Intelligent Design Based on Knowledge Capture and Reuse

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Abstract. Engineering design is a creative activity which is depending on both scientific knowledge and innovative ideas of human being. Intelligently recommend the scientific knowledge to the designers would certainly shorten the time they spent in finding the data, information and knowledge they need for design decision-making. Thus, they can spend more time in the innovative activity of design. The design of a flexible gear for harmonic drive reducer is a knowledge intense job, where intelligent design method is required to facilitate the design process and thus well applicable. This paper explores a systematic methodology of undertaking intelligent design of such a mechanical component, through on knowledge capture, representation and reuse. A case study on a double-arc flexible gear design is undertaken as the evaluation and improvement of this methodology, whose results have shown the good effectiveness of the methodology in shortening the time for modelling, information retrieval and decision-making.

1. Introduction

Engineering design is a creative activity which is depending on both scientific knowledge and innovative ideas of human being. The creative ability is various for each designer, while is also depended on the data, information and knowledge he or she possessed. Since engineering designers spend above 50% of their time looking for data and information to assist their design tasks, finding a way to intelligently deliver the data and information to the designers needed is significant in improving design efficiency. This intelligent recommendation requires to firstly recognize the working context of the designers, and then provide the data and information related to the design context. In this way, the time engineering designers used in searching data and information is dramatically shorten, which allows the designers to spend more time on innovative part of the design. However, present computer-aided design tools focus either on streamlining the design procedures (e.g. 2D/3D modelling) or undertaking design documentation (e.g. Product Data Management), which lacks a kind of design support tool in intelligently recommending the possible data/information designers required for their decision-making on design tasks. To fill this gap, this paper proposes an intelligent design methodology on how to improve design efficiency through intelligent recommendation. This methodology includes three parts; the first one is to acquire the useful data, information and knowledge during the design process, the second one is to present them in a structured way, and the third one is to use intelligent Q&A system for potential solution recommendation. A design of flexible gear for harmonic drive reducer is chosen as example to demonstrate the methodology, where testing have been done to evaluate the effectiveness in undertaking design in a more intelligent way.
The rest of the paper is organized as follows. Section 2 reviews relevant work on design supporting methods and computer-aided design tools. Section 3 explains how to acquire the data, information and knowledge on design object and process, together with Section 4 describing how to present them in a systematic and structured way. Section 5 demonstrates the intelligent recommendation system depending on the design knowledge captured. A discussion and conclusion are drawn in Section 6.

2. Computer support tools for knowledge capture and reuse
Engineering design is a complex process where a range of data and information are required for its decision-making. To support the design process, computer-aided tools are developed and used to assist capturing, managing and reusing the data, information and knowledge, which can be regarded as knowledge management tools for knowledge generation, codification, and transfer [1]. The traditional method for implementing knowledge management is to use Product Data Management (PDM) systems to store design data and information in databases, which merely provide access to schematics, Computer-Aided Design (CAD) models, and documentations[2]. PDM systems manage documents such as reports, CAD data, engineering drawings, and analysis data through the design process. However, there are several shortcomings of these PDM systems, such as the lack of formal product representation in the form of function, behaviour and structure, lack of reuse of design knowledge, lack of impact analysis, etc., [3]. Aiming to improve the traditional method, Product Lifecycle Management (PLM) systems have been developed. The concept of PLM appeared in the 1990s as an extension of PDM [4], and the PLM is defined as the process of managing a company’s products from their conception, design, manufacturing, all the way to its use and disposal [5]. The purpose of PLM systems is to integrate information on the manufacturing processes (CAM systems) with design data (CAD systems) on the one hand, and information about Enterprise Resource Planning (ERP) processes on the other hand [6]. However, these PLM systems lack essential capability for the management and reuse of design knowledge [7], [8] and are less suited for the conceptual design stage [7], [9]. Moreover, a significant shortcoming of existing PLM systems is that they are lack of adequate information models for product presentation, as these models would be needed to effectively capture, exchange, retrieve, and reuse design knowledge [10].

Knowledge management system method is a systematic process of acquiring, accumulating, and sharing individual knowledge, and uses them to strengthen competitiveness [11], and a knowledge management system should be able to explicitly represent the tacit knowledge of designers, and facilitate expansion of the knowledge through the knowledge acquiring-storing-using cycle [12]. Recent research is focusing on developing a generic representation of product knowledge that includes other kinds of product knowledge beyond structure, function, and behaviour, in order to support a broader level of information exchange and interoperability [13]. Product knowledge is represented in terms of requirements, specification, artefacts, structure, functions, behaviours, design rationale, constraints and relationships. Such representation supports multiple levels of abstraction, which provides computational support for early design activities [10]. The support tools currently available for capturing design rationale using visualised and structured knowledge representation include the Compendium [14], [15] and the Design Rationale Editor (DRed) [16]. Also, the DRed tool has been developed and successfully integrated to the Rolls-Royce PLM toolset [4], [16], which provides a solution for the integrated knowledge management in engineering design.

