APPLICATION OF FUNCTIONAL ELEMENTS TO THE CONCEPTUAL DESIGN OF INNOVATIVE HUMAN-POWERED VEHICLES

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ABSTRACT
The purpose of this paper is to propose a simple and quick process for creating new design concepts for human-powered vehicles. First, the design theme for an innovative bicycle is described. Next, the functional elements of the bicycle are selected according to the contents described in the design theme. Based on the design requirements, various spatial arrangements of the creative functional elements are produced. In the final step, we followed the flowchart of the creative functional elements constructed by this research and demonstrated a case study design.

Keywords: functional element; human-powered vehicle; bicycles; creative design.

APPLICATION D'ÉLÉMENTS FONCTIONNELS À LA CONCEPTION D'UN MODÈLE INNOVATEUR DE VÉHICULE À PROPULSION HUMAINE

RÉSUMÉ
Le but du présent article est de proposer un procédé de conception simple et rapide pour la création de nouveaux concepts pour des véhicules à propulsion humaine. En premier lieu, nous décrivons le thème de conception pour un modèle innovateur de bicyclette. Ensuite, les éléments fonctionnels sont sélectionnés selon la composition déterminée dans le thème. En se basant sur les exigences du concept, différents arrangements de la disposition spatiale des éléments fonctionnels sont produits. Enfin à l'étape finale, on a fait le suivi de la disposition des éléments créatifs fonctionnels construit pour cette étude, et on en a fait une étude de cas.

Mots-clés : éléments fonctionnels; véhicule à propulsion humaine; bicyclettes; conception créative.

1. INTRODUCTION

Designing in a black box is very common in practical design [1]. However, this method is not popular in the academic field. In this study, we have analyzed the functional elements and attempted to create new design concepts for innovative bicycles without using the black box. Every innovative bicycle has one or more creative characteristics. Every creative characteristic is associated with a functional element. We can arrive at a new and creative bicycle by integrating several product functions together in our design.

This study proposes a simple creative design method that introduces a concept for rapidly producing bicycles with highly creative functions. At present, the methods used for designing bicycles lack analyses and innovation, which limits the development of creative concepts. This paper is intended to help designers to produce creative design concepts in a short time by applying functional elements. In this study, the functional elements of 242 award-winning bicycles in bicycle design competitions were selected and the creative design method using functional elements was applied to create innovative designs for bicycles. The analysis of functional elements can allow beginners and future designers of this field to shorten the design time and rapidly develop versatile bicycles with highly creative functions.

2. LITERATURE REVIEW

Generally, the definitions of bicycles can be defined into three categories: extensive definition, narrow definition, and intermediate definition. The extensive definition is generalized in nature and covers future prospects and possible advancements in the product, and does not refer to the constraints of the current form of bicycles. The narrow definition is constrained by the currently used description of the bicycle architecture. The intermediate definition is an extension of the narrow definition and includes the scope for advancement and enhanced application of the present form of the bicycle. The above three definitions are briefly described as follows:

1. Extensive definition: A vehicle that carries people and is driven by human power.

2. Intermediate definition: All bicycles and exercise bikes that do not move forward on tracks regardless of the number of wheels and the structure.

3. Narrow definition: The currently used formal requirements as specified in CNS B1340 for bicycle definition. The bicycles referred to by the requirements are vehicles that move forward by human force. These vehicles also satisfy the following regulations:
   (a) The vehicular structure has sufficient durable strength.
   (b) The vehicle has two or more wheels.
   (c) The rider of the vehicle has his/her/their seat(s).
   (d) The vehicle has various driving, operating, and braking devices.

Apart from the above definitions, there are several other definitions such as those based on principles of mechanics and art, and those specified in the encyclopedic dictionary. The nature of these explanations is similar to the above three definitions [2]. The design method used in this study adopts the intermediate definition for bicycles in an attempt to avoid a very narrow definition and to allow creative designing. Accordingly, the human-powered vehicle is included in this research scope.

Liu and Wu [3] have proposed the representations for bicycle characteristics but the process for bicycle design is not mentioned in the study. This paper proposes a symbol representation system using which elements of the bicycles can be represented simply and quickly and innovation designs can be created.

