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基于知识的概念设计理论与冲突解决方法及应用

刘慧敏 著

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图书在版编目(CIP)数据

基于知识的概念设计理论与冲突解决方法及应用/刘慧敏著.—南京：南京大学出版社，2014.12

ISBN 978-7-305-14485-1

Ⅰ.①基… Ⅱ.①刘… Ⅲ.①创造学—研究 Ⅳ.①G305

中国版本图书馆CIP数据核字(2014)第304275号

出 版 者 南京大学出版社
社 址 南京市汉口路22号 邮 编 210093
出 版 人 金鑫荣

书 名 基于知识的概念设计理论与冲突解决方法及应用
著 者 刘慧敏
责任编辑 张 静
照 排 南京紫藤制版印务中心
印 刷 南京京新印刷厂
开 本 787×960 1/16 印张10.5 字数200千
版 次 2014年12月第1版 2014年12月第1次印刷
ISBN 978-7-305-14485-1
定 价 36.00元

网址：http://www.njupco.com
官方微博：http://weibo.com/njupco
官方微信号：njupress
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前　言

概念设计是工程设计的初始阶段，新产品的大部分基本功能与产品原型都在此阶段确定，并对后期的详细设计乃至生产、销售与使用环节产生至关重要的影响。尽管人工智能技术与计算机辅助设计工具已被广泛应用于工程设计领域，但是 IT 技术对前期概念设计的支持依然非常有限。这是因为概念设计由一系列新概念的涌现而形成，它本质上是依靠人类智慧所完成的创新过程。即使在科技高速发展的今天，设计师的直觉与经验依然是概念设计的灵感源泉，并且很难被计算机辅助技术与人工智能技术所取代。

同时，为提高产品的设计质量以满足日益变化的市场需求，概念设计通常由一系列来自工程领域、管理领域乃至艺术领域等多领域的专家主体协同完成。很多学者认为这些拥有不同领域知识结构的主体共同工作，最有可能产生的是一种基于知识异质性而触发的冲突。适当的冲突能实现异质性知识的公开与共享，并激发知识创造与创新。同时，对冲突的管理不当会导致知识偏见、知识获取和转移迟滞、知识共享困难，以致影响产品的设计质量。然而目前缺乏相应的计算机工具支持早期设计阶段的冲突检测与冲突解决。

提高人类创造力的思维方法有很多，如发明问题解决理论（TRIZ）、头脑风暴法、水平思考法等。其中 TRIZ 不仅提供了一套普适的方法用以打破人类的“思维惰性”，而且提供了一系列系统化与结构化的工具以解决技术问题与管理问题。在 TRIZ 所提供的众多工具中，TRIZ 的矛盾矩阵与发明原理可专门用于解决上述技术冲突与管理冲突，并且辅助设计师生成创新概念。然而，TRIZ 的发明原理也因其过于抽象、逻辑性不强以及原理间的等级差距过大等问题常常为人所诟病。

因此，本书的上篇主要针对下述研究假设进行探索、研究与证明：

➢是否有工具或有何种工具可以用来对 TRIZ 的发明原理进行改进？

➢基于改进后的 TRIZ 的设计方法是否能够比传统 TRIZ 更有效地应用于概念设计？

➢如何能够基于 TRIZ 理论，提出一种自动化的冲突解决策略生成机制并将其实现？

为了对上述假设问题进行深入研究，本书作者首先考虑到易经与 TRIZ 具有共性哲学思想基础，尝试从辩证哲学的视角，对 TRIZ 中的哲学思想进行哲理性解读，并将之与中国古老的易经理论进行对比，剖析两者之间的共性特点。结合易经六十四卦的构成方式与卦象含义对 TRIZ 发明原理进行分解与重构，旨在降低发明原理的模糊性。在此基础上，作者整合了基于知识的人工智能技术，提出一种基于知识的创新方法，可用于解决创新设计中的技术冲突。该方法将 TRIZ 的“矛盾”原理和基于协商的多阶段方法结合起来，用于支持概念设计阶段中的冲突解决问题。本书定义了协同设计环境中的三种冲突类型，描述其各自的分类、检测与解决方法，特别关注第三种类型的冲突解决机制，并且使用基于规则的语言 JESS 实现上述冲突解决方法，为提高协同概念设计的效率与设计方案的创新性提供了一种有效的方法与工具。