3. Knowledge capture on the design object and process
In order to intelligently recommend the data, information and knowledge to engineering designer, knowledge acquisition from previous design projects are firstly required. In an engineering design project, the knowledge on decision-making of a design task is the key for the intelligent recommendation. This kind of knowledge includes structured knowledge (explicit knowledge) and unstructured knowledge (tacit knowledge). The previous one is mainly from formula, methods and theories, which is easier to be captured. The later one is more likely from designers’ experience embedded in their brains, which is difficult to be captured and reused. From the authors’ previous research, creating a RFBSE knowledge representation model [17] for a specific design project is able to capture and represent both explicit and tacit knowledge.
In this research, a design on double-arc flexible gear for harmonic drive reducer is chosen as research subject, and the RFBSE model is used to undertake the knowledge acquisition task. During its engineering design process, the knowledge generated in five aspects are particular focused, which are the requirements of the design as well as how to transfer the general requirement into technical function of the design object, the functional analysis and functional decomposition, the expected behaviour generation and actual behaviour evaluation, the structure synthesis and decomposition, and the design evolution. The design knowledge is captured in the form of Know-What, Know-How and Know-Why in a tree structure, resulting a whole knowledge map describing the design knowledge generated together with the relationships during the whole design process, as shown in Figure 1.

4. Representation of design knowledge
A Web-based knowledge management system is developed for the design knowledge representation, allowing engineering designers to easily record their design knowledge during the design process. The user interface of the system uses graphic representation to capture and represent the design knowledge in a tree structure. Firstly, a structural decomposition has been done to give a clear structure to the elements of the design object. Then, a range pieces of design knowledge are attached to the ‘branch’ as ‘leaves’, where three-level representation is used, i.e. know-what, know-how, know-why. Among them, know-what describes the basic information of each element, know-how explains the process knowledge, while the know-why demonstrates the design rationale. By integrating this three-level knowledge representation, the tacit knowledge embeded within engineering designer’s brain can be captured in a systematic way for future reuse. Also, to give a clear view on design object, its 3D model has been attached alongside the knowledge representation tree, giving a 360 degree rotating view on the design object, as show in figure 2.

Figure 1. Method of Knowledge capture and representation

Figure 2. Knowledge capture and representation in the Web-based knowledge management system
In Figure 2, the tree structure on the right records the knowledge related to the design of the flexible gear, e.g. geometry, material, manufacturing, design evolution, maintenance, etc. More detail
representation of these aspects can be added in terms of know-what, know-how and know-why, which gives an extendable frame for the knowledge capture and representation. On the right-hand side of the tree structure, a 3D model, i.e. a flexible gear in this example, has been displayed in panoramic view, which can give users a visual view on the design object and its design knowledge captured. At the same time, a graphic database is used in the back-end to store the responding knowledge elements and their relationship. Also, any data and information related to the design object can be attached in respective element, forming a knowledge graph, as shown in Figure 3.

![Figure 3. Knowledge map](image)

Figure 3 shows how the knowledge elements are connected to each other. The assembly with orange colour can be decomposed into several parts with blue colour which is the minimum structure that cannot be decomposed anymore. For each part, there are several elements, among which know-what with brown colour is used to describe the basic information. Know-how with pink colour is used to explain the procedures while know-why with green colour is linked with know-what or know-how in demonstrating the design rationale. In this case, an integrated knowledge graph is created for knowledge representation and reuse.

5. **Intelligent recommendation on the design solution**

Based on the Web-based knowledge management system and the knowledge graph created, the design knowledge can be reused through intelligent recommendation according to the various working context of the engineering designers. When the designers use the system for recording design knowledge or retrieving specific data and information, the system will record their trace of use and then subsequently recognize the working context of the designers. For instance, when a designer is searching a material, the system will recognize he/she is at the stage of material selection, and then intelligently recommend several possible materials. Thanks to the knowledge representation model and knowledge graph, the relevant data and information can be easily and efficiently located in the database. For example, when a structure decomposition model of the robotic arm is created, it records the relationship between the flexible gear with the motor, harmonic drive reducer and robotic arm, the data and information of the flexible gear can be easily retrieved and recommended when designing a flexible gear in a robotic arm when the system has recognised the designer is designing a specific robotic arm, as shown in Figure 4.
In Figure 4, the Web-based knowledge management system will firstly record the users’ behaviours on searching the data, information and knowledge related to a robotic arm, the information they record in the system, and the key words or sentences they used for retrieving data and information, then the system can recognize the designer is designing a flexible gear and quickly located the relevant data and information in the database, and intelligently recommends the preferred information to the designer for their decision-making. In this way, the time that designers spent in finding relevant data and information they required for decision-making is significantly shorten, which eventually improves the design efficiency.

6. Conclusion

A large number of data and information are generated during engineering design process, and they are also required for design decision-making. In this case, efficiently finding and reusing these kinds of knowledge can significantly improve design efficiency through shortening the time in information retrieval. This paper has proposed an intelligent design method based on capturing and representing design knowledge, and subsequently providing them the designers based on their design context through intelligent recommendation. A case study of applying this method on a flexible gear design on harmonic drive for robotic arm has shown the feasibility of this method in improving design efficiency through knowledge capture and reuse.

7. References

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