Supporting Systematic Conceptual Design with Knowledge-Based System

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Abstract. Conceptual design is the core stage in the process of product design. At this stage, designers make product design decisions with vague and imprecise information. Compared with the high-efficient computer-aided tools in the detailed design, the computer-aided tools are relatively backward in the conceptual design stage. The Systematic-TRIZ conceptual design computer-aided tool (STCD) proposed in this study can assist designers to fill this gap and improve the design process in the conceptual design stage. In order to achieve this goal, the conceptual design support tool (STCD) for product design is developed, which integrates the systematic design method, TRIZ method and knowledge-based system. The STCD tool is in the development stage, and only part of the conceptual design knowledge of the hair dryer is collected and stored in the computer system. STCD supports four stages in the conceptual design process: function modeling, concept generation, concept composition, and concept evaluation. Each knowledge is divided into Subject-Action-Object using the functional definition of TRIZ. This study aims to show how STCD tools acquire conceptual design knowledge from experienced designers and store it in a computer system for later use, and how STCD tools assist designers in conceptual design by dealing with repetitive and time-consuming tasks.

Keywords: Systematic design · TRIZ · Computer aided design

1 Introduction

In the past decades, many scholars have done a lot of research on design theory and methodology [1]. Most of the design theory are based on the German system design method of the 1870s [2] which is also cited in the famous design textbooks in the United Kingdom and the United States [3]. Systematic design method is widely used in conceptual design, and systematic design is the process of system design to meet demand [4]. The systematic design process can be broadly divided into four stages: project planning, task presentation, conceptual design, and detailed design [5]. In these stages, conceptual design is the core stage in the process of product design. Conceptual design exceeds 75% of the cost of the product lifecycle since it is the stage of defining

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the basic characteristics of a product [6, 7]. In the conceptual design stage, decision-making contains vague and inaccurate information. Decisions made at this stage will impose a significant impact on the cost, quality, and manufacturability of the product life-cycle. Usually, it's hard to make up for a poorly conceived concept with a good detailed design process [8, 9]. Therefore, conceptual design requires a reasonable concept in order to succeed in the design.

At present, there are several computer-aided design tools (CAD) can reduce the designer's workload and save the product development time. Most tools, such as geometric information-based drawing, geometric modeling and element analysis, are used in the detailed design stage. These tools, however, can't deal with the four aspects of function modeling, concept generation, concept composition and concept evaluation in conceptual design process. These aspects are important in the conceptual design stage and are based on function. More CAD tools are used only in the detailed design stage than in the concept phase [10].

Conceptual design process, a type of knowledge aggregation, requires the cooperation of professional knowledge from different disciplines [11]. Designers have limitations in dealing with big data in spite of their creativity and design experience. Consequently, a good design scheme and a reasonable judgment are hard to be developed in a given time. On the other hand, computers can process big data quickly and reasonably. Combining designer's creativity with computer function, this study can carry out conceptual design process more effectively than pure manual design.

With the development of the product design process, knowledge about the product needs to be acquired from the conceptual design to the detailed design stage, during which the decision-making influence will decrease [9]. Since the decisions made at the conceptual design stage have limitations on decision-making at the detailed design stage. As the design evolves, the design requirements may be changed or developed into new requirements which are not mentioned at the beginning of the design. This allows the design process to be repeated over and over again, through which a number of design activities are repeated for improvement. Designers shall study feasibility design options in detail so that they can make the necessary changes early in the design process. Because it's more expensive to make changes at the end of the design stage, and ultimately leads to delays in the release of products [12]. The computer-aided tools can deal with the repeated design tasks so as to save the product development time and improve the design process.

The study is targeted at studying the conceptual design process and proposing a computer-based conceptual design assistant tool model. As shown in Fig. 1, a framework of a new conceptual design aid tool (STCD) is proposed in this study, which combines the Input-Output function definition of the systematic design method with the SAO function definition of the TRIZ method, and establishes a function structure by decomposing the whole function into several easy-to-solve sub-functions, so that each sub-function corresponds to the SAO model and is finally integrated into a knowledge-based system. STCD tools can assist designers in the conceptual design process, but that does not mean replacing designers with fully automated conceptual design processes. However, it helps designers in conceptual design by handling repetitive and time-consuming tasks. It presents more time for the designers to focus on the creative parts of the design process.