Ke [4] considers a bicycle to be a module product. Therefore, in terms of design and combinations of spare parts and components, four factors can directly affect the differences in class and price of the bicycle: function, material, appearance, and manufacturing quality. The study also mentions that in research and development, the three new values corresponding to the indexes of material, function, and purpose can be used to define a new product. Therefore, function and material are very important factors in the creative designing of bicycles.

In the study performed by Ma et al. [5], it has been proposed that module design is the concept of introducing a part/component module into the design process and simplifying and organizing various components/parts by application of a systematic method. Doing this can increase the functional performance and adaptability of bicycles to satisfy the application requirements. This study disintegrates a bicycle into various element component modules with each component representing one function. Accordingly, a component can also be regarded as one functional element.

The study by Hung [6] divides a bicycle into five components, which are frame structure, front and rear suspension mechanisms, steering handler, and seat, for engaging in conceptual designing. The outcome of his study was a concrete integral design that integrated various systems by applying a morphological matrix. A shortcoming of this study is that because the design proposed in it divides a bicycle into five components, it reduces the definition of bicycles into a narrow one, which often limits the design results and renders an unfavorable impact on the creative design. In his study, he has proposed that the future development of bicycles can be divided into five categories: (1) Use of new materials, (2) Addition of new functions, (3) New ways of riding, (4) Introduction of new electronic products, (5) Dedicated products developed depending on the individual market requirements. In his research Hung proposed that the addition of new functions is an indispensable factor in the creative design of bicycles in the future. Thus, it is very important to place greater focus on the choice and integration of new functional elements in the design process.

Ji [7] has categorized the spare parts/components of a bicycle into the following six major systems according to function: (1) Transmission system, (2) Steering system, (3) Wheel system, (4) Braking system, (5) Vehicle frame structure system, and (6) Gear system.

Chang [2] categorized the functions of a bicycle into seven major systems based on the composition: (1) Transmission system, (2) Steering system, (3) Wheel system, (4) Braking system, (5) Structure system, (6) Fitting system, and (7) Accessory system.

3. DESIGN METHOD

3.1. Representation of Functional Elements

We performed a functional analysis by defining the various functional elements of the bicycle as shown in Table 1. Each functional element is represented by a unique symbol. The process for transforming a bicycle into a symbolized representation is suggested below:

1. Take a picture of the bicycle.
2. Identify the functional elements of the bicycle.
3. Assign symbols for every functional element of the bicycle.
4. Check and note the correlations between every pair of functional elements.

Using the above process, every bicycle can have its own symbolized representations for its functional elements.

Because bicycles are typical cases of human-powered vehicles, this research collected 242 award-winning designs of bicycle products from bicycle design competitions [8]. The award-winning bicycle designs were

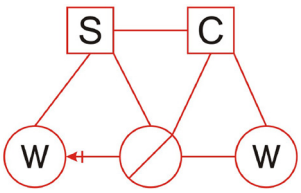

Fig. 1. Functional element representation of a normal bicycle.

sorted based on year, sequence order, and serial number into a comparison table containing the functional elements. The bicycles were preliminarily categorized into "standard" and "specific" categories. The standard category was a normal bicycle category and included designs that were similar in structure to commercially available riding bikes with minor changes in appearance and style. The bicycles included in the specific category were comparatively different from the commercially available riding bikes in structure and functions. For example, they may be contractible, have different provisions for storage, or possess additional/fewer functions compared to the standard category of bikes. The batch number for addition of function P can be known in the categories of standard and specific types. The addition of function P shows the addition and subtraction change for many bike designs. Therefore, we have assigned serial numbers P01, P02, P03, and so on in our analysis process.

We disintegrated and analyzed the creative functional elements of the award-winning designs using the method given above. Then, we sorted them based on their creative functional elements as shown in Table 1.

Taking a normal bicycle as an example, we identified various functional element symbols on the bike and then, connected and defined the relationship between the various functional elements. Under normal circumstances, we use a solid line to show the connection between various functions when the corresponding functional elements are inseparable. The solid line indicates their direct connection. We use a solid line with an arrow when it is indirectly driven by a chain-like object. The arrow points at functional elements from the rider end. A functional element representation is shown in Fig. 1.

3.2. Design Process

After building Table 1, the design process for bicycles and human-powered vehicles is performed. This process involves seven steps as shown in Fig. 2.

