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DEVELOPMENT OF CONCEPTUAL DESIGN SUPPORT SYSTEM BASED ON INTEGRATED THEORY OF INVENTIVE PROBLEM SOLVING AND ANALYTICAL HIERARCHY PROCESS

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By

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF CONCEPTUAL DESIGN SUPPORT SYSTEM BASED ON INTEGRATED THEORY OF INVENTIVE PROBLEM SOLVING AND ANALYTICAL HIERARCHY PROCESS

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November 2014

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After years of fierce rising competition in the market, conceptual design has become the most important stage in product design. In this stage, expediting the problem-solving and decision-making processes is a crucial issue. Hence, a systematic framework or set of methodologies that efficiently support the decision making on the solution ideas generated from problem solving tools is highly in demand**.** A computerized support system needed to assist human limitation in large data processing. This research develops a framework and system for concept generation using an integrated Theory of Inventive Problem Solving (TRIZ) and Analytical Hierarchy Process (AHP). The TRIZ contradiction matrix and 40 inventive principles solution tools are employed for idea generation, and AHP is used to weight the criteria of concept design. The weights applied to the criteria are standardised for any ensuing evaluation and selection task, such as problem prioritisation, idea scoring and alternative design selection. An initial study of a water bottle design illustrates the applicability and effectiveness of the integrated framework. The framework is then formulated in the computer-based Conceptual Design Support System (CDSS) to support the repetitive and time-consuming evaluation tasks in the framework. A pilot CDSS is developed focusing on car interior design. The criteria of the car interior design are analysed for the preparation of the pilot CDSS development. The glove compartment in the car interior is chosen as the pilot CDSS case study. The applicability of CDSS can be extended into a wider range of applications if the criteria of target design in CDSS is modified and developed specifically to a particular type of product design. Hence, CDSS is improved by adding two selected product design types, i.e., a consumer product and an eco-product. The concepts thus generated are assumed to be at a higher level of abstraction without detailed drawings or material information. In case study of glove compartment design, concept A of sliding type door and flexible partition inside scored the highest, 7.39 points. For the case study of in-house dustbin, Concept C scored the

highest with 6.38 points and in the final sketch, the concept has a cap that can be used to compress the rubbish inside by stepping on it. In composite automotive clutch pedal case study, the final concept sketch was designed with ribbed structures and layering the pedal with fire-and water-resistant thin films. The score was 34.36% improved in terms of an eco-product evaluation when compared to the current product. In conclusion, this research provides an effective integrated framework and a computerised system to formulate concept generation and evaluation in the early phase of conceptual design.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PEMBANGUNAN SISTEM SOKONGAN UNTUK REKABENTUK KONSEP BERASASKAN KAEDAH BERSEPADU TEORI MEREKACIPTA DAN PENYELESAIAN MASALAH DAN PROSES ANALISIS BERHIERARKI

Oleh

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Dalam persaingan yang semakin sengit di pasaran sejak beberapa tahun ini, rekabentuk konsep menjadi peringkat yang paling penting dalam rekabentuk produk. Pada peringkat ini, mempercepatkan kaedah menyelesaikan masalah dan proses membuat keputusan telah menjadi isu penting. Oelh itu, satu rangka kerja cekap yang dapat meliputi kerja-kerja membuat keputusan terbaik dalam pemilihan idea penyelesaian yang dijana oleh kaedah-kaedah penyelesaian masalah adalah sangat diperlukan dan sebaiknya dalam bentuk sistem berkomputer bagi membantu manusia terhadap data yang lebih besar. Kajian ini membangunkan rangka kerja dan sistem untuk penjanaan idea merekacipta dan proses membuat keputusan yang melibatkan criteria yang banyak semasa rekabentuk konsep. Teori Merekacipta dan Penyelesaian Masalah (TRIZ) dan Proses Analisis Berhierarki (AHP). TRIZ menggunakan matriks percanggahan dan 40 prinsip merekacipta alat penyelesaian telah digunakan untuk penjanaan idea, manakala AHP telah digunakan untuk mencari pemberat untuk setiap kriteria untuk digunakan dalam proses keutamaan masalah, proses saringan idea dan pemilihan alternatif rekabentuk. Satu kajian awal reka bentuk botol air membuktikan kebolehgunaan dan keberkesanan rangka kerja bersepadu. Rangka kerja tersebut kemudian dipersembahkan dalam sebuah system yang dikenali sebagai Sistem Sokongan Rekabentuk Konsep (CDSS) untuk menyokong tugas yang berulang dan memakan masa dalam rangka kerja tersebut. Sebagai percubaan, CDSS telah dibangunkan khusus untuk rekabentuk dalaman kereta. Laci kereta telah dipilih sebagai produk kajian. CDSS menunjukkan potensi untuk dikembangkan pengunaannya jika kriteria yang digunakan dalam target design diubah mengikut jenis produk. Kriteria yang digunakan mestilah diteliti terlebih dahulu. Jenis produk dalam CDSS telah ditambah dengan dua jenis produk lagi iaitu produk harian pengguna dan produk Eko. Konsep-konsep yang dijana dianggap berada pada tahap yang masih abstrak tanpa dimensi atau maklumat penting. Kes kajian terhadap laci kereta menunjukkan konsep A