以上为本书上篇的主要研究内容，基本来自作者在海外攻读博士期间的研究成果，故以英文撰写。为方便国内读者阅读，本书的下篇选择了概念设计中的 TRIZ 发明原理改进方法与冲突解决方法两个核心内容进行简述。同时，由于近年来很多学者尝试将 TRIZ 的应用范围从解决技术冲突延伸至解决管理冲突，本书作者总结近年来在工程管理领域的研究与实践经验，针对重大工程管理的复杂性特点，分别针对上述两个核心内容研究其在重大工程管理中的应用：(1) 通过结合 TRIZ 中的发明原理与方法，尝试以新的视角对工程管理思想进行变革与创新。首先提出了基于 TRIZ 的知识冲突解决方法在工程建设中的方法与机制，并在此基础上将发明原理分解为“行为元”与“对象元”两个元素，参考了大量工程管理的实际案例，总结出工程管理常见问题所涉及的八大类对象，给出了对应的发明原理与工程冲突管理的应用实例。(2) 考虑到建设工程冲突管理具有涉及主体多、目标多元、知识异质性强、知识能力不足、决策困难、环境动态开放等特点，提出以非妥协的 TRIZ 方法解决技术冲突，并在此基础上进一步整合基于协商的多阶段矛盾解决方法，以提高工程建设中的冲突解决效率。

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Knowledge-Based Inventive Conceptual Design

Chapter 1 Introduction

1.1 Overview

This chapter briefly introduces the research presented in this thesis. The motivation of this research is discussed. Next, the objectives of the research are outlined. Finally, the layout of the remaining structure of the thesis is given.

1.2 Motivation

Product development is concerned with the design, manufacture, assembly, distribution, marketing of products, and so on. Over the past few years, it has been a focus of research for both academics and industrialists. This is due to the widespread recognition that competitive advantage can be achieved by effective product development in industry.

Engineering design plays a crucial role in the process of new product development. It is concerned with the development of detailed specifications for a product which provide a technical function. In order to increase the effectiveness of design, several computer technologies have been developed to support design, known as Computer-Aided Design (CAD).

Conceptual design is the first phase of the design process. Most basic functions of a new product and the solutions for solving design problems are generated in this critical phase, which will affect the attributes in the later detailed design process. Artificial Intelligence (AI) and computer technologies have been integrated to provide computer support for automated design which CAD fails to address.

However, conceptual design, especially the process of concept generation,

is an innovation process that is achieved by human intelligence. The intuition and experience of designers play a significant role during the design process which are hard to be replaced by computer-aided tools or artificial intelligence technology.

At the same time, design is a demanding process that requires expertise in many different fields such as science, engineering, and often art, all of which are distributed in different phases. Most of the literature assumes that conflict exists commonly in engineering design. However, there are few computational tools to provide support for the human designer to detect and resolve conflict in the early stages of design.

In most cases, creative activities such as generating new solutions or detecting and resolving conflicts are still left to human experts. There are a variety of techniques to help people improve creativity, such as morphological analysis, brainstorming, lateral thinking, TRIZ, etc. Compared with other creative thinking tools, TRIZ is one of the most powerful tools as it provides not only a general method for breaking out of the patterned way of thinking, but also a series of tools for solving technical problems.

Among the many TRIZ tools, the TRIZ contradiction matrix and 40 inventive principles are capable of coping with both of the issues in conceptual design identified above, which are innovative concept generation and conflict resolution.