2 STCD in Conceptual Design Process Model

The conceptual design process, a design process that meets the requirements, can be transformed into one or more concepts developed to meet the requirements. The better design solutions can be developed with careful and extensive exploration of the design field. There are more than one solution that meets a given requirement in most cases. A conceptual design process model is proposed in Fig. 1. In this model, the systematic design method, TRIZ method, and knowledge-based system are integrated, including a range of activities and outcomes [5]. Activities (i.e. function modeling, concept generation, concept composition, and concept evaluation) are performed by the designer's knowledge and design knowledge base system. The results of the specified activity will be displayed to the user and will be used as input to the design knowledge-based system to perform the next activity.

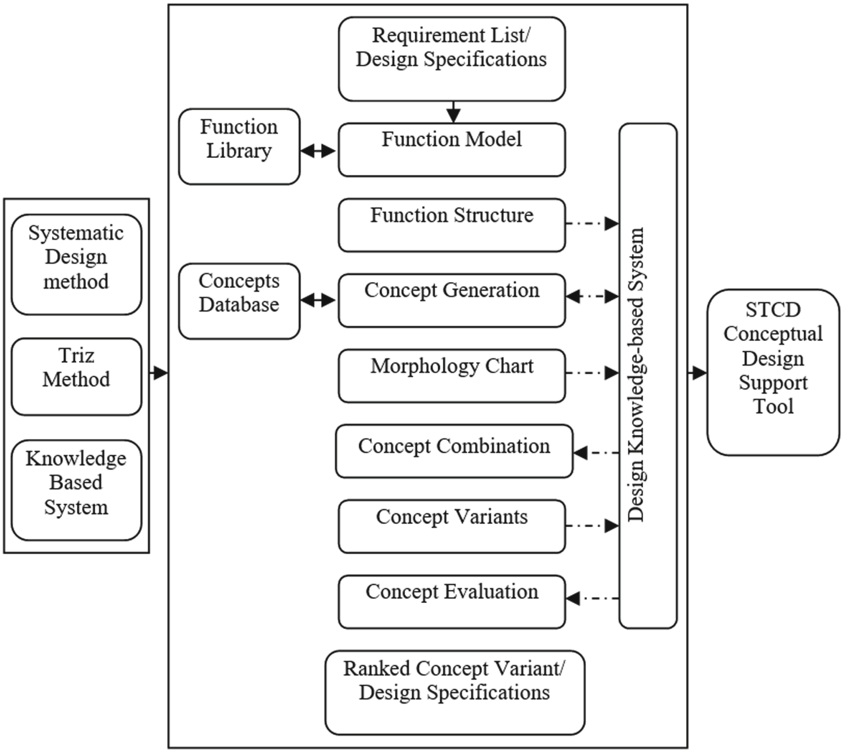

Fig. 1. Conceptual design process model.

Function Module

There are several documents that define function from different perspectives [5, 13, 14]. As shown in Fig. 2, function can be defined as the system's input-output relationship, designed to perform tasks independently of any particular solution. A function model is the overall function of a design problem raised after the analysis of a requirement or design specification and then decomposing it into several sub-functions that are easy to solve to establish a function structure [11]. Form follow-up function, each product has its function meaning. Function plays a key role in conceptual design. As shown in Fig. 3, input-output information function is represented as noun (subject) verb (action) + noun (object) by TRIZ method, which is convenient for computer knowledge system identification and storage [13]. The repeatable design process also requires a unified standard of functional vocabulary. In this study, it adopted the method of developing a computer function library based on the coordination function proposed by Hirt et al. [14]. On the basis of coordination function, function can be divided into 8 Class I, 45 Class II and Class III verbs. There are three types of Class I conduction in this function library: material, energy and signal, which are further divided into 42 Class II and Class III conduction. Function can be expressed as (noun + verb + noun) Class I function, Class II function and Class III function composited by conduction.

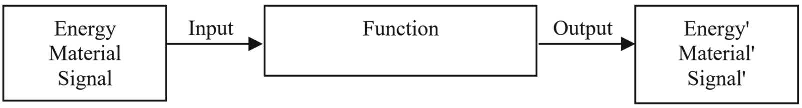

Fig. 2. The EMS function model.

