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ORIGINAL ARTICLE

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A case-based reasoning approach to generating new product ideas

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Abstract This paper presents an approach to facilitate the generation of new product ideas. In this approach, a product is represented by a vector, which involves a number of product attributes. These attributes are defined based on the user-centered design (UCD) paradigm. That is, the context of use and interactions with users for the product is described by these attributes. By the product representation, a product database can be established. For a benchmarking product, we use the case-based reasoning (CBR) technique to retrieve those products, which are "*sufficiently relevant*" to the benchmarking one, from the database. The functions of the retrieved products are the candidate new ideas to be added on the benchmarking product. These retrieved products are screened manually to identify creative and valuable ideas. A prototype system of this approach has been implemented. Experiments show that the proposed approach outperforms the brainstorming technique, which has been widely used in industry.

Keywords User-centered design · Case-based reasoning · New product development · Product attributes

1 Introduction

In this competitive era, the product life cycle is getting shorter and shorter. New products have to be constantly developed and timely placed to market. Enhancing the productivity of new product development is therefore a very important issue.

The tasks of new product development can be categorized into four stages [1]. The first stage involves the idea exploration of new products; that is, which new functions shall be included for a particular product. The second stage is to screen and rank the new ideas, generated in the first stage, according to their potential market capacity. The third stage is to design the prototypes for the selected ideas. The fourth stage is to perform a marketing test for the new products to get customers' feedbacks.

Among the above four stages, the first stage—*idea exploration*—is the most important because the other three stages are essentially to justify the effectiveness of the new product ideas. Therefore, how to create good and new ideas is a critical factor for successfully developing new products. In creating new ideas for products, designers often use *creative problem solving (CPS) techniques*. More than one hundred CPS methods have been developed [2]. Among these CPS techniques, the brainstorming method proposed by Osborn [3] has been most widely used in industry [4].

Using the brainstorming (BS) method for generating new product ideas has three drawbacks. First, the BS method in nature is developed for a team and not suitable for an individual. Second, the performance of the BS method highly depends on the capacities of team members. Third, the BS method facilitates team members to generate new ideas through a *free-association* mechanism. The mechanism is not customer-oriented or user-centered. Therefore, some ideas good for users might be ignored in the BS method.

Kankainen and her team use a user-centered design (UCD) paradigm to generate new product ideas [5]. In their UCD approach, they first analyzed the demands of users. Based on the users' demands, a "social map" is drawn to illustrate the scenario of using products. Based on the social map, two designers emulate the activities of users and create new product ideas by discussion. The social map approach is essentially a *human-based* approach. The quantity and quality of new product ideas, in a human-based approach, are undoubtedly limited by the capacities of designers.

To overcome the above drawbacks, this research proposes a computer-aided technique to create new product ideas. Based on the UCD paradigm, a product is represented by a vector consisting of 87 elements. Each element represents a product attribute, which relates the product to users from a user-centered perspective. By such a product

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representation scheme, a large amount of products are coded in vectors and stored in a database. To create new ideas for an existing product (called *benchmarking product*), we use the case-based reasoning (CBR) technique to retrieve other products that are "*sufficiently relevant*" to the benchmarking product. The functions of the retrieved products are the candidate new ideas to be added on the benchmarking product.

The remainder of this paper is organized as follows. Section 2 reviews the literature on brainstorming (BS) techniques, user-centered deign (UCD), and case-based reasoning (CBR). Section 3 introduces the product representation scheme. Section 4 describes how to create new product ideas by using the proposed approach. Section 5 uses two benchmarking products to compare the performance of the proposed approach and the BS technique. Concluding remarks are presented in Section 6.

2 Relevant literature

This section briefly describes the basic idea of brainstorming (BS) and its applications to product innovation. Applications of user-centered design (UCD) and case-based reasoning (CBR) techniques are also presented.

2.1 Brainstorming

The basic idea of the BS technique is to provide an *encouraging* and *inspiring* environment for facilitating a team of participants to generate new ideas [3]. The *encouraging* environment is established by temporarily withholding any criticisms on the new ideas raised by the participants. The *inspiring* mechanism is achieved by encouraging the participants to modify, extend, or associate the ideas raised by others. Only at the end of a BS process, the new ideas thus generated will be sorted and evaluated.

