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UXDs-driven conceptual design process model for contradiction solving using CAIs

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ABSTRACT

Design is situational, which means the explicit consideration of the state of the environment, the knowledge and experience of the designer, and the interaction between the designer and the environment during designing interact. When computer-aided innovation systems (CAIs) are applied to the design, the environment and the situation are different from the traditional design process and environment. The basic principles of some CAIs available in the world market are directly related to theory of inventive problem solving (TRIZ). Special TRIZ solutions, which have a few inventive principles and the related cases for contradiction problem solving, are medium-solutions to domain problems. The second stage analogy process is used to generate domain solutions and in this process, the TRIZ solutions are used as source designs of analogy-based process. Unexpected discoveries (UXDs) are the key factors to trigger designers to generate new ideas for domain solutions. The type of UXDs for the specific TRIZ solutions is studied and a UXDs-driven contradiction solving for conceptual design is formed. A case study shows the application of the process step by step.

1. Introduction

It is generally agreed that the conceptual design is the most critical phase in the design processes [1]. The inputs for this phase are product or design specifications, and the outputs are principle solutions or concepts [2]. There are many research results in this field, which may be divided into three types: studies on process models; methods for generating ideas or concepts; and computer applications. The process models [2–5] for conceptual design are descriptions at some level for real conceptual design processes in industrial firms. Pahl and Beitz's model [2], as a case in point, includes seven steps. Many methods to generate ideas or concepts [6] have been developed, such as brainstorming, mind mapping, lateral thinking, etc. These methods are basically brainstorming-driven. Different types of methods [7,8] to assist designers to generate concepts are continuously studied. Computer systems [9–11] have been applied in conceptual design processes. In these systems the lack of formal product representations of function, behaviour and structure [12], which are the knowledge base for conceptual designs, have been identified as a kind of shortcoming.

Contrary to the brainstorming-driven methods, theory of inventive problem solving (TRIZ) [13] is a systematic method to guide designers on a high plane to generate ideas for inventive problems [14]. Today, several computer-aided innovation systems (CAIs) [15], such as Goldfire Innovator, IWB, and InventionTool, have been developed and commercialized to support designers in conceptual design. The basic theory for developing these systems is TRIZ. Several knowledge bases are included in the CAIs, which are abstracted from patent analysis or different scientific branches. By these knowledge bases, designers have a chance to apply the cases of other designers and the effects from the scientific world. Nevertheless, how to integrate the TRIZ and CAIs into a conceptual design process is also a problem.

Design situation is a particular state of interaction between designers and the environment at a particular point in time [16]. CAIs are new systems for most designers and will change the design situations when they are applied. In this new situation, the interactions mainly happen among designers and a serial of interfaces of CAIs. The reason that the interfaces will support designers to generate ideas is needed to be studied.

Contradictions are a kind of inventive problems in conceptual design. Contradiction matrix in TRIZ is a tool for solving that kind of problems. The matrix was developed many years ago [13], but it is still applied today [17,18]. The matrix does help designers to solve some contradictions faced during the design. This study will be restricted to find solutions for contradiction solving. The target is to form a new conceptual process model under the environment of CAIs.

2. Contradictions in conceptual design and solving them using CAIs

Pahl and Beitz [2] divided a design process into four phases. The conceptual design is a phase or process to develop the principle

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solution. Several sub-processes are divided, which are an abstract of the essential problems, establishment of the function structure, search for suitable working principles, and combinations of these principles, to form a working structure. Some difficult problems, which exist during conceptual design, may be as follows:

(1) Adoption for a suitable principle solution of a function in a function structure that will result in the existence of a new harmful function, or intensifying an existing harmful function.
(2) Elimination or reduction of a harmful function in a function structure will deteriorate a useful function.
(3) Intensification of a useful function or reduction of a harmful function will cause the unacceptable complication of the design.

All of the above problems are technical contradictions from the point of view of TRIZ [13]. As a result, designers in conceptual design face some difficulties to solve these contradictions. The tool in TRIZ for solving technical contradictions includes 39 generic engineering parameters to represent contradictions; 40 inventive principles to solve the contradictions; and a matrix to find a few suitable inventive principles. Under each inventive principle there are several design cases abstracted from patent bases of the world. Every case shows a result to solve a contradiction by former designers. Fig. 1 shows the structure of the tool.