In step 1, the designers describe the design theme. The theme is decided by the design requirements or constraints. A designer may choose one or more existing bicycles that correspond to the theme for development. The design characteristics were collected by analyzing the existing bicycles.

In step 2, the existing bicycles are symbolized by creative functional element representations.

In step 3, the symbolized bicycles are generalized. The original representation of every symbol in the symbolized bicycles is meaningful. They are changed to non-meaningful symbols by generalization. All elements will be represented by circles and all connected relationships will be represented by straight lines.

In step 4, different topologies obtained from the generalized bicycles and from various combinations of the functional elements can be used for designing. Thus, the atlas of the generalized bicycle is obtained.

In step 5, every non-meaningful symbol in the atlas of the generalized bicycle is sequentially assigned a creative functional element by specialization. Design requirements and constraints are considered simultaneously during the assigning process. The atlas of a feasible specialized bicycle is obtained in this step.

In step 6, the feasible specialized bicycle is particularized. The form of all the bicycles can be observed easily.

In step 7, an innovative bicycle is obtained by deleting the existing bicycle from the atlas of feasible bicycles obtained in step 6.

Table 1. Functional element table of bicycles.

Symbol	Name	Meaning and Description
	Driven by direct power	Indicates that the source of power is integrated into the vehicle. For example, pedals are directly attached to the wheel without chain to transmit the driving force.
	Driven by indirect power	Indicates that the driving force is transmitted by another body. Most frequently, the chain transmission is the indirect driving force.
	Control	Generally indicates that the steering system is controlled by hand.
	Single wheel	One wheel.
	Double wheels	Two wheels in horizontal arrangement or a combination arrangement.
	Seat	Place for people to sit.
	Driven by human power	Human force is the main source of power and chain mechanism is used for power transmission.
	Driven by electricity	Vehicle is driven by electric power.
	Driven by human sliding board	With human power as the main power source and with a sliding board mechanism as the driving force.
	Driven by spring force	With human power as the main power source and with spring mechanism as the driving force.
	Direct linkage	Hardware and functional element(s) are connected together and cannot be removed.
	Functional linkage that can be removed and changed	Can be detached, removed, or the connection can be changed.
	Integration of functions	The integration of two functions gives the bike the appearance of a single vehicle.
	Contractible	The bike can be downsized or its shape can be changed.
	Light	Illuminating device that cannot be removed from the bike.
	Basket	A carriage basket in square or oval shape.
	Basket (with wheel)	A carriage basket in square or oval shape and fitted with a wheel.
	Tent	Vehicle carries a camping tent.
	Hand-use torch light	Illuminating device that can be removed from the bike.
	Snowboard	A thin board for use in snowy ground.
	Backpack	A bag that can be carried on the back by the rider.
	Wing canvas	A canvas device to provide power and steering control
	Connectivity to another vehicle	Can integrate with another bike and provide normal function when additional function is added.
	Storage shelf	A shelf for holding articles.
	Storage bag	A bag for carrying articles.
	Pet shelf	A shelf for pet to exercise and rest.
	Pushing handler	For pushing the bike forward when equipped.
	Solar energy board	A device that can generate electric power by solar energy.
	Safety helmet	A wearable device to protect the rider from head injuries.
	Electric mileage meter	An electronic device with an LED screen.
	Air-pumping device	A device to pump air into the tires of the bike.
	Bike wall mount rack	A shelf that allows the bike to be mounted on the wall when not in use.
	Camping device	Necessary camping devices such as hard roof tent and illuminating device.
	LED	LED light for visibility and decoration purposes.
	Rear view reflection mirror	A mirror that allows a rider to see the back view without turning his/her head backward.