yang mempunyai pintu bergelongsor dan fleksibel mendapat markah tertinggi iaitu 7.39 mata. Untuk kes kajian tong sampah di rumah, Konsep C mendapat markah tertinggi dengan 6.38 mata dan dalam lakaran akhir, konsep ini mempunyai penutup yang boleh digunakan untuk memampatkan sampah dalam dengan memijak di atasnya. Dalam kajian kes pedal komposit untuk automotif, lakaran konsep akhir telah direka dengan struktur berjalur dan pedal dilapis dengan lapisan filem nipis yang kalis api dan air. Ia memberikan skor yang lebih baik iaitu 34.36% lebih baik berbanding produk semasa dari segi penilaian eko-produk. Kesimpulannya, kajian ini menyediakan rangka kerja bersepadu yang berkesan disertakan dengan sistem berkomputer untuk memenuhi proses penjanaan dan penilaian dalam fasa awal reka bentuk konsep.

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I certify that a Thesis Examination Committee has met on 28 November 2014 to conduct the final examination of Mohd Uzair Bin Mohd Rosli on his thesis entitled "Development of Conceptual Design Support System Based on Integrated Theory of Inventive Problem Solving (TRIZ) and Analytical Hierarchy Process (AHP)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

TRIZ	Theory of Inventive Problem Solving
AHP	Analytical Hierarchy Process
CAD	Computer Aided Design
SWOT	Strength, Weakness, Opportunities, Threats
WSM	Weighted Sum Model
DFMA	Design for Manufacture and Assembly
VE	Value Engineering
QFD	Quality Function Deployment
MCDM	Multiple Criteria Decision Making
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
CR	Consistency ratio
CI	Consistency index
RI	Random index
GUI	Graphical User Interface
GD	Good Design
WBCSD	World Business Council for Sustainable Development
BPA	Bisphenol-A

LIST OF SYMBOLS

$\lambda_{\max}$	Maximum or principal eigenvalue of the pairwise comparison matrix
n	Number of activities in the matrix.

CHAPTER 1

INTRODUCTION

1.1 Background of study

The engineering design processis the formulation of a plan to help an engineer build a product with a specific performance goal. It is a multi-step process, including the establishment of design requirements, conceptual design, detailed design, production management planning, and final production (Boothroyd et al., 2010). Among those processes, conceptual design is known as the most important phase,requiring attention and concentration. Maleque and Sapuan (2013) stated that the conceptual design phase can be broken down into two cyclical major components,i.e., the generation of solutions to meet the need and the evaluation of those solutions to select the one that most meets the product design specifications (Pugh, 1991).

The conceptual design phase does not yet include the physical product. It is the abstract concept of the product (Olivia, 2011). It is the starting point of product development. Although the concept design is not physically represented, it is the most important phase for corrections or improvements. Shai et al. (2007) stated that in the conceptual design phase, the designers have the freedom to generate and explore ideas without being constrained by parameters that exist at the later design stages. The activities in the conceptual phases differ from the latter detailed design work. Detailed design generally employs well recognised tools to solve previously specified problems. The conceptual design phase is concerned with the problem of generating new ideas or new solutions to the identified problems. At this stage, designers and other members of the development team identify the true problem and search for the broadest possible range of alternative solutions. The goal is to ensure that the final solution is a relatively good one. At the conclusion of the idea generation stage, sketches or outlined specifications are formed for evaluation. After a thorough evaluation, the most promising concept goes forward to detailed design and development. Once production of the product begins, it is more difficult to change the characteristics of the product (Wang et al., 2002). Therefore, it is important to make sure the design is flawless before production.

The subjective and abstract nature of conceptual design in product development implies that designers need more complicated technical support and more sound methodologies when conceiving a new product idea. Apparently, it is difficult for a designer to obtain highly innovative achievements relying on manual processes alone; therefore, the assistance of a Computer Aided Design (CAD) support system is required. Using the complementary skills of computer and human, the designer can think out of the box, make up for his own knowledge limitations, and then quickly develop an innovative design. There are many mechanical CAD tools on the market to reduce the workload of the designer and thereby reduce product development time; however, they are still limited in applicability in the conceptual design phase. The strength and the use of the currently available CAD tools are more applicable in the detailed design phase than in the conceptual phase (Robertson and Radcliffe, 2009; Jenkins and Martin, 1993).According to Robertson and Radcliffe (2009), knowledge of the design requirements and the constraints during this early phase of the product life cycle is usually imprecise and incomplete, thus complicating automation. To date, there is no known commercial computer-aided conceptual design tool that is widely applicable to any type of product design on the market. Most of them are limited and designed specifically to a particular field of study (Rentema and Jansen, 2009; Chakrabarti et al., 2005; Hernandez and Shah, 2004).

