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Review

Enhancing CAD/CAM Design Processes via Intelligent Data Retrieval: Moving Beyond Similarity Comparison

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ABSTRACT

Both producers and designers are very interested in the potentially lucrative idea of improving the design of a new product by reusing technical information from previously produced goods. Product quality, design lead time, and prices may all be enhanced by reusing collected know-how. Organizing all CAD/CAM product data into a repository and labeling it is a critical step in making the collected information reliably accessible for reuse. Furthermore, a standardized data format is necessary for the presentation of different items. Group Technology is a leading approach that includes extra information beyond the product's geometry in its categorization and standardization of topological and geometrical data from a 3D model. This study presents a new technique to design choices using a classified database, which is based on Opitz code one of the Group Technology's methodologies. In addition, the most recent developments in categorization algorithms for 3D forms with the purpose of comparing their similarities are outlined.

Keywords
Similarity comparison; Opitz code; CAD/CAM.

INTRODUCTION

Developing a new product in a competitive market requires a shorter design lead-time and optimum life-cycle performance. Ullman [32] claims that 70% of the total cost is attributable to judgments made at the idea stage of product design. This work presents a novel approach to optimizing design choices that incorporates manufacturing and design factors throughout the geometrical design phase. It is a replacement for traditional and sequential design. In this approach, all necessary design criteria are considered simultaneously at the initial design phase or throughout the geometrical design using CAD software. Factors such as production costs, environmental impact, functional and side effects, and manufacturability are part of the design process. Modern, promising computer-aided design (CAD) software can compute many geometrical features and physical functionalities. Nevertheless, expert programs that compute a specific physical design parameter (e.g., heat, noise, pressure, etc.) could be more accurate than such all-encompassing calculation programs. The design process is laborious and often yields less-than-ideal results for businesses that are responsible for calculating designs using various software programs.

TA designer may need to make several iterations of a design before they've optimized it for all geometrical and functional needs. To overcome these obstacles, a clustered repository containing the knowledge of previously created and produced goods is being considered in a quantitative and thorough similarity comparison method. It is feasible to predict the features of a newly developed product and make more informed design choices by drawing on prior knowledge about comparable product designs. Research efforts such as case-based reasoning, concurrent engineering [33], and semantic models [22] aim to shorten the design lead time. In this research, we provide a novel method that uses a robust similarity comparison toolset to address the design challenge you outlined. A database and an algorithm for quantitative similarity make up this set of tools. Data standardization is achieved by the use of the Group Technology (GT) method.

Here is how this paper is organized: The second section provides an overview of the standard design technique and current approaches to form signature. Section 3 provides an overview of Group Technology and its history; Section 4 details the methodology used in this study, which is the Opitz coding system. Sections 5, 6, and 7 will shed light on the core idea of the suggested similarity searching approach, including the algorithm, database structure, implementation, and outcomes. You may find the conclusion at Section 8.

1 RELATED WORKS

When a designer gets fresh specifications for a new product, the traditional design process begins. The first phase is to create a rough product design; the second is to optimize that model (see Fig. 1). Since optimization is an iterative process, making a perfect initial design draft is one way to cut down on the number of iterations. In this approach of design, the designer's expertise is crucial for starting with an optimal first draft. With 85 percent of industry workers expected to be under 40 in the next 15 years, passing on important knowledge to younger, less experienced designers is an absolute must.

Basically, the goal is to make the traditional design process more efficient in terms of time, money, and energy without sacrificing quality. In essence, this issue may be addressed in two ways. Increasing the iteration speed is the primary goal, while decreasing the iteration count is the secondary objective. Research into hardware components is the starting point for the initial solution. In pursuit of the second option, iteration reduction may be achieved alone via the correct commencement of the initial design draft, which must be based on a proven and tested model. All things considered, the most important things are a retrieval system, algorithms for comparing designs, and a structured database that stores all of that information.