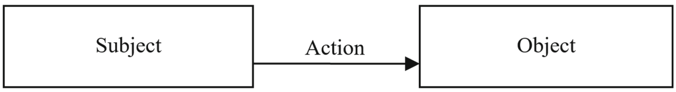

Fig. 3. The EMS function model.

Each product designed by the STCD tool includes a function model that breaks down the overall function into sub-functions by analyzing existing products and experts' opinions. Designers can also modify it to new function, and all of the sub-functions in the function model are represented by function in the function library. In a knowledge base, the function is represented by the following attributes:

Function
Name: Subject(noun) + Action(verb) + Object(noun)
Complement: additional information
Input: input conduction
Output: output conduction
Matched: yes/no

The Name column refers to the function represented by a noun + verb + noun. The Composition column is optional and can be used to complement the description information.

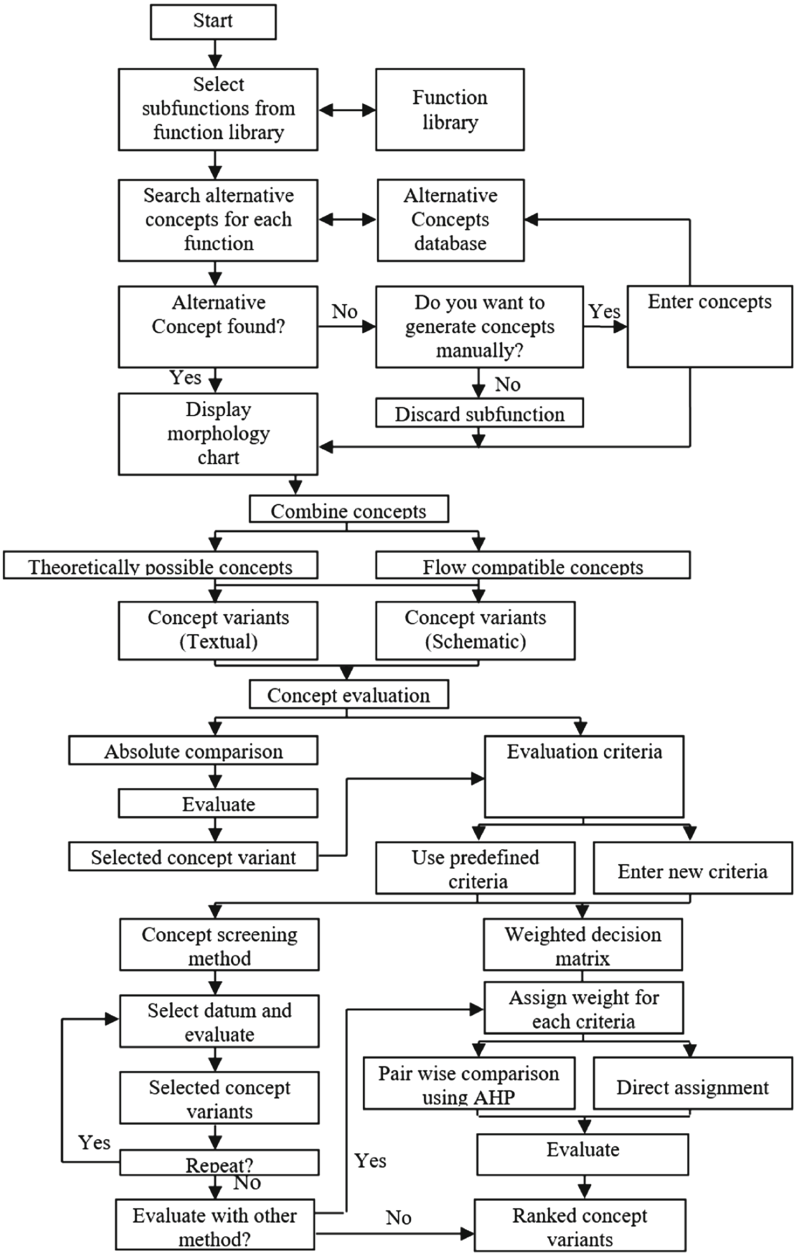

Fig. 4. Flow chart of the STCD.