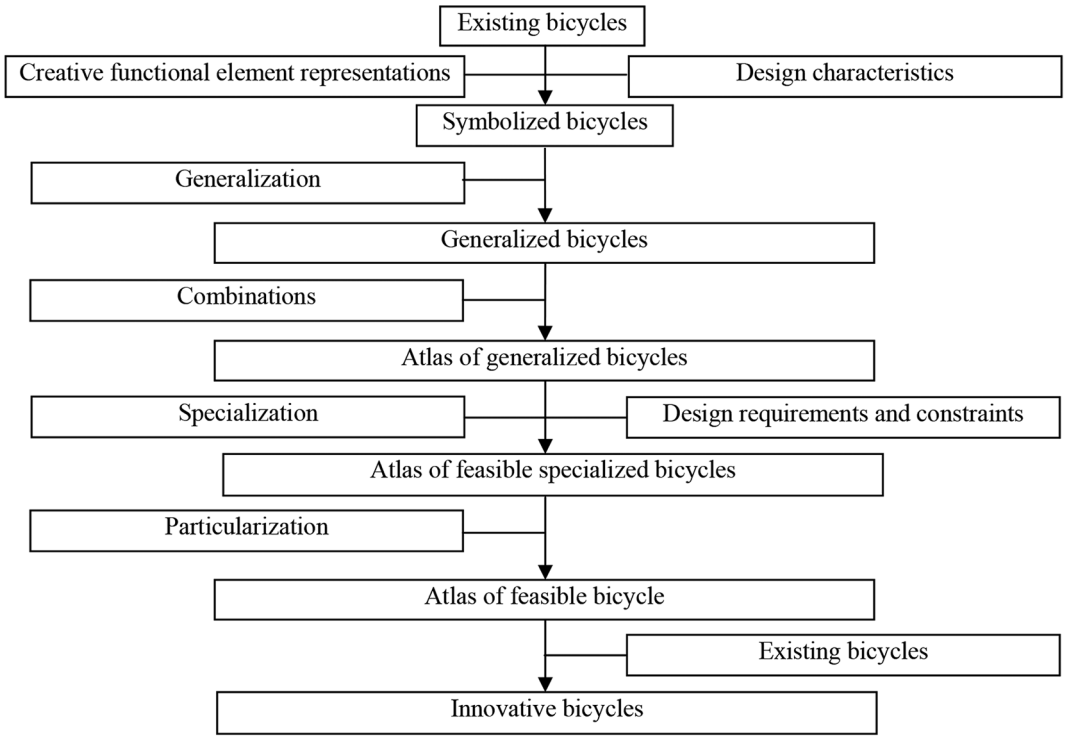

Fig. 2. The design process using functional element representation.

4. CASE STUDY

The design theme of the prototype design is called "A Common Life Form".

In step 1, the description of this design is stated as follows: "Two people ride on a bicycle in a face-to-face position. We have provided rear view reflection mirrors for steering control and to ensure mutual understanding and trust".

The bike described in the design theme does not differ significantly from the standard bike structure. This example only specifies a special need for rear view reflection mirrors. Therefore, the existing bicycle is a vehicle with two reflection mirrors.

In step 2, an attempt is made to obtain the symbolized bicycles but no existing bicycle fits this design theme. Considering the theme, we need two pairs of wheels, controls, a bicycle driven by human power, and two reflection mirrors. Thus, there are six elements here.

In step 3, the notations in the circles or squares must be erased for generalization and all lines are changed to straight lines. The six elements become six circles.

In step 4, the atlas of the generalized bicycle is obtained from step 3 using various combinations of the elements. There are many combinations for the six circles and 1 to 7 straight lines.

In step 5, we try to assign a meaningful notation to the circles and straight lines from step 4.

In step 6 and 7, the infeasible concepts are deleted and 18 feasible concepts are obtained as shown in Fig. 3. Here, concept D is chosen as an example for particularization.

We created the designs for the external appearance by applying creative functional elements. This research directly used the CAD software to perform the creative design for the development of external appearance. The control method adopted designs similar to a human-powered vehicle on the railroad track as shown in Fig. 4. The rear view reflection mirrors was attached to the cover of the wheels.

