A Product Family Knowledge Management Framework using the Semantic Web

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시맨틱 웹을 이용한 Product Family 지식관리 프레임워크

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Abstract

오늘날 치열한 글로벌 마켓의 경쟁환경에서 많은 회사들이 제품의 경쟁우위를 확보하기 위해 고객에 대한 빠른 대응과 유연하고 효율적인 새로운 제품을 적기에 개발하기 위한 방법으로 product family 기반의 제품개발과 고객맞춤형 제품개발 방법을 도입하고 있다. 많은 제품들의 가장 중요한 비즈니스 프로세스 요소는 제품의 전체 라이프 씨이클동안 제품 데이터를 관리하는 것이다. 서로 다른 저장 구조를 가지는 이기종 소프트웨어 시스템에 의해 수집되는 제품 정보는 서로 다른 조직의 정보시스템내에서 인덱싱, 탐색, 정제, 재사용, 분배되는 것이 어렵다. 본 연구에서는 현재의 제품 설계 저장소의 이러한 문제점을 해결하기 위해, 시맨틱 웹 패러다임을 사용하여 product family를 대상으로 지식 관리 프레임워크를 개발하고자 한다. 시맨틱 웹 패러다임의 formal product representation은 제품 플랫폼의 구조를 저장할 수 있고, product family의 서로 다른 부품들을 공용으로 사용할 수 있도록 도와줄 수 있을 뿐만 아니라, product family 기반의 제품개발과 고객맞춤형 제품개발이 가능하다. 본 연구에서는 일회용 카메라를 대상으로 제안한 프레임워크의 타당성의 입증을 위한 프로토타입을 제시한다.

Keywords : Product Family, Platform-based Product Design, Knowledge Management, Semantic Web

1. Introduction

Product representation schemes and design repositories have progressed remarkably in the past decade to facilitate platform-based product development and product family design to support mass customization [1]. In engineered products, one of the most critical business processes is managing product and process data over the total product life-cycle [2]. Developing complex, customized products requires timely, accurate design information be exchanged between designers who are usually distributed across space and time. As design becomes increasingly knowledge-intensive and collaborative, the need for computational design frameworks to support the representation and use of knowledge among distributed designers becomes more critical [3].

In addition to sharing and exchanging information, pressure to reduce product development time has resulted in an increased focus on methods for representing and storing engineering artifact knowledge in a way that facilitates its retrieval and subsequent reuse [3]. In order for designers to create or develop better designs in a limited time, they need more than the geometric data and its associated documentation while designing a product. A computational framework that can capture the design process and the associated knowledge is driving the research in the area of design repositories- knowledge bases of heterogeneous

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product design knowledge that can be searched and reused [4].

As the number of products in a product family increases it becomes increasingly difficult to coordinate product design information. The burgeoning proprietary standards for product design information storage make it exceedingly difficult to manage all the possible variants while designing a product family. In a product family, where a wide variety of products are derived from a common platform by reusing existing modules and components, it becomes difficult, if not impossible, to integrate design information. In order to overcome these limitations, we propose a product family knowledge management framework using the semantic web paradigm which helps integrate and reuse data and reduce data redundancy in a product family while increasing data comprehensiveness. As an example, a product family consisting of seven one-time-use cameras is presented.

2. Background and Related Works

2.1 Product Family Design

In a product family there are three different types of components: common, variant, and unique. A unique component is a part only used by one product in the family. A variant component has the same function between some or all the products in the family, but the design, shape and/or material differ slightly from one product to the next. A common component is the exact same part shared by some or all of the products in the family. To measure the commonality within a family of products, several commonality indices have been proposed. A commonality index is a metric to assess the degree of commonality within a product family.

It is based on different parameters such as the number of common components, component costs, manufacturing processes, etc. These indices are often the starting point when designing a new family of products or when analyzing an existing family [3].

They are intended to provide valuable information about the degree of commonality achieved within a family and how to improve a product's design to increase commonality in the family and reduce costs.