Every case under an inventive principle in Fig. 1 is the result of analyzing patent bases from outside world. The knowledge, which is tacit in different domains of a patent base, is difficult to have them applied by designers because it is a problem to find a useful one from different domain. If a patent abstracted from any domain is stored in the case base of TRIZ it becomes explicit knowledge or codified knowledge, which can be found following the TRIZ problem solving routine and applied for idea generation.

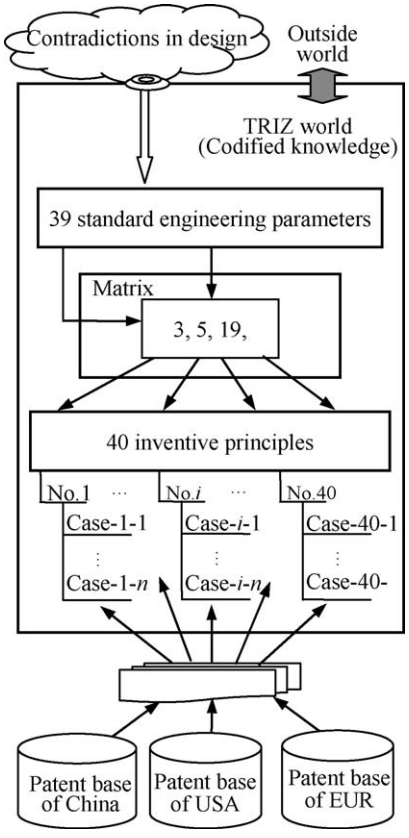

Fig. 1. Contradiction solving model in TRIZ.

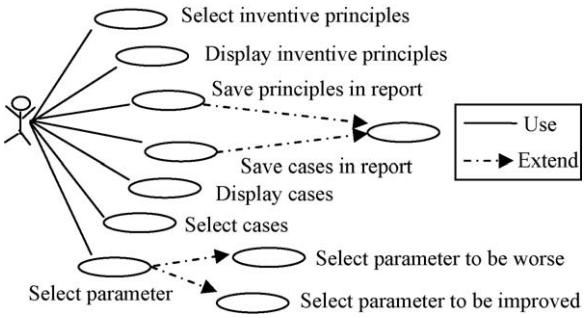

Fig. 2. Use cases for contradiction solving in InventionTool.

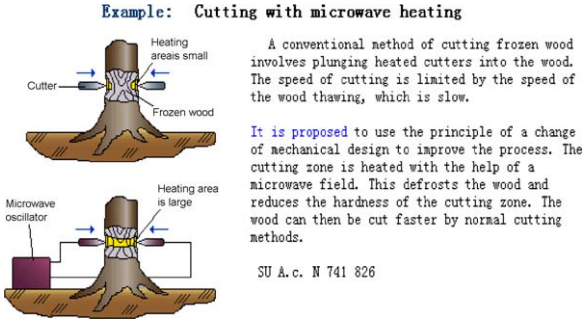

Fig. 3. A cases in knowledge base of CAIs.

The TRIZ world in Fig. 1 has been programmed as a kind of arithmetic and a module of CAIs, such as in the Goldfire Innovator and InventionTool, which are cases of CAIs. Interaction between TRIZ world and outside world is realized by the interfaces of the CAIs. Fig. 2 shows a used cases model to describe an interface of a module for contradiction solving in InventionTool. The application of different CAIs based on TRIZ has made the TRIZ more powerful and applicable. There are a few knowledge bases in CAIs. The knowledge is arranged by the framework of TRIZ. By applying the knowledge base, the design cases from different industrial fields are accessed by designers.

In the knowledge base of CAIs, a case for a technical contradiction solving is described using a sketch with text to explain the working principle of that sketch. Fig. 3 shows an example of a case in which the sketch shows the working principle for cutting with microwave heating and the text is the explanation. When one principle as a TRIZ special solution is selected, all the cases relevant to that principle can be browsed one by one. New ideas for the domain solutions may be formed from designers' mind during the browsing process.

3. An analogy-based concept generation for contradiction solving

The process of solving inventive problems using TRIZ is shown in Fig. 4. The TRIZ process is supported by CAIs, in which the TRIZ's special solutions, inventive principles and the cases related to the principles, are produced automatically after TRIZ mapping. The designer can browse them one by one as shown in use case model in Fig. 2.

From the TRIZ special solutions to domain solutions is an analogy-based process. Analogies are partial similarities between different situations that support further inference. Analogy-based conceptual design (ABCD) means the application of an analogy to generate a new concept in the process of the conceptual design. In this process, the existing designs and the designs to be carried out are source designs and goal designs, respectively. One of the