However, TRIZ inventive principles have limitations such as their often illogical sequencing, their level of overlap and the gaps that they contain. As I-Ching and TRIZ use the same philosophy of dialectics thinking, the principles can be restructured and improved by the inspiration of I-Ching.

These modified TRIZ tools involve massive knowledge for resolving innovative problems. They can be integrated with the AI technique of Knowledge-Based Systems (KBS) to improve automation, efficiency, and creativity in conceptual design.

The starting points for the investigation of the proposed method are research questions and hypotheses, which can be summarised as:

① I-Ching can be a suitable tool for modifying TRIZ inventive principles.

② Modified TRIZ-based design methodology can be more efficient than classical TRIZ.

③ Integration of TRIZ and negotiation-based methods can provide inventive conflict resolution strategies.

The methodologies used in this research to prove the above hypotheses involve classifying TRIZ inventive principles, analysing symbolic expressions, developing a TRIZ-based design model, including a mathematical model of conflict resolution, and conducting a case study of aircraft fuselage design. The details of the research methods are described in Chapter 3, Chapter 4, and Chapter 5 of this thesis.

1.3 Objectives

The main objectives of this research are therefore as follows:

- To evolve TRIZ inventive principles and apply them to supporting creative concept generation.
- To integrate a negotiation-based approach and TRIZ to support conflict resolution.
- To provide, using KBS, computer support for this concept generation and conflict resolution at the stage of conceptual design.

1.4 Outline

The first part comprises six chapters. The remainder of its structure is as follows:

Chapter 2 reviews the background literature relevant to the work presented in the thesis.

Chapter 3 discusses the representation of TRIZ inventive principles as symbolic expressions. It also presents a collection of modified principles based on this representation.

This chapter discusses how 40 TRIZ inventive principles are restructured by analysing the similarities between them and I-Ching. Then the symbolic

expression for representing an inventive design solution is defined based on the new structure. The main meaning of the principles and other TRIZ derived tools are extracted and represented as symbolic expressions. They are then analysed and compared to remove redundant information and the new principles are selected.

Chapter 4 describes an approach that employs a knowledge base comprising rules that implement a Behaviour-Entity-Constraint (BEC) representation of modified TRIZ inventive principles.

A TRIZ-based concept generation model is presented. A case study conducting the design of the passenger cabin layout in an aircraft by applying the proposed method and a method using classical TRIZ is described to show the benefits of the new TRIZ-based approach.

Chapter 5 presents the detection and resolution of three types of conflict in conceptual design. It also details the implementation of a rule-based system developed using JESS (Java Expert System Shell) to generate automatically design concepts and the resolution of conflicts.

This chapter proposes an inventive conflict resolution model. A mathematical model for calculating the weights of conflict resolution strategies is described. The example of aircraft fuselage is used to illustrate the application of the method.

Chapter 6 presents the conclusions, contributions of the research and recommendations for further study.

Chapter 2 Literature Review

2.1 Overview

This chapter reviews the background literature relevant to the work presented in this thesis. First, conceptual design as an essential phase of engineering design is surveyed. This is followed by a review of current techniques supporting four phases of conceptual design. These four phases are: design specification and representation, concept generation, concept selection, and evaluation. Next, the literature on conflict resolution in conceptual design is reviewed. TRIZ, an inventive problem-solving tool, has been applied to solving engineering design conflicts and to generating inventive design concepts. This chapter then reviews the literature on TRIZ and its application to conceptual design.

2.2 Conceptual Design

Many researchers have tried to present a definition of conceptual design relevant to their own research background. However, so far there is not a well-accepted definition for conceptual design. According to previous literature articles, conceptual design has the following common features.

New and innovative: The conceptual design is a very important task in Computer-Aided-Design (CAD) [Wang 1994], particularly when designing new and innovative products, or when generating a completely new design for an existing product [Wang 2002].

Difficult: Knowledge of the design requirements and constraints during this early phase of a product's life cycle is usually imprecise and incomplete, making it difficult to utilise computer-based systems or prototypes [Hsu 2000]. It