Concept Generation Module

As shown in Fig. 4, the concept generation stage uses preset product rules in the knowledge base to complete the concept generation process by searching for alternative concept databases. To this end, a conceptual database of hair dryers is established by collecting manuals, patents, manufacturer's catalogs and concepts from the designer's personal experience. Concept generation has two available types. The first is mapping, in which the system searches for concepts of Class I and Class II that match the sub-functions in the working memory. Sub-functions and all optional concepts will appear in the schematic and be stored in working memory if there are alternative concepts in the conceptual database. If a single or multiple sub-functions in the database do not have alternatives, the second approach will be automatically executed. In this case, the user will be required to perform concept generation manually and provide an optional solution for input, and moreover, these concepts will be stored in the database for future use. In the end, the sub-functions and their corresponding alternatives are shown in the schematic diagram. With 40 problem-solving principles in the TRIZ approach, the existing design knowledge can be acquired and stored in a database.

Concept Composition Module

After generating alternative concepts for each of the sub-functions in the function structure, the overall function can be achieved by combining these concepts. Preset product rules can be used to create concept variants. For reducing the failure rate of the composite, designers evaluate the concept of sub-function generation and delete the useless concepts in the schematic before the composite concept. Generally, a total of two types of product rules in the knowledge base can be used to perform the concept composition process:

A General Principle for Creating Concept Variants in Theory. In this case, a concept variant is created by adopting a scheme for each of the sub-functions in the schematic.

Conductive Constraint Principle, To Create a Conductive-Compatible Concept Variant. The synthesis process is the same as the general rule, but increases the constraint of conduction compatibility. Only if the output stream applicable to the previous concept is the same as the input stream of the subsequent concepts in the schematic diagram, it is a variant of the compatibility concept.

Because the number of sub-functions of different products varies, the knowledge base contains product rules for each case. The combined concept variants are shown in text and schematic form, displaying all the components that make up the concept variants.

Concept Evaluation Module

The concept evaluation process will be conducted in three steps. First, an absolute comparison method is used for evaluation, in which concepts are compared directly with a set of requirements. This leads to the elimination of some unworkable concept variants. Next, the concept-filtering approach is used to evaluate the remaining concept variants over and over again, based on a product or a concept variant. If a product is used as a benchmark concept, it should be reduced to the same level as other concept variants. This process will further reduce the number of concept variants, and the remaining variants will be evaluated using the matrix decision method. The degree to which the criteria are chosen can be assigned directly or compared in pairs in virtue of the analytic hierarchy process. The output from this evaluation process will rank the concept variants based on grades, select one or more concepts for further development, or combine some concept variants so as to achieve the concept variants with better performance and repeat the conceptual design process.

3 STCD of Knowledge-Based System

In this study, the implementation and application of STCD tools requires the development of knowledge-based systems. A knowledge-based system is an artificial intelligence system that uses stored knowledge to solve problems in a particular domain. Three major components of the knowledge-based system structure are: 1. Knowledge base containing knowledge domain; 2. Inference engine (control device); 3. Interface with the outside world (user interface). In these major components, the knowledge acquisition components are also included, so as to add the new knowledge to the program development process and the program life-cycle [15].

The STCD prototype tool is developed by applying these programming environments on the basis of the above-mentioned methods. Users can easily browse the design information according to the flow chart's using buttons, options and menu bar, and perform the conceptual design on Windows program.

4 Hair Dryer's Application of STCD

In this section, the hair dryer conceptual design is taken as an example so as to demonstrate the auxiliary role of the STCD tool proposed in this study in the conceptual design stage. Meanwhile, in this second, it also explains how to use the auxiliary tools to design the function.

4.1 Function Model

The designers' job is to design a hair dryer that generates hot air by heating and spinning at high speeds. As shown in Fig. 5, the overall function can be defined from customer requirements: split wet hair into water and hair.

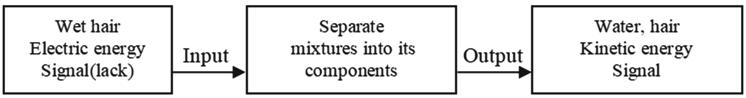

Fig. 5. Overall function of hair drier.

In the first step, the designers manually transform customer requirements into function model. This step can be used to weaken the relationship between the sub-functions and separate them into components, while studying the existing products, the function structure can be gained and the function in the function library can be used to represent the function structure.