2.2 Product Information Management Systems

Due to past limitations in information technology capabilities, product information management systems often evolved in an uncoordinated fashion resulting in islands of automation that do not easily communicate with each other. Many data formats evolved to capture product design information across different phases of the product realization process.

Existing product design information systems produce output in one or more of the standards summarized in <Table 1>.

The burgeoning proprietary standards for product design information storage make it difficult to integrate and thus reuse component design information across an enterprise. A computational framework that can capture the design process and the associated knowledge is driving the research in the area of design repositories-knowledge bases of heterogeneous product design knowledge that can be searched and reused [5].

A design repository captures design processes, design rules, constraints, rationale, etc., which helps reduce product design and development time.

The National Institute of Standards and Technology (NIST) is involved in the development of an intelligent design repository based on Data Language and a Design Representation Language [6, 7].

<Table 1> Different types of product data [4]

Product data type	Traditional data format	Web-enabled data format
3D solid models	STEP	VRML
2D engineering drawings	DXF, DWG etc.	DWF
Images	TIFF, GIF, JPEG etc.	GIF, JPEG
Unformatted documents	TXT	XML, HTML, TXT
Formatted documents	MS Word, Postscript	PDF, MS Word
Forms	Lotus 123, MS Excel	HTML
Sectors of database	Database	XML, HTML
Audio	WAV etc.	MP3
Video	MPEG etc.	MOV
Animations	-	VRML

Shooter, et al. [8] present a model for the flow of design information that is sufficiently formal to eventually support a semantics-based approach for developing information exchange standards. Several commercial software packages provide a hierarchical decomposition of product structure, but they all lack a standard open repository structure.

More recently, the design repository at the University of Missouri has implemented a XML-based approach to import and export the product knowledge from the design repository [5]. Though XML representation provides a standard data structure for describing the artifacts, it does not provide the semantics, i.e., the meaning of the data structure.

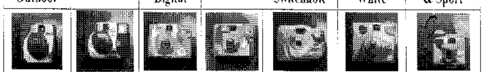
2.3 One-time-use camera family example

In this paper, the one-time-use camera family is used as an example to verify and validate the proposed framework. The one-time-use camera family consists of seven Kodak cameras readily available in the market with specific functions: flash, digital processing, waterproof, black and white, and Advanced Photo System with switchable format. These products represent a typical product family. <Table 2> summarizes the seven cameras and the major distinguishing characteristics of product.

3. A Product Family Knowledge Management Framework

As product complexity increases, there is an increased need for ubiquitous access of product design information from a variety of sources. Well suited to meet this need are design repositories - knowledge bases of heterogeneous product design knowledge that can be searched and reused [4].

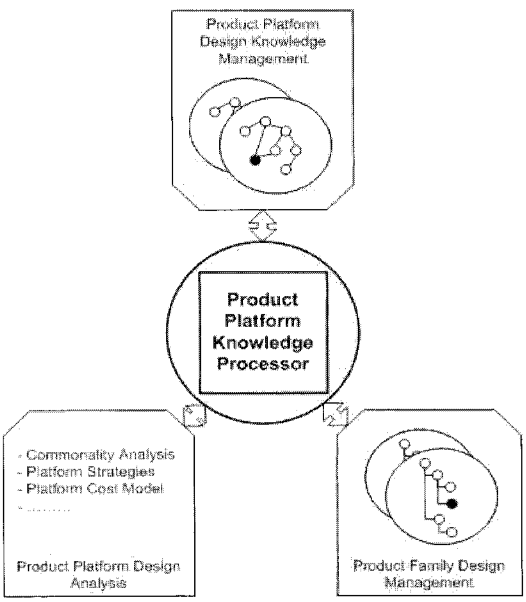
<Table 2> Summary of one-time-use cameras

	MAX Outdoor	MAX Flash	Plus Digital	MAX HQ	Advantix Switchable	Black & White	MAX Water & Sport
							
