Development of model identification methodology based on form recognition for Computer-Aided Process Planning

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Abstract
Computer-Aided Process Planning (CAPP) systems have become essential in manufacturing environments to integrate the information between CAD and CAM systems, and to automatically generate the NC code from the CAD model. Though the future of these systems seems to belong to the use of Artificial Intelligence to create knowledge-based algorithms which emulate human decisions, the CAPP systems based on feature recognition and model matching, which use databases of previously known mechanical components to generate new process plans, are also a very interesting option due to their accuracy and smaller development costs. Many researchers have proposed different kind of feature recognition algorithms before. However, these algorithms are usually application-dependent and require external codes to identify the features of wireframe models. This paper proposes a new methodology for shape recognition and model matching stages which improves the accuracy of the recognition tasks, uses solid models instead of wireframe models and can be successfully applied to any kind of part. The methodology is based on an original coding system that links the geometric information extracted from the CAD model with the features of the part by means of an identification sequence which is detailed in the text. Also, a score system has been created for the model matching stage. The obtained results show that the system presents high accuracy in shape recognition, feature identification and model matching tasks, even when the analyzed part is similar to the ones in the database. In addition, quantitative geometric data is also extracted from the CAD model on behalf of future steps of the CAPP system, such as the NC code generation stage. In contrast to other systems, this methodology can be easily applied to the industry since it makes use of the CAD model only.

Keywords: CAD, CAM, CAPP, Shape recognition, Model matching, Coding system, Database

1. Introduction

As stated in Steudel (1984), process planning is the act of preparing detailed instructions for turning an engineering design into a product, i.e. a part. This means that it is necessary to translate the design specifications of a part into appropriate manufacturing instructions in order to obtain that part in its final state from the raw material. As process planning usually requires many kinds of human abilities and knowledge, traditionally the plans were handed over to manufacturing experts, who specifically decided the adequate procedures to make the product. These experts used their experience and knowledge in order to generate the manufacturing instructions based on the design specifications and the available installations of the company.

However, two experts may come up with different plans when facing the same problem, indicating the high heterogeneity that exists in process planning (Ciruana et al., 2006). This has led to the development of the Computer-Aided Process Planning systems (CAPP), which are becoming more and more important in an integrated manufacturing environment (Kumar and Rajotia, 2003). Generation of a consistent and accurate process plan requires adequate standard databases as well as the implementation of an efficient methodology to process the data. The current automation of process planning is a consequence of the need for the incorporation of new knowledge and
manufacturing processes. CAPP systems have also been developed as a link between Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Material Requirement Planning (MRP) (Ciruana et al., 2006). In an integrated manufacturing environment, CAPP systems allow the designers to manage the flow of information between CAD, CAM, MRP and Numerical Control (NC) programs.

This paper focuses in the first stages of CAPP systems which analyze the CAD model of the part and select, from a previously known database, the most similar one. The process plan of the new part can be created automatically based on the process plans of the database’s parts. Because of that, this research proposes a new methodology in order to work directly with the CAD model and, consequently, simplify the shape recognition process while improving its accuracy. To do so, the developed system has been divided in three stages (shape recognition, component identification and database-based model matching), and has been laid out as a sequential flow in which the output of a stage is the input for the next one. The proposed methodology works in a solid model environment, avoiding unclear wireframe models of the part and allowing the system to be applied in current industry. As this methodology has been programmed in VBScript using the SolidWorks API interface, only SolidWorks is required (except, of course, Microsoft Excel or similar to view the output files). This can be achieved by means of an original coding system that generates an identification sequence. This sequence links the information of the part, extracted directly from the CAD model, with the features and components that make it up. Therefore, no external application-dependent codes are required to recognize the features of the analyzed part. Besides, the development of a score system that, among others, makes use of these identification sequences, improves substantially the accuracy in model matching tasks.

The paper has been divided as follows: first, a review of some existing shape recognition and model matching methods is presented in Section 2; the proposed methodology is explained in detail in Section 3 (including a practical application), which in turn has been divided in three sub-sections, one for each stage of the methodology; finally, Section 4 outlines some of the most important conclusions, and states the advantages of this methodology when compared with other existing shape recognition and model matching methods.

2. Shape recognition and model matching in existing Computer-Aided Process Planning systems

Usually two kinds of approaches can be used in CAPP systems: the variant approach and the generative approach. The variant approach consists on modifying the process plan of a previous part to get a new process plan. In these CAPP systems, parts are usually classified in different groups called “families” according to their main characteristics. For each “family”, a database storing geometric and manufacturing information is generated. To obtain the process plan of a new part, this part is compared with the ones existing in the database based on its geometry. Consequently, recognition of the geometry of the part is required before comparing within the database. The main disadvantage of this approach is that the quality of the process planning depends on the quality of the algorithm that conducts the model matching and on the quality of the previous process plans in the database.

