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A similarity measurement framework of product-service system design cases based on context-based activity model

Yu Wu [a], Ji-Hyun Lee [b,*], Yong Se Kim [c], Sang Won Lee [d], Sun-Joong Kim [b], Xiaofang Yuan [e]

[a] China-Korea Institute of New Media, Zhongnan University of Economics and Law, Wuhan, People's Republic of China
[b] Graduate School of Culture Technology, KAIST, Daejeon 305-701, Republic of Korea
[c] Creative Design Institute, Sungkyunkwan University, Suwon, Republic of Korea
[d] School of Mechanical Engineering, Sungkyunkwan University, Suwon, Republic of Korea
[e] School of Art and Design, Wuhan University of Technology, Wuhan, People's Republic of China

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ABSTRACT

Design experience from previous design cases could help designers solving current design problems. Therefore, a case-based recommender system can recall suitable design cases for designers based on a similarity measurement mechanism. In the context of Product-Service System (PSS) design, the measurement of similarity between different cases becomes more challenging because of the complex nature of the PSS design. In this research, we propose a similarity measurement framework of PSS design cases based on the context-based activity model. In the proposed framework, a PSS design case is indexed and quantified by design activity element, design process, and function requirement. Ways to measure similarity between design indexes and design cases are also specified. A case study along with an empirical validation was conducted to validate the framework.

1. Introduction

Product-Service Systems (PSSs), the combination of products and services, have been increasingly emphasized since the realization that service in combination with products could provide higher profits than products alone. The success of several leading companies such as General Electric Co., IBM Corp., Siemens AG and Hewlett-Packard Co. was illustrative of this (Baines et al., 2007; Sawhney, Balasubramanian, & Krishnan, 2004). The involvement of designers in the development of services brought an extension of the traditional discipline of design, towards a new domain that requires designers with expertise to manage particular characteristics of both products and services (Morelli, 2002). Design experience from previous designs plays a key role in developing design solutions to the problems that confront us (Maher & Zhang, 1993). Thus, the demand for reusing design experience in PSS design is essential to the design problem-solving process. A case-based reasoning (CBR) system can help designers reusing design experience by recalling a suitable design case based on a similarity measurement mechanism and acting as a recommendation system.

One of the important issues in developing a case-based recommender system is to measure the similarity between different cases, as determined by the case representation framework and case recall methods. The development of a case representation framework is more complicated in the context of PSS design because of the complex nature of PSS design and the interdependencies of products and services. The similarity measurement between different PSS design cases becomes challenging. Consequently, there are few comprehensive design knowledge representation frameworks developed for case comparisons. Existing frameworks capture the design knowledge of products and services, not the design knowledge of the design process and other issues. Thus, the design experiences from PSS design cases are incomplete (Lin, Shih, Lu, & Lin, 2010). Most of them lack measurable factors utilized to index PSS design cases. Further, they lack case retrieval strategies that could be developed according to the characteristics of these factors. Accordingly, existing frameworks are suitable for design knowledge reuse, but are not competent for design process comparison (Baxter, Roy, Gao, & Mann, 2009).

Our aim is to develop a similarity measurement framework of PSS design case that could be utilized to build a case-based recommender system (CBR-RS) for accessing design experience more efficiently. A CBR-RS is one application of CBR in the reuse of design knowledge, creating an index of the problem area and applying artificial intelligence techniques to find similar cases (Wood &

* Corresponding author at: Graduate School of Culture Technology, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea.
E-mail address: jihyunlee@kaist.ac.kr (J.-H. Lee).

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Agogino, 1996). Specifically, we focused on the representation and similarity measurement of PSS design cases. To achieve the goal, our methodology is divided into three parts. First, a PSS design case representation framework for capturing design knowledge of products, services, and design processes is proposed. Second, a PSS design case is indexed by PSS design activity elements, PSS design process, and function requirement, and further quantified by using quantitative attributes. Third, similarity measures are developed to calculate the degree of similarity between PSS design cases. The similarity measurement framework of PSS design case, along with methods for case indexing, quantification, and a measure of similarity, is validated through the case study. The similarity measurement framework of PSS design case, along with methods for case indexing, quantification, and a measure of similarity, is validated through the case study, and the similarity results derived from the framework were assessed by a group of experts through the empirical validation survey.

