for the levels are the averages of non-dimensional values for the measured levels divided by the maximum levels. The numbers in round blankets correspond to the factor numbers in Table 2. Because the parts introduced for redesign have simple structures and are connected in simple and easy ways, this table shows that the difficulty of operations is reduced for factors (4), (5), and (6).

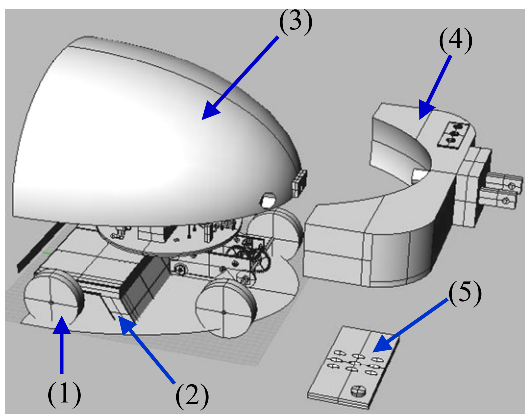


Figure 12. Schematic diagram of product redesigned by considering hierarchical structure of functions.

5.3 Design of Products Using Hierarchical Structure of Functions

In this section, we try to design a robot for cleaning the floor by modifying the functions of the original robot, Medusa II. Table 6 lists the hierarchical structure of the functions considered for redesign from the original robot and the parts related to these functions. As for the original robot, it is necessary to construct a database to list the relationship between the functions and parts and the hierarchical structure of the functions by using the information obtained from previous design experience. In order to design the robot for cleaning, “automatic cleaning”, “easy maintenance”, and “attractive appearance” are selected as requirements for the first labels of functions. The second or third labels for functions related to these requirements are investigated, and engineering mechanisms or measures, and parts are created to realize these requirements considering the label information. Furthermore, the engineering mechanisms or measures, and the parts created are exchanged and modified into parts or modules from the original product. From the second or third labels of functions related to the requirements, the following functions are selected to realize the automatic cleaning function:

(1) The structure of four legs is exchanged for a four wheel system based on the second and third labels

for the movement function considering the third label for the functions and engineering measures: Part (1);

(2) A vacuum device for dust and a small garbage can are added to the original product as engineering parts and mechanisms to realize the functions “vacuuming of dust” and “easy removal of dust collected” (Part (2)).

(3) The egg-shaped cover is exchanged for a spherical cover, and a sensor, to recognize hitting an obstacle, is added to the top of the cover as an engineering part and mechanism to realize the functions “automatic recognition”, “covering of electric plate”, and “attractive appearance” (Part (3)).

(4) A battery and a plug for charging it are added to the original product as engineering parts to realize the functions “convenient to use” and “charging of battery” (Part (4)).

(5) A remote controller is added to the original product as an engineering part to realize the functions “convenient to use” and “remote control” (Part (5)).

After these modifications, the redesigned product comprises 19 parts. On the other, the original product comprises 13 parts. Figure 13 shows 3D diagrams of the redesigned product and the original product. Here, the numbers pointing to parts in Fig. 13 correspond to the parts numbers explained above.

Table 6. Relationship between hierarchical structure of functions considered to redesign the original product and parts used for functions.

Functions		
First label	Second label	Third label
Automated cleaning	Rapid movement	Method of movement
		Speed
		Smooth
	Vacuuming of dust	Vacuuming
	Automation	Convenience
		Non-contact control

Third label of functions	Measures	Parts	Characteristics
Method of movement	Wheel	Wheel, Tire, Motor, Gear	Simple structure, High speed
	Caterpillar	Motor, Gear, Caterpillar	Easy movement on coarse floor, Complex structure
	Ball	Motor, Ball, Frame to fix a ball	Smooth movement, Difficult power transfer
	・・・・	・・・・	・・・

6. CONCLUSION

This paper proposed a redesign process for new products that utilizes information related to the design and manufacturing of existing products. The proposed process involves a process to design products by evaluating the operation process by modifying specific parts or modules in existing products. The process can realize originality (c) shown in the introduction. In addition, an information system was developed to support the proposed process. This system is based on tables that list the relationships between the information related to parts and modules, functions, and manufacturing. This system involves data structure for evaluation of difficulty of assembly process. Originality (a) and (b) are realized in the system. Furthermore, the graphic user interface is developed to generate new ideas of structure of parts and mechanism from abstract functions to realize originality (d). A case study to apply the proposed process to design a new product was also shown using a simple structural robot designed as an educational tool to show originality (e).

In a future study, the proposed process should be adopted to design complex and large scale products in order to evaluate its effectiveness. In addition, the hierarchical structure of functions should be expanded by categorizing their characteristics in accordance with environmental conditions to adopt functions. Although cost is one of the significant measures for redesign, the construction of data structure to evaluate cost for redesign with operation difficulties should be discussed in the future study.

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APPENDIX

In this appendix, measured levels for some factors responsible for operation difficulty in assembly process are presented. The categorization and the factors were determined from discussions with workers who assembled actual products.

Figure 13 and Table 7 show the standard levels of difficulty associated with the direction of assembly of a single part or support parts into a semi-finished product; the difficulty corresponds to the category "positioning", (1) and (4) in Table 2. When the aspect of a semi-finished or finished product set in front of a worker is predetermined, the difficulty of operation can be evaluated by determining the direction of assembly of a single part. Here, the standard levels were predetermined under the assumption that the dominant hand is the right hand.