The geometrical 3D computer-aided design (CAD) models are difficult to compare. An injective (one-to-one) function or principle is needed to convert a three-dimensional shape into a computational model, also known as a shape signature, in order to do this. When all of an object's important geometrical and topological characteristics are included in a solid model, we say that the model has a shape signature. Furthermore, the shape signature should be presented in a computer-friendly format that can be automatically computed and compared, such as a picture, graph, vector, or an ordered sequence of numerals or letters. So, comparing the form signatures of two 3D shapes yields the result of a similarity evaluation. As a result, there are essentially two stages to determining if two 3D forms are similar: computing a shape signature and then comparing the shape signatures using an appropriate distance function. Shape signature approaches are classified virtually identically by Cardone et al. 2003 [4], Gao et al. 2006 [10], and Liverani and Ceruti 2010 [21], with the exception of Iyer et al. 2006 [15], whose categorization is somewhat different. The inclusion of the multi-resolutional approach into the first categorization model is the only distinguishing feature between the two otherwise identical classification models. And the initial classification of feature-based attributes correctly splits them into global and manufacturing characteristics.

In the following list, a comprehensive combination of both major categorizations is briefly described. The methods in parentheses belong to Iyer et al. classification and they refer to the identical characteristic of object.

- GLOBAL FEATURE-BASED METHODS (INVARIANT-BASED METHODS AND HARMONIC- BASED). Using invariants of a 3D shape such as volume, surface area, higher order moments, geometry ratios, distances, etc. [8],[6],[19].
- MANUFACTURING FEATURE-BASED METHODS. In this method, the manufacturing features are recognized from a CAD model. Belonging to this category, MDG (Model Dependency Graph) approach for a 3D CAD model is used to compare machining parts [4].
- HISTOGRAM-BASED (STATISTICS/PROBABILITY-BASED) METHODS. Using shape functions to create a shape distribution of random sampling of points [13],[26].
- GRAPH-BASED METHODS. A graph-based method develops a graph based on the encoded shape, geometry or feature of a 3D model [17]. In some methods, the sub-graph isomorphism is used in order to match B-Rep graphs, or to match eigenvalues of a model signature graph which is constructed from the B-Rep graph [7].
- 3D OBJECT RECOGNITION BASED METHODS. Ruiz-Correa et al. [28] introduced spin images as a signature and Lamdan et al. [20] established a method based on geometric hashing as a shape descriptor.
- MULTI RESOLUTION DESCRIPTOR- BASED. This method has been investigated by Gao et al.

[10] with a Dilation based Multi-Resolutional Skeleton (DBMS) method for retrieving similar parts. Their method for shape signature generation consists of several consequent stages including: B-rep building of component, voxelization, DBMS graph generation. The direct result of having several phases to get the signature is dramatically escalating the cost of time and computation.

- PRODUCT INFORMATION-BASED METHODS: (GROUP TECHNOLOGY-BASED METHODS). Hendeson et al. [12] used GT for similarity detection in concept of Agile Manufacturing. Iyer and Nagi [16] developed a new Group Technology (GT) method to compare the similarity between parts. A Type Abstraction Hierarchy (TAH) is considered as an alternative for GT [30].

All mentioned methods do have advantages and disadvantages. The application and the feature type of a 3D shape are two major factors to determine which method has the highest efficiency for the appointed purposes.

2 GROUP TECHNOLOGY (GT), SELECTED SHAPE SIGNATURE

For two primary reasons, this work relies on the GT approach to generate the form signature:

1. Design that is interactive, as opposed to isolated, is crucial. The design phase must be seen as the beginning of the product development process, which culminates in production. It doesn't matter how good a geometrical design is if it can't be made. You can't do design on your alone; it's a collaborative process. A perfect design would be one that can be mass-produced affordably without sacrificing quality. Using GT as a manufacturing-based grouping approach to create a design signature helps bridge the gap between CAD and CAM (see Fig. 2). Also, by including GT early on in the geometric design process, the designer has a better picture of the whole design lifecycle from concept to manufacturing.

The second reason to use GT is its adaptability, which means you may use it for product signatures instead of form signatures. Additional product data may be added to the GT format, which is an alphanumerical string, by adding more digits. Having this quality should be an improvement above just having shape information.

Although GT is most often used in production, it has also had a significant impact on the design process. Standardization is the main advantage of use GT for design. By increasing quality, productivity, and overall profitability, estimates demonstrate that GT improves design and, by extension, production [31]. Based on the geometrical form, dimensional precision, material, and manufacturing quality of an item, GT creates an alphanumeric string [29]. By drawing on a set of predefined attributes, designers working with the GT idea in design have a wealth of options from which to launch a brand-new design. Here he may find the spark for a brand-new, ground-breaking design—or he may choose to build upon the already-popular concepts. Therefore, it becomes a simple task to retrieve prior successful design information.

