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Shape-based searching for product lifecycle applications

Natraj Iyer, Subramaniam Jayanti, Kuiyang Lou, Yagnanarayanan Kalyanaraman, Karthik Ramani*

Purdue Research and Education Center for Information Systems in Engineering, PRECISE, School of Mechanical Engineering, Purdue University, 1288 Mechanical Engineeering Bldg, West Lafayette, IN 47907, USA

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Abstract

Estimates suggest that more than 75% of engineering design activity comprises reuse of previous design knowledge to address a new design problem. Reusing design knowledge has great potential to improve product quality, shorten lead time, and reduce cost. However, PLM systems, which address the issue of reuse by searching for keywords in filenames, part numbers or context attached to CAD models, do not provide a robust tool to search reusable knowledge. This paper presents a brief overview of a novel approach to search for 3D models. The system is built on a client–server–database architecture. The client takes in the query input from the user along with his search preferences and passes it to the server. The server converts the shape input into feature vectors and a unique skeletal graph representation. Details of the algorithms to perform these steps are presented here. Principal advantages of our graph representation are: (i) it preserves geometry and topology of the query model, (ii) it is considerably smaller than the B-Rep graph, and (iii) it is insensitive to minor perturbations in shape, but sensitive enough to capture the major features of a shape. The combined distance of feature vectors and skeletal graphs in the database provide an indirect measure of shape similarity between models. Critical database issues such as search system efficiency, semantic gap reduction and the subjectivity of the similarity definition are addressed. This paper reports our initial results in designing, implementing and running the shape search system.

1. Introduction

Traditional Computer Aided Design (CAD) software has undergone rapid transformation and has evolved into an industry commodity. Technological progress enabled CAD software to incorporate engineering know-how into the design process and develop Product Data Management (PDM) systems. CAD models were further integrated forward in the design cycle into analysis and manufacturing to develop Computer Aided Engineering (CAE) tools. Rapid development in each of these areas resulted in a lot of ‘pockets’ of automation. Currently, all of these ‘pockets’ are being integrated by Product Lifecycle Management (PLM) systems thereby producing a completely digital design through manufacturing solution.

Conservative estimates suggest that more than 75% of design activity comprises case-based design, i.e. reuse of previous design knowledge to address a new design problem [1]. Most PLM systems address the issue of reuse by searching for keywords in filenames, part numbers or context attached to the CAD model. However, this method is not robust primarily because of the following reasons:

1. All models will not have a well-defined attached context.
2. Keywords such as project names or part names may be unknown to the user.
3. Context may be too narrow or too broad to retrieve relevant models.
4. Context changes with time—such as when designers or naming conventions change.

Design reuse spans across the entire product lifecycle as shown in Fig. 1. Design reuse includes not only the CAD design but also of physical inventories such as tooling or other knowledge such as cost data and lead time information. Clearly, effective deployment of a knowledge mining system that will enable knowledge-reuse would require a combination of text and shape-based searching.

* Corresponding author. Tel.: +1 765 494 5725; fax: +1 765 494 0539.
E-mail addresses: iyern@purdue.edu (N. Iyer), jayantis@purdue.edu (S. Jayanti), kuilou@purdue.edu (K. Lou), yagna@purdue.edu (Y. Kalyanaraman), ramani@purdue.edu (K. Ramani).