According to two empirical surveys [6, 7], the BS technique, compared to some other idea generation techniques, has received the highest awareness and has been most widely used in industry. For the processes of developing new products, the BS technique is mostly used in the stage of generating new product ideas [6]. A comprehensive review of brainstorming literature has been presented by Isaksen [4].

2.2 User-centered design

User-centered design (UCD) had its origins with the seminal work of Norman and Draper [8]. UCD has been defined as "a philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable" [9]. The basic idea of UCD is to explore the *context of use* for the design of a new product in order to enhance the product usability [10].

The process of implementing UCD has been developed by much literature [11, 12]. The ISO 13407 standard also provides a framework for applying UCD [13]. According to the standard, the following four UCD activities need to start at the earliest stage of developing a product: (1) understand and specify the context of use, (2) specify the user and organizational requirements, (3) produce design solutions, and (4) evaluate designs against requirements.

UCD has been widely used in industry [10, 14] and two handbooks have been published [15, 16]. Some example applications of UCD involve the design of modern microelectronic products [12], the design of a website [17], the design of a user interface of a welding machine [18], the user-interface design of a chemical process [19], the design of software [20], and the design of new product concept [5] as discussed in Section 1.

2.3 Case-based reasoning

Case-based reasoning (CBR) is the process of using past cases to solve the new problem case [21–23]. The basic idea of CBR is to retrieve the past cases that are *similar* enough to the new case. These retrieved past cases and their associated solutions are then used to develop the solution of the new case. Two survey papers of CBR can be referred in [24, 25].

A CBR system involves the following three components: (1) a case representation scheme, (2) a similarity metric, and (3) a case-retrieval mechanism. A case representation scheme is to model a case by a set of attributes, which are intended to characterize the case for a particular application. A similarity metric is designed to measure the similarity between any two cases that are described by the case-representation scheme. A case-retrieval mechanism is to retrieve the past cases that are similar to the new case, according to a predetermined similarity threshold.

CBR has been applied in a wide variety of design problems [26]. A review paper on the application of CBR to architecture designs and mechanical designs has been published [27, 28]. In the domain of product design and development, CBR has been applied to retrieve existing product data or product design [29, 30], to manage the assignment of physical structures to the functions of a product [31], to integrate the structure–behavior–function model of products [32], to develop a decision support tool for product design in a concurrent engineering environment [26].

The previous CBR studies relevant to product design focus on the engineering aspect. That is, given a product idea (a functional requirement), they investigated how to apply CBR to effectively and efficiently develop a design for fulfilling the functional requirement. Yet, how to apply CBR to create new and meaningful functional requirements is rarely studied.

3 Product representation

In this research, a product is modeled by a vector consisting of a number of product attributes. Based on the paradigm of

UCD, these product attributes are developed from five dimensions: (1) *interface modality*, (2) *task*, (3) *physical feature*, (4) *environment*, and (5) *user*. These five dimensions are further deployed into 20 groups (or called sub-dimensions) that are subsequently used to yield 87 attributes (Table 1).

3.1 Interface modality

The first dimension—*interface modality* is to identify the *medium* through which the product interacts with the user. Here, the medium denotes a particular portion of the user's body. This research classifies the interface modality into three groups: (1) *sensory modality*, (2) *response modality*, and (3) *positioning location*.

Sensory modality denotes the mediums or sensors through which the user *receives* the messages sent from the product. In modeling the sensory modality, the following five human sensors are taken as product attributes: (a) visualization(or sight), (b) audio (or hearing), (c) gustatory (or tasting), (d) olfactory (or smelling), and (e) tactile. For example, the sensory modality of a watch is *visual* and that of a radio is *audio*. A product may have two or more sensory modality; for example, the sensory modality of television involves *audio* and *visual*.

Response modality denotes the mediums through which the user *responds* to or *manipulates* the product. The response modality is composed of seven attributes: (a) eye, (b) mouth, (c) face, (d) neck, (e) hand, (f) foot, and (g) finger. For example, a pair of glasses involves two response modality attributes: *eye* and *face*. A saxophone involves three response modality attributes: *mouth*, *hand*, and *finger*.