While working in the USSR in the 1950s, S.P. Mitrofanov was the first to propose the idea of Group Technology. Although it was first published in the original language much earlier, he translated and published Scientific Principles of Group Technology in English in 1966. In recognition of his exceptional performance in GT, Mitrofanov was awarded the Lenin prize [27]. The three main issues that he felt GT should address were: An active technological process must first be free of undesired deviations. Secondly, enhancing processes to a point where they can be used with mass production methods and big batches, and thirdly, adding equipment that can be quickly and readily altered [29]. Following this, A. P. Sokolovskiy continued to build upon Mitrofanov's work.

Herwart Opitz was another prominent figure in the field; he studied the German machine tool industry extensively in the late 1950s and early 1960s and found that, despite possible differences in part design and function, the manufactured parts were very similar. The Opitz coding and categorization system, which is extensively used in German business, was created as a successful outcome of his work [9].

Thirdly, in 1959, the valves manufacturing business Serck Audco Valves began standardizing their processes. As a means of distinguishing one from another, they came up with an eight-digit code for each step of manufacturing as an individual GT system. As a consequence of component standardization, there was a 20% decrease in work pieces and bought parts [29].

E.G. Brisch, who came up with the idea for code categorization, then tried again in England. E.G. Brisch and Partnes Ltd. went on to hire him after that. In addition, the French firm Forges et Altelliers de Construction Electrique de Jeument effectively implemented Brisch's standards and codes in 1959 [11], [14].

Several GT applications have been studied and put into practice in the last ten years. The following phrases provide a quick summary of some of the significant studies. In order to input a component into the Opitz algorithm, Kaperthi and Suresh used a neural network to extract features from bit-mapped 2D drawings [18]. Codes may be generated from 3D data sources using a technique that was created by Ames [2] and Nadir et al. [23]. Engineering drawings may be automatically encoded to GT according to a technique proposed by Barton and Love [3].

Group Technology has made design uniformity one of its primary goals. Group Technology uses a set of predefined product attributes, such as physical, functional, and design engineering attributes. Standardization allows for the optimization and improvement of searching and retrieval systems. Considerable effects of GT are associated with its use in industrial design and production. Agile manufacturing, manufacturing cell layout, variant process planning, and design and manufacturability assessment of manufacturing technology systems are all areas where GT finds use in industry [1], [29].

From Germany's University of Aachen comes the Opitz classification system; from Brisch-Birn Inc. comes the Brisch System; from Manufacturing Data System, Inc. comes CODE; from Metcut Associates comes CUTPLAN; from Brigham Young University comes DCLASS; from the Organization for Industrial Research comes MultiClass; from Lovelace, Lawrence & Co., Inc. comes the Part Analog System [1], [33].

The fundamental premise of all of these methods is to give a GT code—an alphanumeric string—to each component after collecting its most important design and manufacturing characteristics.

The Opitz coding system is one of the most popular and widely used coding systems that is based on the GT idea. What follows is an explanation of a novel method for optimizing designs that is based on the Opitz coding system.

3 OPITZ CODING SYSTEM

Machine tools and production engineering professor Herwart Opitz of Germany's Technical University of Aachen developed the Opitz coding scheme [24]. A large number of factories have used the Opitz categorization system ever since. The thirteen main numbers that make up an Opitz code are separated into three areas, and they represent the part's design and production information. The "form code" (the first five numbers) describes the features of the design. The reserved "supplementary codes," which make up the second set of four digits, are used to specify certain production characteristics. The third portion, often called the "secondary code," consists of an additional four digits that may be utilized as flexible requirements or presentation sequences for operations [1]. For the remainder of this study, just the first five digits, or the "form code," will be referred to as Opitz code as the emphasis is on the geometrical component of Opitz code.