1.2 Problem statement

Improvements made during the conceptual design stageespecially in the decision-making task, can significantly reduce the time to market and the overall costs for high-quality productsrather than at the detailed design stage. A hasty decision made during the conceptual design phase may be impossible to change during the following detailed design phase. The implication is that poor decisions at the conceptual design phase can cause companies to commit to wasteful spending before detailed development starts. The conceptual design phase demands a well-structured framework or set of methodologies that efficiently formulate the decision making task and support the solutions generated by the idea generation tools (Yu et al., 2008; Ho, 2008; Xu et al. 2007; Hsiao, 2002). Therefore, there is a need to generate and evaluate concepts in a proper and concise framework.

The conceptual design phase of the design process is generally dominated by the generation of ideas, which are subsequently evaluated against requirement attributes. Designers who recognise that a concept does not meet the market needs and specifications must therefore make the decision not to proceed (Al-Salka et al., 1998; Seiger et al., 1997). Developing products that do not meet the design specification or customer needs can prove an expensive mistake (Ulrich and Eppinger, 2011). Evaluation and selection processes might be better supported if the design methodology and the selection attributes were adapted to a particular design (Derelov, 2009). Therefore, an in-depth study of the related criteria, attributes or parameters is an important task related to the concept generation and the selection of new products.

The conceptual design process is a knowledge-intensive phase. It generally requires the collaboration of expertise from different disciplines (Wang et al., 2002). Even though the creative part relies totally on human input, humans are limited with respect to large data processing. It is difficult for them to explore all the design variants in a short time and make sound judgments (Buchal, 2002; Hsu and Liu, 2000). However, computers are capable of handling and processing large amounts of data. Hence, by combining human creativity with computer capabilities, it is possible to perform the conceptual design process more efficiently than using a manual design process alone (Woldemichael and Hashim, 2011).

1.3 Research objectives

The overall intention of this research is to identify and improve the crucial activities in the conceptual design phase.The general objective is to develop a conceptual design support system based on integrated Theory of Inventive Problem Solving (TRIZ) and Analytical Hierarchy Process (AHP). The specific objectives of this study are summarised as follows:

1. To integrate Theory of Inventive Problem Solving (TRIZ) and Analytical Hierarchy Process (AHP) in a framework for conceptual design phase.
2. To develop a computerised conceptual design support system from the integrated Theory of Inventive Problem Solving (TRIZ) and Analytical Hierarchy Process (AHP)framework.
3. To validate the Conceptual Design Support System (CDSS) using case studies.

1.4 Significance of the study

This study integrates the TRIZ and AHP methods for use in the concept generation and evaluation processes for product design development. A new product design framework applies a standardised target design for every ensuing decision-making task. Itappliesweightsdetermined earlier in the framework to the target design to keep the evaluation consistent with the target design. Indirectly, this integration enhances the TRIZ method by introducing solution refinement and selection.Most of the established TRIZ derivation methodsemphasiseproblem-solving issues. For a TRIZ-based system, this is the first attempt to integrate a decision-making tool in the system. Moreover, this is also the first conceptual design support system that introduces TRIZ in the idea generation task. The system also improves the concept generation session by providing an automated suggestion function for idea combination. In TRIZ methodologies, this is the first attempt to introduce idea combination as part of the methodology. The final applications of this research output are resulted as a valuable support at the industrial and academic level in product design.

1.5 Scope and limitation of the study

The conceptual design stage of this study is limited on concept generation, evaluation and selection. Three categories or types of product design are developed in CDSS, i.e., a car interior, a consumer product and an eco-product. The criteria have been specified to the particular category of product design which it can't be customized by user. The outputs are in concept sketches, which are usually at a high level of abstraction, i.e., without detailed drawings or material information.

1.6 Structure of thesis

This thesis is divided into five chapters. Following this chapter, chapter 2 presents a review of the literature related to the conceptual design phase and the integration between theory of innovative problem solving (TRIZ) and analytical hierarchy process (AHP). Chapter 3 presents a thorough description of the method used to develop the integrated support system and the survey conducted for a case study. The results and the discussion for the integration framework, the conceptual design support system (CDSS) development, case studies for each category and the system validation provided by the expert are covered in chapter 4. General conclusions and recommendations for future work, based on the present research, are discussed in chapter 5.

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