Positioning location denotes the medium through which the user *carries* the product. The positioning location involves six attributes: (a) head, (b) neck–shoulder, (c) chest–waist, (d) back, (e) hand, and (f) foot. For example, the positioning location of a typical watch involves *hand*, while that of a pocket-watch involves *chest-waist*. Some products may have no positioning location; for example, a refrigerator is typically not carried by user.

3.2 Task

The second dimension—*task* is to model the tasks to be performed by the user through using the product. According to users' needs, the tasks are categorized into seven groups: (1) *eating*, (2) *clothing*, (3) *living*, (4) *transportation*, (5) *education/entertainment*, (6) *working*, and (7) *health care*.

The first group, which describes the tasks relevant to eating, is characterized by the following four processes: (a) preparation, (b) processing, (c) serving, and (d) cleaning. For example, a cooking pot is for the *processing* of food; a dish is for the *serving* of food; and a brush is for *cleaning* purpose. The second group, describing the tasks relevant to clothing, is characterized by three processes: (a) preparation, (b) modification, and (c) cleaning. For example, a cloth closet is for the *preparation* purpose; and a washing machine is for *cleaning* purpose.

The third group, which denotes the tasks relevant to living, is characterized by the following four processes: (a) cleaning, (b) maintenance, (c) monitoring, and (d) decorating. For example, a hammer is for the purpose of *maintenance*; a vacuum cleaner is for *cleaning* purpose.

The fourth group, which describes the tasks relevant to transportation, is characterized by the five processes: (a) planning, (b) navigating, (c) monitoring, (d) emergency handling, and (e) vehicle. For example, GPS (global positioning system) is used in the tasks of *path planning* and *path navigation*. Cell phone is used for the purpose of *emergency handling*.

The fifth group—education/entertainment is characterized by the following five processes: (a) searching, (b) understanding/integrating, (c) creating, (d) storing, and (e) distributing. For example, a tape recorder is for the purpose of *storing*; and an e-mail system is for *distributing* purpose.

The sixth group, which describes the tasks relevant to working, is characterized by five processes: (a) planning, (b) execution, (c) inspection/review, (d) decision, and (e) communication. For example, telephone is for the purpose of *communication*; and a thermometer is for *inspection* purpose.

The seventh group—health care is characterized by the following processes: (a) daily maintenance, (b) detection/diagnosis, (c) remedy, and (d) rehabilitation. For example, soap is for the *daily maintenance* purpose; and wheelchair is for the *rehabilitation* purpose.

3.3 Physical feature

The third dimension of the product representation is called *physical feature*. This dimension is characterized by three features: (1) *physical size*, (2) *movability*, and (3) *scaleability*. For the feature of physical size, products are classified into five types: (a) mini, (b) small, (c) medium, (d) large, and (e) extra-large. For the feature of movability, products are classified into two types: (a) portable and (b) stationary. For the feature of scalability, products, according to the extent of change, are classified into three types: (a) small, (b) medium, and (c) large. For example, a notebook has the following attributes: *medium* in size, *portable*, and *medium* level in scalability.

3.4 Environment

The fourth dimension of the product representation describes the *environment* where the product is used. The dimension is characterized by the following three sub-dimensions: (1) *number of users*, (2) *indoor/outdoor plac*e, and (3) *the harshness of environment*.

The sub-dimension "*number of users*" is classified into two types: (a) single user and (b) a group of users. For example, PDA (personal digital assistant) product is for *single user*; and television is for a *group of users*.

The sub-dimension "*indoor/outdoorplace*" is classified into two types: (a) indoor and (b) outdoor. For example, a walkie-talkie is for both *indoor and outdoor* places; a printer is for *indoor* use.

The sub-dimension "*the harshness of environment*" is characterized by the following six attributes: (a) illumination, (b) temperature, (c) humidity, (d) noise/vibration, (e) dust, and (f) pressure. For example, an industrial computer can be used in a high-*temperature* and high-*noise* environment.