The first digit of the Opitz code is "part class," and there are two basic types of parts: those that rotate and those that do not. The ratio of a part's length to its diameter is used to categorize rotating components, while the dimensions of non-rotating components are length, breadth, and thickness. Long parts, cubic parts, and flat parts are the three main types of non-rotational components. While there is a distinct system for classifying the two types of parts stated, there are ten possible values for the five digits that represent each category, ranging from zero to nine, depending on the unique characteristic of the component in question. Table 1 shows the intricacies of the cubic shape of the Opitz code numbers (1–5) allocated to the rotating components, with each digit describing and detailing a characteristic. Part class, primary shape, rotational machining, auxiliary holes, and gear teeth occupy the first five digits of non-rotational components, in that order. Each digit may have its own grouping; for example, tabulated in Table 1 is the number 5, which has three more groupings. Alternately, it might be tabular with no intergrouping at all, like number 3.

The comprehensive similarity comparison consists of a coordinator module, a similarity comparison algorithm and a database illustrated in Fig. 3. The coordinator is responsible for controlling and applying the weights or priorities to the parameters, to ask from the designer about the significant parameters (which can not be ignored in the design). In addition, the coordinator establishes the temporary database and sets and determines the tolerances.

To configure the toolbox, the first steps are the standardization of the products and setting the similarity algorithm off. For the standardization, the Opitz code has been selected as a GT code for its extensive classification of parts.

5 DATABASE DESIGN FOR INTERACTIVE SIMILARITY COMPARISON AND DATA RETRIEVAL

In section6.1, we discussed two big problems with database designs that deal with similarity searching and retrieval. Consequently, in section 6.2, two approaches to database architecture are presented in order to circumvent any issues that may arise from the obstacles.

6.1.1 Current Database

It is important to take into account the “responding environment” and the “flowing behavior” of pairwise similarity comparison while designing a database for a similarity searching application.

6.1.1 Continual action

There is a natural progression to pairwise similarity searches in databases. So, after a certain amount of similarity comparisons in a database of comparable models, the similarity detection criteria change. Picture 1 and 2's percentage of similarity is shown by S1,2 in Figure 4, whereas picture 2 and 3's percentage of similarity is shown by S2,3 and so on. The percentages indicated by S1,2 and S2,3 are quite close to one another, but the percentages indicated by S1,6 are drastically different and far lower. To rephrase, after a certain number of items in a domain that includes variants, the pair similarity comparison may reveal just a passing resemblance between the initial and final objects. Isolation from the right search direction could result from a continual similarity comparison.

Fig. 4: Flowing behavior of pairwise similarity comparison: every side pairs have a high similarity although the first and the last images are not very similar. Fig. based on [5].

Environment that responds 6.1.1

In addition to being instantly accessible for future similarity searches and retrievals, every newly successful design must be preserved in the database. In order to accommodate the new member properly, the database's search algorithm has to be both flexible and organized.

To provide the best possible result for the similarity searching process, this technique performs the searching procedure in two phases, i.e., similarity retrieval with an equal priority for all digits. The next paragraph will explain the two steps involved, which are horizontal searching and vertical searching.

Searching in a horizontal plane. Someone is looking through the headers. To proceed with the vertical search, we will choose a heading if its similarity result is satisfactory. In such case, we will skip over this heading and look at the one after it.

Using a vertical search bar. Includes cluster searches. Within the specified header clusters, the second stage of similarity comparison will be carried out.

- Step 1: Comparing the query code with the code in header 1.

- Step 2: If similarity comparison between the two codes is less than the defined minimum similarity by user, then the current header is ignored and the next header will be compared. Otherwise the current header is saved in the temporary database.
- Step 3: After all headers were checked; working on the temporary database is started. A tolerance domain (minimum similarity<tolerance<100) will be established to find the most similar models. The tolerance number is an additional value to the requested similarity percentage; see Fig. 7.
- Step 4: The process is finished when with decreasing of the tolerance; until only few designs are left in the temporary database. In presented workflow in Fig. 6, 10 designs were desired and set, however the number of retrieved designs can be defined by the designer.

6.1.1 Second possibility: similarity retrieval with prioritized digits

For such condition an interactive communication with the database has been considered. The user determines and chooses the digits with priorities. In this model, only the Opitz codes containing an identical value for the prioritized digits are retrieved and any other similarity is ignored. After the user sets the priorities, in an active system, the most similar designs are located in the headers and are retrieved. This method benefits from a flexible attitude referring to the ‘responding environment’ of similarity searching; as discussed before.

As mentioned earlier, two similar Opitz codes with equivalent priorities for digits may have one of the singular forms of similarity, calculated by Eqn. (6.1). This equation is changed to Eqn. (6.3), when the digits have priorities. In this equation, n is the number of total digits in the Opitz code and x is the number of prioritized digits.