Film	35 mm color	35 mm color	35 mm color	35 mm color	24 mm color	35 mm black and white	35 mm color
Flash	No	Yes	Yes	Yes	Yes	Yes	No
Waterproof	No	No	No	No	No	No	Yes
Switchable format	No	No	No	No	Yes	No	No
Digital Processing	No	No	Yes	No	No	No	No

As mentioned before, there are several existing commercial products and research initiatives existing for product design information management. All the packages store product data in their own proprietary data structure, and no common vocabularies have evolved to capture product platform domain knowledge.

The proposed knowledge management framework seeks to apply the Semantic Web paradigm to develop design artifacts using OWL [9], which will support platform-based product development on a common ontological foundation. <Figure 1> shows the conceptual model of the proposed knowledge management framework. The product platform knowledge management module stores the platform design information with the help of the Semantic Web standards. The Product platform design analysis module provides the techniques for computing various metrics and indices for analyzing the stored product families. Product platform design manipulation and visualization will be performed by the product family design management module. The Product platform knowledge processor module acts as the aggregator for the relatively decoupled other three modules of the framework.

In this paper, we describe the product platform design knowledge management module and the product platform design analysis module.



<Figure 1> Conceptual product platform knowledge management framework

3.1 Product Family (Platform) Design Knowledge Management

The product family (platform) design knowledge management module primarily performs design information acquisition, classification and storage using the Semantic Web standards.

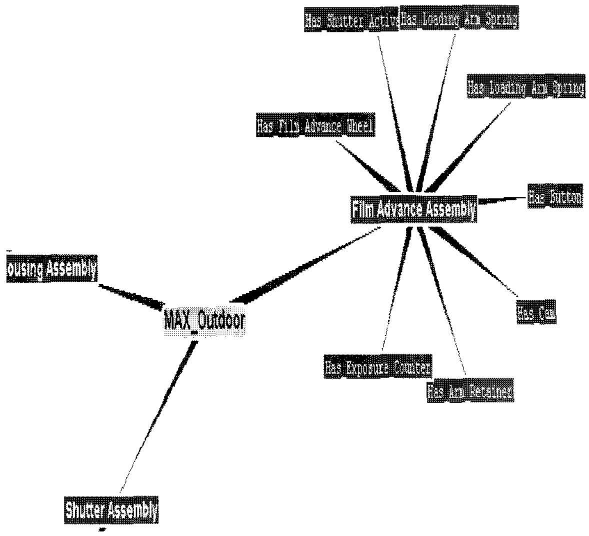
3.1.1 Product Family (Platform) Design Information Acquisition

A function of a product is a statement of a clear, reproducible relationship between the available input and the desired output of a product, independent of any particular form. Functional decomposition and physical disassembly of existing product families will help in acquiring the initial design information for building the proposed knowledge base. Functional decomposition of a product leads to identification of product architecture, assemblies, solution principles, modularity, and interactions that are part of the product. The initial stages of building the knowledge base for product platform requires systematic teardown of existing product families with the objective of finding assembly and component structures. Subsequently the captured design knowledge is reused for alteration of existing components and development of new products in a product family.

After physically disassembling a set of products, the components are analyzed to transform the results into an ontology for exploring and evaluating the physical and functional design. Product family teardown helps in understanding the engineering manifested within a product family and ontologies help in capturing the design knowledge in a structured way. The basis of the proposed disassembling procedure will be the reverse engineering and redesign methodology proposed [10]. This methodology helps in developing a complete understanding of the product through disassembly, functional analysis, compatibility studies, and physical modeling.

As an illustration, <Figure 2> shows the components of the MAX Outdoor camera's film advance assembly.

The MAX Outdoor camera is a part of the Kodak one-time-use camera product family, and the information presented in <Figure 2> is obtained after disassembling the camera.