Table 1 Shows the vector representation of two products, cell phone and ball pen

ID	Dimension	Group	Attribute	Cell phone	Ball pen
1	Interface Modality	sensory modality	visualization (or sight)	0.5	1.0
2			audio/hearing	1.0	0
3			gustatory (or tasting)	0	0
4			olfactory (or smelling)	0	0
5			tactile	0.5	0.5
6		response modality	eye	0.5	1.0
7			mouth	1.0	0
8			face	0.5	0.5
9			neck	0.5	0
10			hand	1.0	1.0
11			foot	0	0
12			finger	0.5	0.5
13		positioning location	head	0	0.25
14			neck-shoulder	0.25	0
15			chest-waist	1.0	1.0
16			back	0	0
17			hand	0.5	0.5
18			foot	0	0
19	Tasks	eating	preparation	0	0
20			processing	0	0
21			serving	0	0
22			cleaning	0	0
23		clothing	preparation	0	0
24			modification	0	0
25			cleaning	0	0
26		living	cleaning	0	0
27			maintenance	0	0
28			monitoring	0	0
29			decorating	0	0
30		transportation	planning	0.5	1.0
31			navigating	0	0
32			monitoring	0	0
33			emergency handling	1.0	0
34			vehicle	0	0
35		education/entertainment	searching	0.5	0
36			understanding/integrating	0	0
37			creating	0.5	1.0
38			Storing	0.25	0
39			distributing	0.25	0.75
40		working	planning	0.25	1.0
41			execution	0.5	0.25
42			inspection/review	0	0.5
43			decision	0.25	0
44			communication	1	0.25
45		health care	daily maintenance	0	0
46			detection/diagnosis	0	0
47			remedy	0	0
48			rehabilitation	0	0

Table 1 (continued)

ID	Dimension	Group	Attribute	Cell phone	Ball pen
49	Physical Feature	physical size	mini	0.25	0.25
50			small	0.75	0.75
51			medium	0	0
52			large	0	0
53			extra-large	0	0
54		movability	portable	1.0	1.0
55			stationary	0	0
56		scaleability	small	0	0.5
57			medium	1.0	0.5
58			large	0	0
59	Environment	number of users	single user	1.0	1.0
60			group of users	0	0
61		indoor/outdoorplace	indoor	0.5	0.5
62			outdoor	0.5	0.5
63		the harshness of environment	illumination	0.75	0.75
64			temperature	0.5	0.5
65			humidity	0.5	0.5
66			noise/vibration	0.25	0.5
67			dust	0.5	0.5
68			pressure	0.5	0.5
69	Users	gender	male	0.5	0.5
70			female	0.5	0.5
71		age group	infant	0	0
72			child	0.25	0
73			teenager	0.5	0.25
74			young adult	0.5	0.5
75			adult	0.5	0.5
76			the aged	0.25	0.25
77		workingindustry	agriculture	0.5	0.5
78			manufacturing	0.5	0.5
79			trade	0.5	0.5
80			service/education	0.5	0.5
81			government	0.5	0.5
82		job position	top management	0.5	0.5
83			middle management	0.5	0.5
84			supervisor	0.5	0.5
85			engineer	0.5	0.5
86			office clerk	0.5	0.5
87			operator	0.5	0.5

3.5 Users

The fifth dimension of the product representation is about *users*. Users are characterized by the following demographic features: (1) *gender*, (2) *age group*, (3) *working industry*, and (4) *job position*. The feature gender denotes the population of users in terms of gender. The feature age group involves six clusters: (a) infant, (b) child, (c) teenager, (d) young adult, (e) adult, and (f) the aged. The feature "*working industry*" involves five clusters: (a) agriculture, (b) manufacturing, (c) trade, (d) service/education, and (e) government. The feature "*job position*" involves six clusters: (a) top management, (b) middle management, (c) supervisor, (d) engineer, (e) office clerk, and (f) operator.

Based on the representation scheme discussed above, a product can be modeled by a vector consisting 87 attribute values. Each attribute of a product can be valued in five scale points: *extreme relevance* (1.0), *high relevance* (0.75), *relevance* (0.5), *low relevance* (0.25), *no relevance* (0). Table 1 shows the vector representation of two products, cell phone and ball pen.