The next step is using these sub-functions as input information for STCD, and the function structure is used as input to the system and to generate concepts in the function library. The sub-functions in the function structure can be selected from the function library, and then these sub-functions can be added to the system one by one. The function library can also be used to load the function structure. The user must use the following format to edit function in the function structure in any text editor and save as "filename.txt":

(function(noun airflow) (verb distribute) (noun hair-water location))
(function(noun wind) (verb separate) (noun hair-water location))

Function Model

Once all the sub-functions are added to the working memory, the concept generation step is taken. If each of the sub-functions in the database has a corresponding concept, it shows that "the concept has been successfully generated for all of the sub-functions". If there are no alternative concepts for a single or multiple sub-functions, a notification message window will pop up, where the user can generate the concept by manually entering the concept. What's more, in cases where the concept has side-effects, the system will advise users to consider its side-effects as new requirements. It explains that there will be ever-changing requirements arising during the conceptual design process and it also describes how the STCD tool integrates this situation.

STCD users can reject concepts that are not feasible in schematics, which helps to reduce the error rate in later concept composition. The concept name is displayed when the user clicks on any concept in the schematic. If considering that the concept is not feasible, the user can delete it by refreshing the concept sketch and redrawing the schematic.

Concept Composition

When a user starts a concept composition function, there are two options: create all theoretically feasible concept variants or create concept variants of compatibility conduction. A number of theoretical concept variants will be produced in the concept composition process. Based on the user's requirements and the feasibility of using the hair dryer concept, the user can remove the unusable concept from the schematic diagram. The rest of the concepts are merged after refreshing the schematic, so as to form some alternative concept variants. The concept variants can be viewed from both text and schematics. Completed concept variants represent the names of all the concepts in each concept variant in textual form. Theoretically, all concept variants can satisfy the overall function. The reason is that the concept of generation is designed to satisfy the sub-functions in a function structure that is decomposed from the overall function. Concept composition is a bottom-up process, the reverse operation in function decomposition.

Concept Evaluation
The concept evaluation process begins with defining the evaluation criteria. Users can either use the default evaluation criteria or define a new one. Next, the concept variants are evaluated by the STCD tool in virtue of absolute comparison, concept filtering, and weighted decision matrix iteration methods. After each evaluation process, unworkable concept variants can be eliminated or recombined, and viable concept variants will proceed to the next evaluation process. According to the evaluation results, the most suitable concept variants are selected for further development. Finding out the component of the selected concept variant from the existing concept variant of the hair dryer ensures the validity and practicability of the selected concept variant. The concept evaluation stage explains how to use STCD to re-apply existing concepts saved in the database to the design process. Through selecting the name of the concept variants in the matrix, users can view information about each concept variant.

5 Conclusion

In this paper, the STCD tool can assist the designers to perform conceptual design processes more efficiently than they do by hand alone by handling repetitive tasks and providing concepts that are available in the database. The STCD tool supports the designers through the conceptual process of inputting the designers' decisions step-by-step and providing the output. The STCD tool proposed in this study generates alternative concepts for a given set of sub-functions in a function structure, and the alternative concepts are shown in a schematic diagram. Design knowledge is stored in the brain of experienced designers. STCD can be used as a knowledge management system to retain knowledge of an expert when the expert leaves the company or retires from the company for future use. The concept that the tool generates and displays on the schematic may inspire the user to generate new concepts. What's more, novice designers can learn from expert experience by exploring concepts. It is important to note that conceptual design is not a one-step process and cannot be fully automated. Its nature is dynamic, and requirements may change over time.

STCD tool combines the Input-Output function definition of the systematic design method with the SAO function definition of the TRIZ method, and establishes a function structure by decomposing the whole function into several easy-to-solve sub-functions, so that each sub-function corresponds to the SAO model and is finally integrated into a knowledge-based system. STCD tools can assist designers in the conceptual design process, but that does not mean replacing designers with fully automated conceptual design processes. However, it helps designers in conceptual design by handling repetitive and time-consuming tasks. It presents more time for the designers to focus on the creative parts of the design process.

Currently, the STCD tool is in the experimental stage of development and cannot be placed in the paper for demonstration. At present, the available conceptual database is still in the development stage, which can not be used by the general users for the time being. The STCD tool can be further improved by extending the relevant database and solving problems through the provided knowledge acquisition module.

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