7 IMPLEMENTATION

Based on the categorization and layout of the Opitz code, a software solution has been built to generate the Opitz code for any form created in a commercial CAD program. An Initial Graphics Exchange

Specification (IGES) file, retrieved from a computer-aided design (CAD) model, may facilitate this conversion. The created system takes an IGES file, processes it to extract shape data, and then builds the Opitz code for that form. An integrated GUI initiates the similarity finding mechanism after Opitz code generation. The program may prioritize certain digits of the Opitz code to emphasize the specified needed qualities after extracting it from the requirements. Two further user interfaces have been developed to display the recovered models' CAD drawings together with their Opitz codes. Searching with comparable value for digits and searching with non-equivalent digits or prioritized digits are two kinds of similarity searching that the system takes into account.

Searching with equal weights for query digits: the user is prompted to set a similarity percentage for the returned models when they opt to search with comparable weights for the query digits. One use of this is to cap how many models may be retrieved. There is no restriction on the number of retrieved models; in fact, Eqn. (6.1) allows for an infinite number of retrievals.

To search using prioritized or non-equivalent digits, the user should utilize the GUI shown in Figure 7 to choose the prioritized digits. Prioritization may be set by him from one to five digits. Equation (6.1) and the number of prioritized digits, as well as the value of each digit, are used to specify the degree of similarity. Equation (6.3) is used to determine the potential number of recovered models with prioritized digits.

The system displays the relevant CAD models together with their Opitz codes. By raising the degree of resemblance, the designer may narrow down his search.

A new window will pop up when you click on "CAD sketch of similar models." It will show you all the CAD models that are quite close to each other.

7.1 Results and Evaluation

Here we showcase and assess an experiment that uses our built algorithms to display the retrieved comparable parts for a query part. The experiment relies on a database that contains over 200 non-rotational pieces from both comparable and dissimilar solid models. The Institute of Computer-aided product Development Systems at Universität Stuttgart in Germany created the database.

In contrast to the other method that gives equal weight to each digit, the prioritized searching approach yields fewer results for varying degrees of similarity and is thus more structured; this is in contrast to the similarity retrieval method that was chosen for the experiment. Figure 8 shows the obtained forms with varying degrees of similarity according to the red-colored priority digits.

Figure 8 shows the results of an experiment with three retrievals. Priorities for the initial retrieval are two numbers, 2 and 4. Of the 41 forms that were obtained, only a subset of them are shown in Figure 8. Using Eqn. (6.1), we can determine that each of the five digits in the applied Opitz code is 20% of its total value. Therefore, 40% similarity between the query model and the returned shapes is the bare minimum. With a minimum similarity of 60% and three prioritized digits in the second retrieval, a smaller set of 22 forms was produced. In addition, the most recent experiment using four prioritized digits achieved a similarity rate of 100% for the recovered Opitz codes, although the goal had been an 80% similarity rate. Fig. 8 also shows the recovered model's Opitz codes, with Tab. 1 providing explanations for each number.

As we can see from the search and retrieval example, there are four prioritized digits in retrieval #3, which leads to 80% similarity; yet, the codes that were recovered are identical, which indicates 100% similarity. The retrieval result shows that two seemingly distinct solid models with identical Opitz codes were retrieved. The possible disadvantage of Opitz code as shape signature is shown by the recovery of these two equal codes. Considering that the manufacturing qualities form the basis of the Opitz code feature description for each digit, it is conceivable for two forms to have the same Opitz code yet have distinct geometries and shapes. The current Opitz code resolves this issue.

include additional digits, such as secondary codes and auxiliary codes, or even more digits depending on the unique attributes of the product.

8 CONCLUSIONS

This study produced a full-featured similarity comparison toolset, which includes an Opitz coding-based shape signature and two distinct data retrieval approaches. In order to standardize and categorize the geometrical information of a CAD model, the Opitz coding structure has been chosen as a Group Technology. Get the GT code out of the requirements as precisely as possible; that's one of the biggest issues here. The produced Opitz code's quality is another issue. Nevertheless, starting a manual coding structure for a certain product might increase the Opitz code's quality. Improving the similarity retrieval accuracy will need further work to augment the Opitz code with extra digits allocated to certain unique attributes of a component.

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