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Recording the design thought process as time variation in parameter network

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ABSTRACT

Understanding of the design thought process of experts with different disciplines is indispensable for the success of multi-disciplinary design projects. Although protocol analysis is a widely used method for understanding the nature of the design thought process, its application on multi-disciplinary design projects is not easy due to its limited capability for interrelating every action recorded in the entire process referring to various types of information. To solve this problem, the paper proposed a method that records and analyses the design thought process as time variation in parameter network. A case study is provided to discuss the feasibility of the method.

1. Introduction

Due to growing complexity of current engineering systems, multi-disciplinary collaboration among various experts in different domains (including non-engineering experts such as purchasing, marketing, and business planning etc.) is crucial for designing innovative systems [1]. Much research has been conducted to enhance multi-disciplinary collaboration in product development (e.g., 2–6). For example, some focused on information technologies that help share knowledge and information among experts [3,4].

Regardless of such research, mutual understanding of professionals with different backgrounds is difficult because each has a different mental framework regarding design thought process. Protocol analysis (e.g., 7–10) is a widely used method since it helps externalise designers' thinking by the transcribed verbal record based on a predefined coding scheme.

However, application of this method to a multi-disciplinary design project is not effective enough at designers' mutual understanding due to two problems. One is that protocol analysis cannot distinguish various types of information recorded in the design thought process. These types are related to, e.g., design rationale and design object. The other is that many of existing protocol analysis methods cannot interrelate these various types of information to each other, because they simply record every action of design thinking in a temporal sequence. It should be noted that linkography [10], which clarifies the interrelationship between two activities in the design thought process, is an attempt to address the second problem.

The goal of the study is to propose a computer-aided protocol analysis method for multi-disciplinary design projects. As a first step, this paper proposes a method for representing and analysing the design thought process. Our approach to solving the above two problems is as follows:

1. Representing designers' thought at a particular time as a *parameter network* [11], which is a network-based knowledge representation scheme aiming at describing every idea generated in the design thought process.
2. Recording the entire design thought process as a temporal sequence (i.e., time variation) of parameter networks.

In addition, we analyse the structural changes in the time variation of parameter networks to understand the design thought process in a systematic manner.

The rest of the paper is organised as follows. Section 2 proposes a design thought representation model based on parameter network and explains our approach to record and analyse design thought process based on the model. Section 3 provides an example of analysing the design thought process of a software system. Section 4 discusses the analysis results. Section 5 concludes the paper.

2. Design thought process as time variation in parameter network

2.1. Representing the design thought process as parameter networks

When developing a representation scheme for a protocol analysis method, it is required (i) to distinguish various types of information and (ii) to interrelate every action recorded in the entire design thought process. To solve problems (i) and (ii), we employ a parameter network model [11], which explicitly represents the relationship among any type of design knowledge by using graph.

A parameter network model is defined as a graph consisting of three types of nodes (i.e., *parameter*, *relation*, and *entity*). Parameters correspond to any attributes or properties with entity concept in Yoshikawa's general design theory [12]. Relations correspond to any kinds of relations among multiple parameters that are focused and named by the designer including hypothesis and actions for controlling subsequent design process (e.g., "Dimension of the shaft should be optimised after its noise and vibration level is

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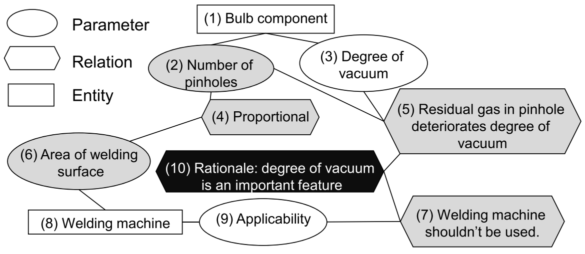

Fig. 1. An example of parameter network model.

expected.") as well as knowledge about design object. Entities, which correspond to any concrete objects that are existing, existed, or will exist, are used to specify its associated parameters.