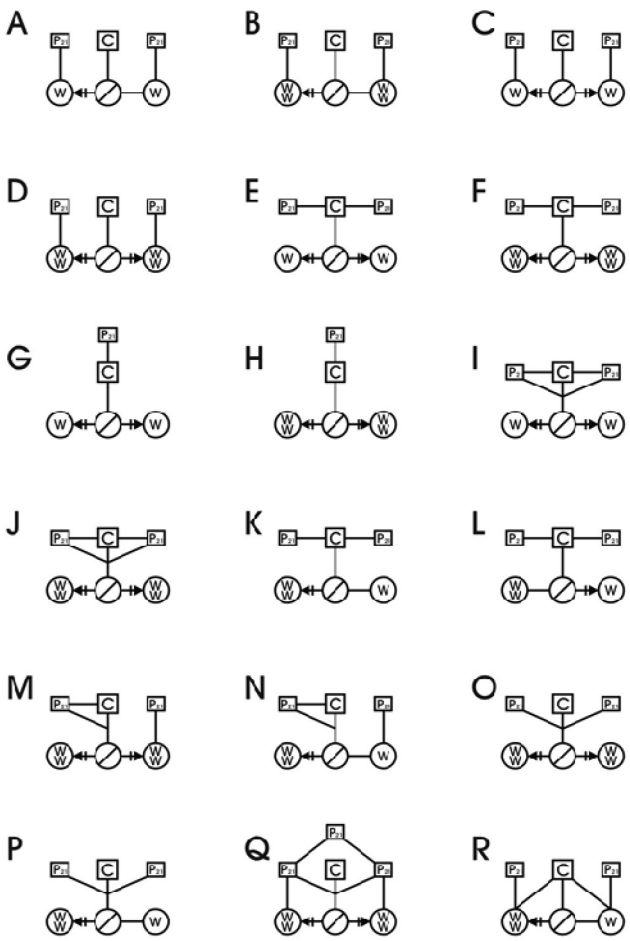

Fig. 3. Feasible bicycle designs.

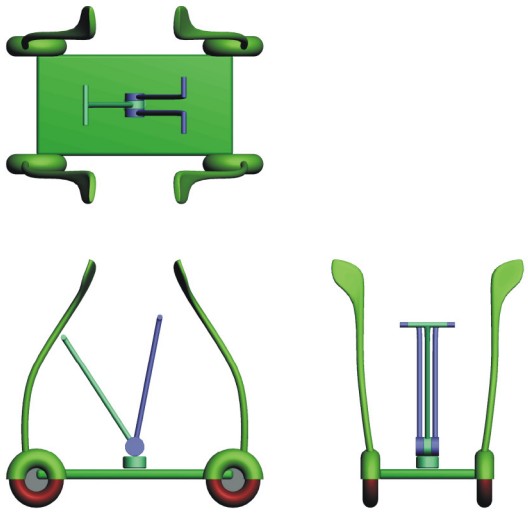

Fig. 4. Three views of the design concept D.

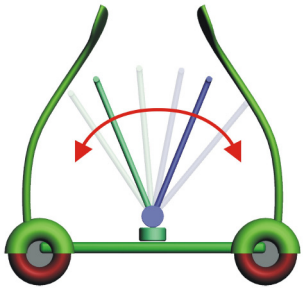

Fig. 5. Bike driven by human force.

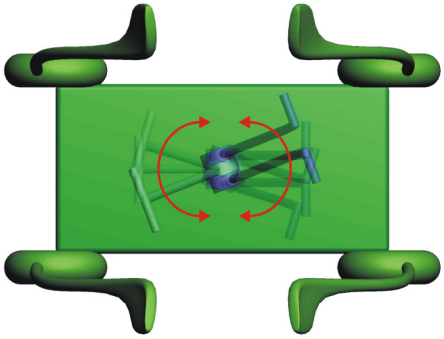

Fig. 6. Steering of the bike.

Fig. 7. 3D simulation drawing of the creative design of the bike.

The bike can be made to move forward by two people who repeatedly press the pedal from up to down. This movement allows the transmission power to transmit the driving force to the wheels as shown in Fig. 5.

The direction of the bike can be changed by rotating the control system of the transmission power. The change in direction of the bike is shown in Fig. 6. Figure 7 shows a 3D simulation drawing of the design concept.

5. CONCLUSIONS

The method proposed by this research uses functional element analysis as the basis for the construction of functional element symbols. The advantage of this method is the possibility of creating multiple concepts easily. Obtaining a greater number of functional elements can enable designers to create more design concepts. The disadvantage of this method is the complexity of the relationships between functional elements. The representation of the combination of functional elements is easy but the practical rationality needs to be considered rigorously.

Using the method, we have generated 35 elements in this paper. We have come up with 18 combinations from A through R by selecting functional element symbols according to the description of the design theme following the creative design process. We then specifically selected Item D as the design example in the case study related to functional spatial arrangement of the design elements. The method proposed in this study is expected to promote the design of innovative human-powered bikes and will be especially useful to beginners by facilitating the easy and quick designing of vehicles.

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