<Figure 2> Section of the "MAX Outdoor" camera product structure

Decomposition of the product helps in the acquisition of design information in the Semantic Web standard, particularly in OWL ontology form.

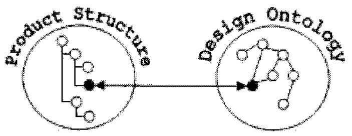
3.1.2 Product Family (Platform) Design Information Representation

The ability to define design artifacts in a way that makes it easy to manage information about the product during all stages of the product life cycle is crucial for product-oriented organizations. During the early phases of product development the product design information remains rather incomplete and most often also inconsistent. Ontologies developed for many fields to establish common vocabularies and capture domain knowledge have proven to be an advantageous paradigm over recent years. The high payoff of saved effort due to reuse of pre-existing knowledge captured in ontologies is discussed. The use of ontologies in product platform design will yield similar benefits [11].

An ontology consists of a set of concepts, axioms, and relationships that describes a domain of interest.

These concepts and relationships between them are usually implemented as classes, relations, properties, attributes, and values (of the properties/attributes) [12].

<Figure 3> illustrates a mapping between a design ontology and a product structure. Every component in a product structure is an instance of a node of the design ontology.



<Figure 3> Mapping between product structure and design ontology

The design ontology provides the standard vocabulary for creating and maintaining products in a product family. The inheritance-based representation using OWL helps in consolidating scattered information in a hierarchical structure and decreases the amount of information needed to describe design artifacts.

Management of the design information is facilitated through OWL because any change in a parent object reflects throughout the inherited design artifacts.

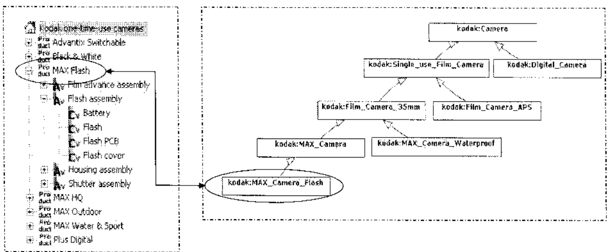
For example, <Figure 4> shows the mapping between an OWL ontology for Kodak one-time-use camera product family and the Kodak MAX Flash one-time-use camera. All the subclasses in the design ontology have a "is a" relationship with their parent classes. An individual of type "MAX_Camera_Flash" is a "MAX_Camera", which in turn is a "Film_Camera_35mm", which is a "Kodak_Single_use_Film_Camera" that is a "Film_Camera" which belongs to the "Camera" domain.

All the properties of class "Camera" will show up in "MAX_Camera_Flash".

The properties of the camera ontology classes are either DatatypeProperty or ObjectProperty. Data type properties are given preference while describing basic attributes of a component, and they are grouped together in generic classes that form object properties.

For example, all the classes that belong to the base class "Component" have Weight, Color, and Material that are object properties as shown in <Figure 5(a)>.

Thus, "Washer" class that is a sub-class of class "Component" has the "has_Weight" property.