Fig. 1 shows an example of a parameter network model for the machining process of a bulb component. Ovals, hexagons, and rectangles in this figure represent parameters, relations, and entities, respectively. In Fig. 1, the designers' knowledge about the machining process "The number of pinholes produced in welding process increases as the area of welding surface increases." is given as the partial graph including two attribute nodes (2) and (6) with one relation node (4). Two entities "Bulb component" (node (1)) and "Welding machine" (node (8)) are also used to specify their associated parameters (nodes (2) and (6)). In the design situation given in the figure, the designer evaluated the applicability of the welding machine and decided not to use it (as given in relation node (7)). The rationale for this decision is "Degree of vacuum of the bulb component is an important feature, which is deteriorated by the number of pinholes." is also represented by drawing a relation node (10) and connecting it to the node corresponding to the rationale (node (5)) and that corresponding to the decision (node (7)). In this way, the parameter network model enables the following:

- A clear representation of design object and design rationales.
- An explicit representation of the interrelationship between a design object and associated design rationales.

2.2. Analysis method

As depicted in Fig. 2, a design thought process is recorded as the time variation of parameter networks. To comprehend the design thought process from both microscopic and macroscopic viewpoints, we analyse the design thought process based on two types of element:

- Model edit operation (microscopic): the smallest unit of design activities, which corresponds to a verbal sentence in conventional protocol analysis method. Examples of model edit operations in a parameter network include "addition of nodes" and "deletion of nodes."
- Design phase (macroscopic): a semantic unit of design activities, which corresponds to a particular task or mental process, upon which overall design process is structured and understood. Examples of design phase may include understanding the problem, generating a solution, evaluating the solution, deciding, and controlling the design process.

In Fig. 2, parameter networks, model edit operations, and design phases correspond to ovals, arrows, and rounded rectangles in dotted line, respectively.

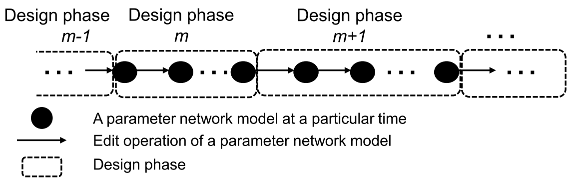

Fig. 2. Relationship between parameter networks, model edit operations, and design phases.

The analysis consists of three steps as follows:

1. Segmentation of the design thought process: categorises the time variation of parameter networks into several groups (i.e., design phases) based on the number of nodes. Our hypothesis here is that the number of nodes is a critical indicator because, typically, design activities are the iteration of diverging and converging ideas.
2. Characterising and labelling design phases: analyses distribution pattern of model edit operations in each design phase to understand how the phase is positioned in the entire design thought process. The classification scheme used in this step is provided in our previous study [13], which was empirically determined through several case studies. An example of classification scheme will be illustrated in Section 3.
3. Comparing design phases: compares parameter networks in different design phases. For this comparison, one or more indicators (e.g., total number of nodes/edges, network density, centrality, and graph partitioning pattern) should be determined to mathematically characterise the structure of a parameter network. Comparing the values of an indicator of parameter networks in different design phase, overall evolution of the design thought is analysed.

In order to record the design thought process and support the analysis method based on it, we have developed a parameter network editor that records every edit operations in the session.

3. Case study: Design Brain Mapping (DBM) system

As a case example of the proposed method, we chose the Design Brain Mapping (DBM) system as a targeted design object. The focus was on the conceptual design process, which is an early phase of the design thought process. The DBM system is a computer-aided communication and knowledge sharing system that especially aims at enhancing the idea generation in brain storming sessions. The system consists of several computers located in different sites, each of which is connected to the others via the Internet so that people located in different sites are able to attend the same session. The DBM system has been developed in the Japanese governmental project [14], which aims at fostering the collaboration between industry, academia, and government. AIST, authors' affiliation, is leading the development of the DBM system and the design team were requested to discuss its future development directions based on the user's feedback and technical constraints of current version. Therefore, four designers were invited to a series of design sessions (three sessions in total). All of the designers had learned how to represent their thought as a parameter network before the sessions began. Below, we present the results of the three-step analysis in Section 2.

3.1. Segmentation of the design thought process

Fig. 3 shows the numbers of nodes and edges at each step in the sessions. The horizontal axis corresponds to the cumulative number of total model edit operations and the vertical axis corresponds to the number of nodes and edges. We segmented the design process into three design phases, each of which has a different trend in terms of the differential of the number of nodes.

3.2. Characterising and labelling design phases

Table 1 summarises the distribution of model edit operations in each design phase. As shown in Table 1, we applied seven types of model edit operations (viz., addition of nodes, deletion of nodes, moving of nodes, changing contents of nodes, addition of edges, deletion of edges, and classification of nodes) referring to our previous work [13]. Table 1 shows that three design phases (I)–(III) had different distribution patterns in model edit operations. Detailed differences are described as follows.