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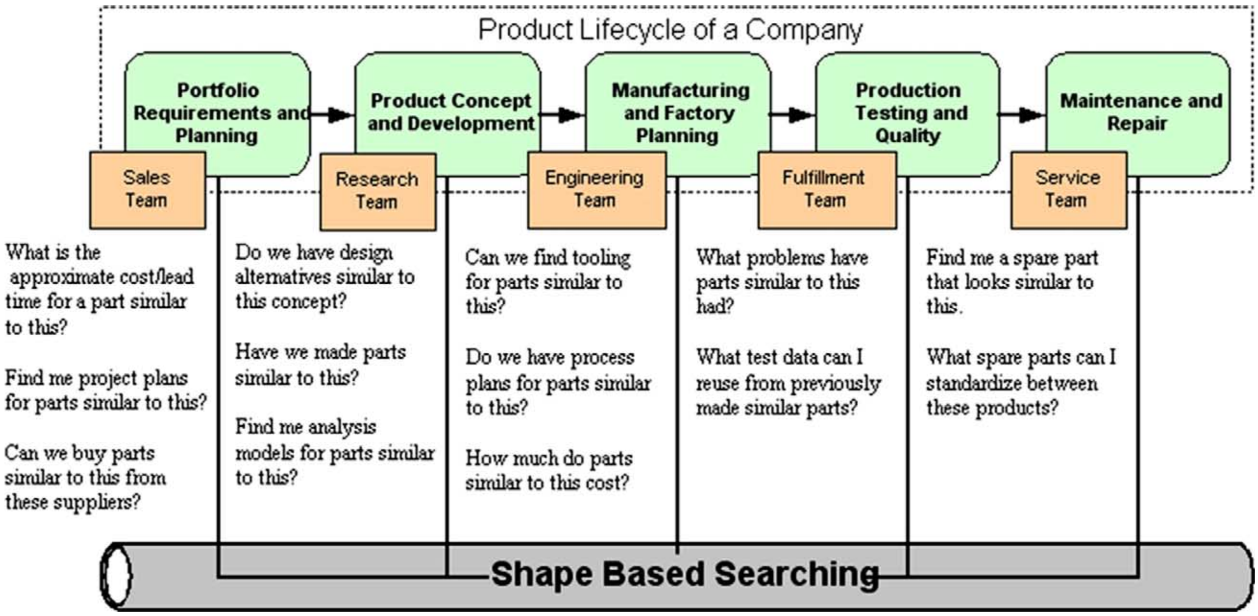

Fig. 1. Knowledge-reuse across the Product Lifecycle.

Significant benefits of design reuse include:

1. Reduction of variability, leading to lesser quality and warranty problems.
2. Eliminating unnecessary parts, thus increasing inventory turnovers.
3. Elimination of downstream activities such as testing and verification and prototyping.
4. Uniform engineering specifications, leading towards standardization.

A significant amount of knowledge generated during design and manufacturing is associated with 3D CAD data. Most of this information (context) is in the form of documents, images and text. From the viewpoint of design engineers who want to reuse design knowledge, 'similar products' usually means those designs that have 'similar' attributes such as shape, materials, processes, tolerances and applications. Among these attributes, shape is the most complex to compare and evaluate. In addition, the 3D shape of an object transcends language and is an unambiguous representation of an engineering artifact and is tightly coupled with other engineering information such as analysis and manufacturing information. Hence, a search system which is capable of retrieving similar 3D models based on their shape will retrieve shape and related knowledge that would not be discovered by other means. Furthermore, shape is one of the factors that significantly influence decision-making and analysis. Thus, we focus our research on developing efficient and effective 3D engineering shape search for design reuse. This paper describes the related literature and experimental results of a 3D engineering shape search system.

2. Literature survey

The past years have seen limited attempts in searching for 3D CAD models. Almost all related methods for matching 3D shapes decompose a shape into a signature. An extensive review of related methods is available in [2,3]. Based on the methods used to convert a shape to a signature, they can be classified into the following categories:

1. *Invariant/descriptor-based*. These methods use invariants or descriptors of the 3D shape such as volume, surface area, aspect ratio, higher order moments or moment invariants as signatures [4–6].
2. *Harmonics-based*. These approaches use a set of harmonic functions of a shape as its signature. Spherical or Fourier functions are usually used to decompose a discrete 3D model into an approximate sum of its (first *n*) harmonic components [7–9].
3. *Statistics/probability-based*. Osada et al. [10] use shape functions and construct a shape distribution by random sampling of points. Ankerst et al. [11] use shape histograms to approximate and search for a 3D model.
4. *3D object recognition-based*. Some 3D object recognition approaches that have been used for 3D shape searching are Aspect Graphs [12], Spin Images [13], and Geometric Hashing [14].
5. *Graph-based*. Graph-based approaches have employed subgraph isomorphism for matching B-Rep graphs [15, 16], matching eigenvalues of a model signature graph [17] constructed from the B-Rep graph [18–21]. A multi-resolution Reeb graph that captures the topology of a part is proposed in [22].
6. *Feature recognition (FR)-based*. Ramesh et al. [23] decompose a part into cells which are further processed