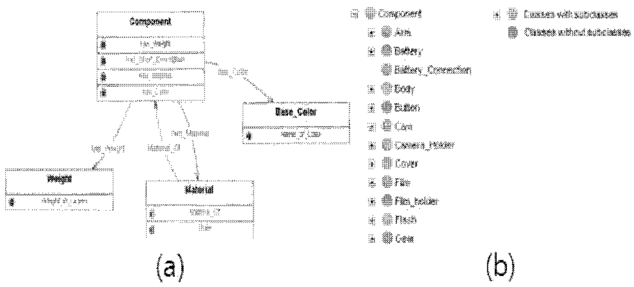


<Figure 4> Kodak one-time-use camera product family representation

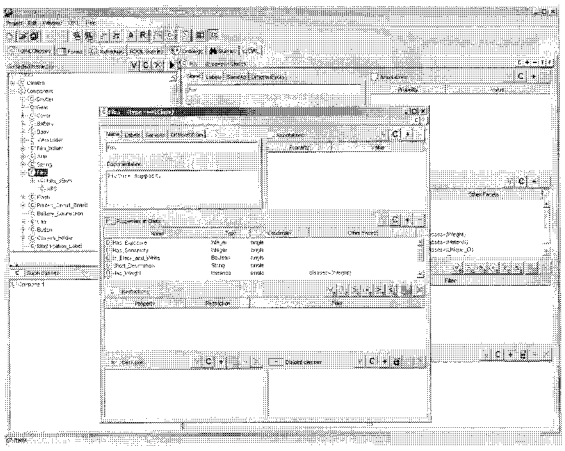
To capture the weight of a washer, the "has_Weight" ObjectProperty of the washer class's "Weight_in_grams" DatatypeProperty, which is a float, needs to be filled. The complete listing of the base class "Component" for the Kodak one-time-use camera family is shown in <Figure 5(b)>.

<Figure 6> shows a screen capture of the implementation of the ontology for the one-time-use cameras using Protégé-2000 [13].

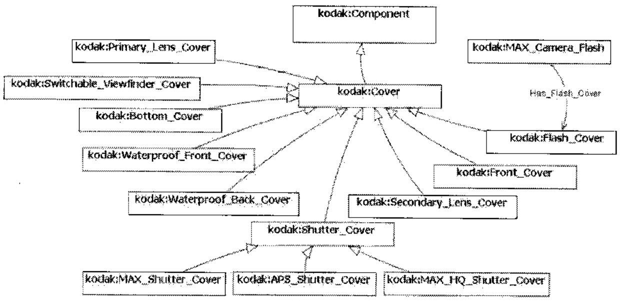
When designing a new product in the camera product family, the designer extends (creates subclass of) one or more of the existing cameras. Thus the class diagram not only captures the relationship among products but also traces the evolution of the products in the product family. For example, a standard ontology will greatly assist in the design of a Shutter Cover for a new or existing Kodak one-time-use camera. A part of the ontology developed for the Kodak one-time-use cameras product family is shown in <Figure 7>.



<Figure 5> One-time-use camera ontology:
(a) property reference of component class
(b) component class and sub-classes of ontology



<Figure 6> The one-time-use camera ontology using Protégé-2000



<Figure 7> Shutter cover component representation of Kodak one-time-use camera family

```
<owl:Ontology rdf:about="" />
- <owl:Class rdf:ID="MAX_HQ_Shutter_Cover">
  - <rdfs:subClassOf>
      <owl:Class rdf:about="#Shutter_Cover" />
    </rdfs:subClassOf>
  </owl:Class>
- <owl:Class rdf:ID="Rubber_Band">
  - <rdfs:subClassOf>
      <owl:Class rdf:about="#Camera_Holder" />
    </rdfs:subClassOf>
  </owl:Class>
- <owl:ObjectProperty rdf:ID="Has_Primary_Lens_Cover">
    <rdfs:range rdf:resource="#Primary_Lens_Cover" />
    <rdfs:domain rdf:resource="#Kodak_Single_use_Film_Camera" />
```

<Figure 8> Example of the OWL ontology for the cameras

The subsumption hierarchy of the camera product family is captured using OWL, and a designer can explore various types of Shutter Covers as well as other covers used in the camera product family.

<Figure 8> shows the source code of the OWL ontology.

3.2 Product Family (Platform) Management Module

This section outlines the methods by which the design knowledge base can be shared, visualized, and administered.

3.2.1 Internet-based design knowledge sharing

Internet-based product information sharing and visualization is the foundation for many collaborative product design and manufacturing approaches [14].

Considerable research in utilizing the Internet for distributed design and manufacturing exists in the literatures that promote ubiquitous access of design data as long as the designer confines the design activity within the proposed software system.