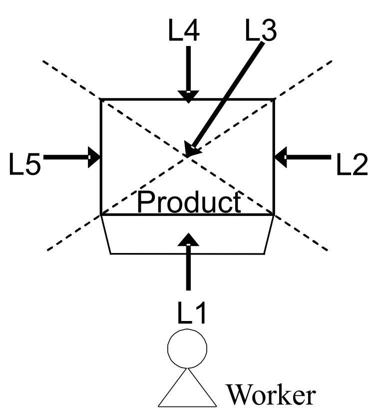

Figure 13. Schematic diagram of standard levels of difficulty related to the direction of assembly or side from which parts are assembled (Table7).

Table 7. Levels of difficulty associated with the direction or side from which parts are assembled (Figure 13).

Level	Standards
1	Parts assembled from the front side of a worker into the front side of a product
2	Parts assembled from a worker's dominant-hand side to the opposite side; for example, when the worker's dominant hand is the right hand, the parts are to be assembled from the right side to the left side of a product
3	Parts assembled from the upper side of a product
4	Parts assembled from the back side of a product
5	Parts assembled from the side opposite to a worker's dominant-hand side to his/her dominant-hand side; for example, when the worker's dominant hand is the right hand, the parts are to be assembled from the left side to the right side of a product.

Figure 14 and Table 8 show the standard levels of difficulty associated with the unsteadiness of a semi-finished product; the difficulty falls under the category "support", (9) and (10) in Table 2. If a semi-finished product is unsteady when a single part is being assembled into it, a worker would need to provide additional support to the product, which can be viewed as a difficulty in operation. The levels of the difficulty related to the unsteadiness of a semi-finished product for the case given above were predetermined. In addition, the levels of other types of difficulties associated with the unsteadiness of a semi-finished product are predetermined on the basis of the direction in which a part in the semi-finished product can move when a single part is assembled into the semi-finished product.

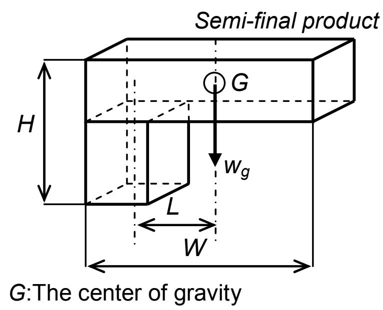

Figure 14. Schematic diagram of the standard levels of difficulty related to the unsteadiness of a semi-finished product (Table 8).

Figure 15 and Table 9 show the levels of difficulty associated with the presence of an obstacle during the assembly of a single part or support parts into a semi-finished product; this difficulty falls under the category "positioning", (3) and (6) in Table 2. The standard levels were determined by considering the distance between the position where the part was to be assembled and the obstacle and its relationship with the ratio of the size of the part to that of the obstacle. The size of a hand was used as the unit of measurement to determine the standard levels. If the distance between the obstacle and the part was smaller than the size of the hand, the operation to assemble the part was considered difficult. On the other hand, if the distance was larger than the hand, the obstacle doesn't affect the operation to assemble the part. The number of levels of difficulty for other factors is given in Table 8.

Table 8. Levels of difficulty associated with the unsteadiness of a semi-finished product (Figure 14).

Level	Standard support conditions for a semi-finished product
1	Semi-finished product does not require the support of a worker
2	Semi-finished product needs to be supported by a worker with his/her fingers
3	Semi-finished product needs to be supported by a worker with his/her hands
4	Semi-finished product needs to be supported by a worker with his/her arms
5	Semi-finished product needs to be supported by a worker with his/her body

Relationship between the levels and the physical structure			
($Se < S_0/10$) OR ($Se < S_0/2$ AND G is located outside Se)			
Level	Category	Level	Category
2	C1	4	C3
3	C2	5	C4
($S_0/2 < Se < S_0$) OR ($Se < S_0/2$ AND G is located in Se)			
Level	Category	Level	Category
1	C1	3	C3
2	C2	4	C4

Category	Condition (unit: mm)
C1	(H < 10) AND (W < 10)
C2	((10 < H < 50) AND (W < 50)) OR ((H < 50) AND (10 < W < 50))
C3	((50 < H < 150) AND (W < 150)) OR ((H < 150) AND 50 < W < 150))
C4	(H > 150) OR (W > 150)
Se	Area of contact of the product with the ground
S_0	Area of the ground onto which the product is projected

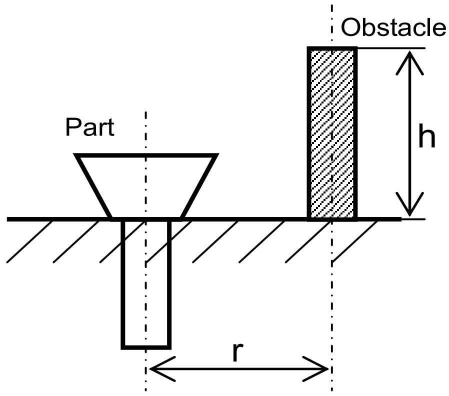

Figure 15. Schematic diagram of the standard levels of difficulty associated with the presence of an obstacle during the assembly of a single part or support parts (Table 4).

Table 9. Levels of difficulty associated with presence of obstacle in the vicinity of parts (Figure 15).

Level	Standard conditions for the assembly of a single part
1	Obstacle does not affect assembly process (r > 400 mm OR r > h)
2	Obstacle does not affect a worker's handling of the assembly (r > 200 mm)
3	Obstacle affects a worker's handling and the range affected by the obstacle is as large as the worker's hand (r > 100 mm)
4	Obstacle affects the movement of a worker's fingers during assembly (r > 50 mm)
5	Obstacle hinders the movement of a worker's fingers during assembly. Since the movement of the worker's fingers is restricted by the obstacle, he/she needs to perform additional movements to remove the obstacle (r > 30 mm)
6	Obstacle affects the movement of the tip of a worker's fingers during assembly (r > 10 mm)
7	Obstacle hinders the movement of the tip of a worker's fingers during assembly (r < 10 mm)