4 Generation of new product ideas

Based on the proposed product representation scheme, this research applies the CBR (case-based reasoning) technique to create new product ideas. The idea-generation mechanism starts with a *benchmarking product*, an existing product on which new functions are to be added. For the benchmarking product, its high-value attributes (≥0.75) are used as keys to retrieve other products that are "*sufficiently relevant*" to the benchmarking product. These retrieved products are then screened and subsequently rated manually to determine the quality of new ideas. Here, the quality of new ideas implies how *creative* and *valuable* it is to add the main function of a retrieved product to the benchmarking product.

The method for computing the *relevance metric* between two product vectors is first described. Then, the CBR procedure for retrieving the "*sufficiently relevant*" products is explained.

4.1 Computing relevance metric

Suppose a product database has been established, which involves a large amount of products and each product is modeled by the proposed representation scheme, a vector form. Let $P = \{P_i, i = 1,\ldots, K\}$ represent the database, where $P_i = [p_{ij}]$ $1 \leq j \leq 87$ denotes the *i*-th product and p_{ij} is the value of its *j*-th attribute. Let $B = [b_j]$ $1 \leq j \leq 87$ denote the benchmarking product.

Let $AR(b_j, p_{ij})$ represent the *relevance metric of j-th attribute* for product B and P_i. $AR(b_j, p_{ij})$ is defined below.

$$AR(b_j, p_{ij}) = 1 - |b_j - p_{ij}| \quad (1)$$

Let $S = \{j | b_j \geq 0.75\}$ represent the set of high-value attributes of product B. Some attributes in S are selected to form a *key set*, which are used to retrieving "*sufficiently relevant*" products. Define $T \subset S$ as the key set. Let PR_i^T represent the *product relevance metric* between products P_i and B, with respect to the set of attributes T. PR_i^T is defined below, where $W_j \in [0, 1]$ denotes the weighting factor of *j*-th attribute given by users. That is, users can intentionally gives their preferences on the attributes in T.

$$PR_i^T = \sqrt{\frac{\sum_{j \subset T} \left[b_j \cdot AR(b_j, p_{ij}) \cdot W_j\right]^2}{\sum_{j \subset T} \left[b_j \cdot W_j\right]^2}} \quad (2)$$

4.2 Procedure of CBR

The concepts presented above can be used to develop a *product innovation retrieval system*, called PIRS. The procedure for using the PIRS to generate new product ideas is presented below.

Step 1: Initialization

- Assign R_Set = ∅, A_SET = ∅
- Ask user to determine the benchmarking product B

Table 2 The results of the two experiments are shown in

Group	Cell phone experiment≥4.0				Ball pen experiment≥4.0			
	B.S.		PIRS		B.S.		PIRS	
	Q'ty	T-score	Q'ty	T-score	Q'ty	T-score	Q'ty	T-score
Group 1	12	49.2	13	53.6	4	16.4	8	33.0
Group 2	11	45.4	14	61.7	5	20.8	9	37.1
Group 3	12	49.3	15	61.4	6	24.7	9	37.7
Group 4	10	41.5	13	45.4	5	20.6	10	41.4
Group 5	9	37.0	14	58.0	6	20.4	9	37.7
average	10.8	44.48	13.8	56.02	5.2	20.58	9	37.38

Step 2: Determine $S = \{j | b_j \geq 0.75\}$, the set of important attributes for product B.

Step 3: Ask users to select attributes in S to form several key sets T_k ($k = 1, \ldots, n$) and give W_j for each attribute in T_k.

Step 4: Retrieve "*sufficiently relevant*" products from the product database

- Ask users to determine a *relevance threshold* $h \in [0, 1]$.
- Retrieve and place the "*sufficiently relevant*" products in *R_Set*; that is, $R\_Set = \bigcup_{k=1}^{n} \{P_i | PR_i^T \geq h \, for \, i \in T_k\}$

Step 5: Ask users to select *creative* and *valuable* product ideas from *R_Set* and place them in *A_Set*.

5 Experiment

To justify the proposed PIRS (product innovation retrieval system), this research performs an empirical study to compare the effectiveness between PIRS and the brainstorming (BS) approach. Two experiments are tested. One experiment uses a cell phone as the benchmarking product and the other uses a ball pen as the benchmarking product. In each experiment, the two approaches aim to find *creative* and *valuable* functions to be added to the benchmarking product. The procedures for the experiments are presented below.