2. Product-service systems and case-based recommender systems

The concept of PSS provides a systemic perspective to view existing environmental problems because it suggests a solution by combining products and services. Product-oriented design strategies have made incremental changes in the economic or environmental performance of the industry; however, PSS fundamentally challenges the current paradigm of the design (Williams, 2006). For consumers, PSS means a shift from buying one physical product to buying system solutions that could reduce environmental impacts. For PSS providers, PSS means a high degree of responsibility for the product's whole life cycle. It consequently means that PSS designers must consider their new role and start to use effective design tools to deal with the complex issue, a typical design process of the PSS. Kim and Lee (2011) introduced a PSS design process including six design stages: (1) requirement identification and value targeting, (2) stakeholder activity design, (3) PSS function modeling, (4) function-activity mapping and PSS concept generation, (5) PSS concept detailing, and (6) PSS concept prototyping. Stakeholder activities are the most important aspect of PSS design. Thus, they also developed *context-based activity modeling* where activities are represented systematically with *actors*, *objects* and *action verbs* as well as *context elements*.

Lorenzi and Ricci (2005) proposed an interpretation framework to model the mechanism of CBR-RSs and explained how generic steps and issues of CBR problem-solving cycles, such as case representation and case retrieval, are specialized in CBR-RS. "Case representation" is vital to produce a set of recommendations for users to retrieve items whose descriptions match the user's query. The knowledge related to a designer's previous activity must be represented for reusing design experience from previous cases; design knowledge can be represented in various formats (e.g., texts, sketches, drawings, behavioral diagrams, or grammatical rules) (Eilouti, 2009). Maher and Zhang (1993) identified three main issues in case representation, the content of design cases, the case memory organization and the presentation of design cases to the user, where identifying the content of the design case determines the design knowledge included. According to Ahmed (2005), the design knowledge concerned could be classified into four types: (1) the design process itself (i.e., description of design tasks in the design stages), (2) The physical product produced, (3) The functions that must be fulfilled and (4) issues that are considered by designers in the design process.

Case indexing is closely related to case retrieval (Jeng & Liang, 1995). There are some guidelines for selecting indexes, such as predictiveness, abstractness, and concreteness. The commonly used indexing methods are checklist-based, relationship-based and explanation-based (Kolodner, 1993). The selection of case indexes depends on the purpose of the CBR system. For example, Lin et al. (2010) proposed a CBR system to provide a strategy for PSS design, in which 12 case indexes related to user behavior, product, and external environment were selected to describe PSS cases. There are two major case retrieval approaches, computational and representational. The computational approach is more widely used in CBR applications where the similarity measures are based on the semantic distance between cases (Liao, Zhang, & Mount, 1998). Similarity measures are more context-dependent and have strong relationships with the type of attributes representing the case: textual, numeric and semantic (Nunez & Sanchez-Marre, 2004). The textual attribute is to describe design requirements and solutions while semantic attributes are used in situations where case indexes have some internal relationship beyond the text. For semantic and textual attributes, taxonomy-based distance is utilized to measure the similarity between concepts in the taxonomy with several approaches such as edge-counting approach, featured-based approach, and information content-based approach.

For the purpose of reusing design experience from previous PSS design cases, the design knowledge related to designers' activity should be represented in the case. According to the context-based activity modeling developed by Kim and Lee (2011), the content of a design case includes the design knowledge of the designer, design tool, design object, and design context. Case index *designer* represents the personal creativity characteristics of a designer. Various tests can be performed to measure creativity characteristics, such as the personal creative test, learning style test, idea generation test, Torrance test of creative thinking, and visual reasoning test. Case index *design tool* includes design methods and software utilized in the PSS design process since they can be organized to build design tool taxonomy. The design methods can be further divided into general design method and PSS design methods, such as CDI PSSD method (Kim & Lee, 2011), MePSS method (Van Halen, Vezzoli, & Wimmer, 2005) and Brissaud method (Maussang, Zwolinski, & Brissaud, 2009)). The design software can be categorized into special software and general software. Case index *design object*, representing the product and service generated in the PSS design process, can be assigned with a unified code as case attribute. Unified codes, such as eCl@ss, UNSPSC, eOTD, and RNTD, provide an open, global multi-sector standard for efficient classification of products and services. The *design context* contains three case indexes: relevant structure, physical context, and psychological context. The relevant structure can be categorized into three sub-categories: PSS design object itself, systemic structure supporting PSS design, and structure of the existing product. Physical context includes time, location and communication. Time can be indexed by two sub-indexes, daily working hours of design activity and the total given time of a design project. Location considers the size of the space determining the collaborative characteristics of the design team, and communication means the physical condition of design communication. The psychological context consists of occupant context, mood context, affect context, social context, cognitive context, and motivation context.

Recent PSS design research emphasizes the importance of reusing past design experiences and cases for achieving creative design outcomes (Ahmed, 2005; Fu et al., 2015; Kim & Kim, 2015; Kim, Lee, & Kim, 2014; Linsey, Markman, & Wood, 2012). In light of this trend, there have been recent studies on the design knowledge management that enable saving and retrieving design cases to design a brand new PSS. Many researchers developed methods, frameworks, and tools for supporting knowledge-based PSS design. Akasaka, Nemoto, Kimita, and Shimomura (2012) represented a