Lack of an open standard for semantic representation on the Internet had prevented the seamless integration of design information across heterogeneous systems. The machine processable, platform-independent, open standards and technologies developed by W3C for the Semantic Web support richer discovery, data integration, navigation, and automation of tasks in the World Wide Web [15].

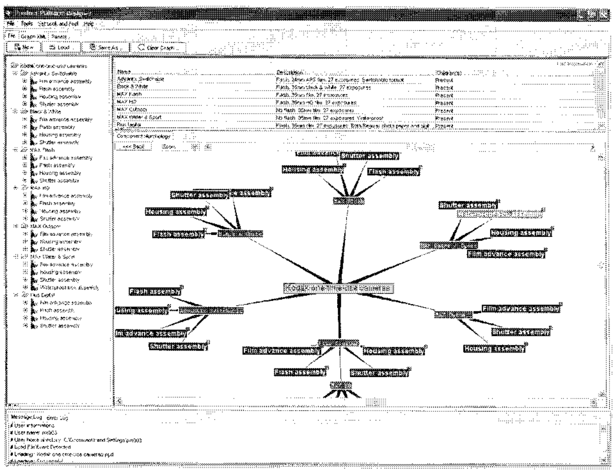
The proposed research will focus on developing a web-based design knowledge management framework that incorporates semantic web standards for representing product design information. The work attempts to foster the use of Semantic Web technologies in engineering design that promises the integration of design data across geographically distributed multidisciplinary product development teams and disparate software and hardware platforms.

3.2.2 Graphical user interface based knowledge management

In a web-based information sharing environment, the user interacts with the server using a standard web browser. The level of real-time interaction and data visualization by the user is limited by the capability of the web browser. One feasible alternative to overcome this problem is a client-side graphical user interface that has both data processing and presentation capability. Web-enabled client-side graphical user interfaces that can interact with web servers using open standards like simple object access protocol (SOAP) [16] promise to provide a flexible environment for remote information management.

For the proposed work, a Java Web Start application is being developed to present a product family in multiple ways. <Figure 9> shows a screen shot of the application that can be started by clicking a link from a browser and supports a rich graphical user interface. The interface represents the product family in a tree structure that depicts the "is a/part of" relationship in a product family.

For example, the film advance assembly is a part of the Kodak MAX HQ camera which is a part of Kodak one-time use camera product family. The same information is also presented in a tabular structure on the top side of the interface which helps, for example, in sorting components that are part of a group.



<Figure 9> Client-side graphical user interface for platform knowledge exploration

The center portion of the interface shows the product family as a link-based blow up where the user can discover the design space by clicking on individual components. The interface is developed using touchgraph which is "a set of interfaces for Graph Visualization using spring-layout and focus+context techniques". For example, the user can set the depth of the product family tree that should be visible as a blow up when a particular link is clicked. In <Figure 9> the Kodak one-time use camera product family, with all the products, is shown up to assembly level.

In the proposed research the client side graphical user interface will be developed to explore the design knowledge base in a more user-friendly manner.

4. Conclusion

This paper propose a product family knowledge management framework using the semantic web paradigm which helps integrate and reuse data and reduce data redundancy in a product family while increasing data comprehensiveness. We focused on (1) product platform ontologies to represent product families in a design knowledge base, (2) product family design visualization and manipulation using a web-based framework.

The contribution of this work is the development of an open standard for product family design knowledge management using the Semantic Web paradigm. OWL will be used to represent the product platform design artifacts. A web-based framework can be developed to help support collaborative product family design. The methodology developed as part of this research will be a step towards designing ontologies for different product families and platforms. Design knowledge representation using the OWL open standard will facilitate seamless interoperability among heterogeneous design software systems and make it easier for designers to use collaboration technology to make informed decisions.

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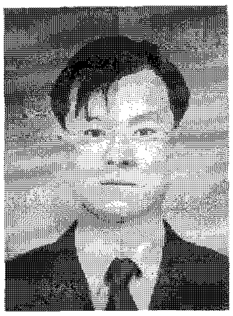

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