Table 3 Product ideas for cell phone generated by PIRS

Language Translator/Dictionary	Radio and Walkman
Remote Controller for Door/Car	Television
USB Flash Memory Drive	Stun Gun for Security
Electronic Pet (Game)	Projector
Mosquito prevention set	Language Learning Machine
E-Map	PDA (personal digital assistant)
Alcohol tester	Pedometer
MP3	e-Book
Anti-camera detector	Bar-code detector (for shopping memo)
Walki-talki	Pulse detector

5.1 Subjects for experiments

Each experiment involves 25 subjects who are sophomores of a university. These subjects are randomly clustered into five groups. In each group, one subject is randomly chosen to use the PIRS approach and the other four subjects are requested to use the BS approach to generate new product ideas for the benchmarking products.

5.2 Product database

A prototype product database involves 500 products is established for the experiments. The product database is coded by Microsoft Access; the user interface is developed by Macromedia Dreamwaver; the retrieval mechanism is coded by ASP (Active Server Page); and Microsoft Internet Explorer is used as the vehicle for web browsing.

5.3 Experiment procedures

The experiment time for each of the two approaches is 1 hour. The BS approach, which has been widely known, follows the procedure described by Osborn [3]. The PIRS approach follows the procedure described in Section 4. Using the benchmarking product ball pen as an example, each step of the PIRS approach is explained below.

Step 1, claims that new functions of a ball pen are to be searched. In step 2, of the 87 product attributes of a ball pen, only 12 attributes are important attributes, which are highlighted in Table 1 and are with the following IDs {1, 6, 10, 15, 30, 37, 39, 40, 50, 54, 59, 63}. In step 3, subjects can freely form several key sets T_k from the 12 attributes. In step 4, the relevance threshold $h = 0.5$ is defined, and new product ideas are generated by the PIRS system. In step 5, of these new product ideas generated, subjects by their own judgments select the creative and valuable ones.

5.4 Evaluation method

Three experts familiar with new product developments are invited to evaluate the new product ideas generated. In evaluating a new product idea, three criteria—*originality*, *valuableness*, and *usefulness* [33] are used. Each criterion is rated in a five-point scale. The higher the point, the more appreciated is the new idea. The creativity of a new product idea is measured by averaging the points of the three criteria.

5.5 Result comparison

The results of the two experiments are shown in Table 2. This table analyzes the new product ideas that are regarded as *creative*; that is, their creativity values are grater than or equal to 4.0. For the cell phone experiment, the BS approach creates 10.8 creative ideas per group, and the PIRS approach creates 13.8 creative ideas per group. The associated *t*-test, with α=0.05, *t*-value=−3.005, *P*-value=0.017, shows that the PIRS approach is statistically better than the BS approach. For the ball pen experiment, the BS approach creates 5.2 creative ideas per group, and the PIRS approach creates 9.0 creative ideas per group. The associated *t*-test, with α=0.05, *t*-value=−8.970, *P*-value=0.0 shows that the PIRS approach is also statistically better than the BS approach. Table 3 shows some product ideas generated by the PIRS approaches for the cell phone experiment.

6 Concluding remarks

This research presents a cased-based reasoning (CBR) approach to generate new product ideas. A product is modeled by 87 attributes based on the user-centered design (UCD) paradigm. For each attribute, a product is assigned a 0–1 value. The higher the value, the more important is the attribute. For a benchmarking product, some of its important attributes are manually selected as keys for retrieving from database the products that are "*sufficiently relevant*" to the benchmarking product. The main functions of these retrieved products are taken as candidate new functions of the benchmarking product. A prototype system of the proposed approach, called PIRS (*product innovation retrieval system*), has been implemented. Experiments show that the PIRS outperforms the brainstorming approach in generating *creative* and *valuable* product ideas.

An extension of this approach is applying the PIRS to enhance the productivity of the brainstorming technique. That is, during a brainstorming process, a BS participant is inspired by other participants as well as by the PIRS system. Another extension is the development of an idea-propagation mechanism. That is, for the products retrieved, we can select some of them as the benchmarking products to retrieved more new ideas.

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