The generative approach for CAPP systems automatically generates a new individual process plan for each part by means of using algorithms that analyze the information of the part and then decide the appropriate manufacturing processes. Information about materials and other factors are synthesized by the system, so usually a comprehensive description of the part is included as input. This approach employs knowledge-based techniques, and provides designers with fast advice for process planning. However, these systems need an algorithm that emulates human experience, so Artificial Intelligence (AI) is required. The lack of skilled process plans experts in many industrialized countries, such as USA or UK, has given impetus to the implementation of AI in CAPP systems. Nevertheless, these systems are still far from a full satisfaction in terms of effectiveness.

Though the variant approach has many limitations that can be solved with the generative approach, the variant approach is widely used since it provides with feasible process plans and an accuracy-effort relation acceptable in terms of time and precision. This paper focuses in the variant approach. As stated in Henderson and Chang (1988), in these kind of CAPP systems, four elements should be considered: the input data, which contains the geometric and other information of the part; the output data, that is, the process plan of the component; the database, which contains the “families” of parts used for model matching; and the algorithm with the manufacturing decision-making rules. Marri et al. (1998) proposes three basic stages in a CAPP system based on the variant approach:

1. First, from the CAD model, which contains all the geometric and design information of the part, a data preparation step is required in order to extract the available information. This step, usually known as
feature recognition or shape recognition, is a vital step in the process. Traditionally, an expert extracted the information that later was going to be used in process planning from the part’s blueprints. CAPP systems must be able to recognize and analyze the complete geometry of the 3D CAD model, determine the parameters and extract them, and finally export all the data in an output file, which will become the input for the next step of the system. A proper algorithm for shape recognition, which is required to correctly extract the information of the model, is proposed in this paper.

2. Once the data preparation step has been completed, the manufacturing decision-making rules of the system are applied. In CAPP systems using the variant approach, this step is called model matching, and it consists on a comparison of the considered part, called target shape, within a database of previously known parts. In this database, detailed information about manufacturing techniques and operations of the parts is included. The output of this step is the manufacturing sequence that builds the target shape successfully. An algorithm for model matching is also proposed in this research.

3. Finally, a post-processing step prepares the data for its real production. After the post-processing step, a NC code is generated by a CAM system, allowing the target shape to be automatically manufactured, from the CAD model to the final part. This step exceeds the scope of the conducted research, which focuses in a new algorithm to get accuracy in shape recognition and model matching stages.

Historically, the shape recognition or feature recognition process has been the most difficult one, as programming a well-aimed but flexible algorithm is definitely not an easy task. Many algorithms for shape recognition are proposed by various researches. Some of them are described now. Zhao et al. (1990) used wireframe models, and by using graph theory, proposed a recognition algorithm of machined features. However, this methodology did not use 3D models, but a 2D representation of closed loops or boundaries of the parts. Rozenfeld and Kerry (1999) used parametric design techniques in CAD models to create a complete CAPP system that was focused in the real necessities of industrial parts. In their system, the part was represented only by parameters, such as lengths or tolerances. Kao and Kumara (1993) proposed the super relation graph (SRG) method for feature recognition, and made use of neural networks and other computational techniques for extracting the features in the part.

Abouel Nasr and Kamrani (2006) proposed a methodology in which the part was introduced directly from the CAD model using constructive solid geometry (CSG) technique as design tool. The part model was contained in an ASCII file format, giving the system the ability to communicate with other CAD/CAM systems, and made use of a C++ code to extract boundary (B-rep) geometrical information. In order to recognize the shape of the part, features were classified in external or internal features, then in concave or convex ones. This led to the necessity of identification and classification of the edges and loops (defining a loop as more than one edge that, together, conform a closed entity) in each face of the part.

As the reader can notice, consensus cannot be reached in this field, and the different authors propose their own algorithms and techniques that are optimized for the application they want to develop. Nevertheless, this is not necessarily a negative aspect, as more researches means more wealth in terms of knowledge and experience that can be used later to upgrade existing systems and adapt them to the new necessities of the industry. Therefore, this paper does not hope to create a revolutionary system that fully covers all the existing requirements, but to provide the shape recognition and model matching quandary with a new practical method on behalf of design and manufacturing engineering.

Reader also may notice that there are not many recent researches in the variant approach field. The industry has focused in the generative approach CAPP systems in the last decade. Nevertheless, the above mentioned algorithms provide with a sufficiently clear idea of the feature recognition quandary of the variant approach systems. This research does not try to create a methodology better than the generative approach; authors know the limitations of the variant approach. The aim of the research here presented is providing with a newer and simpler methodology for shape recognition that can be easily applied to the industry.

3. The proposed methodology

In this paper, a shape recognition and model matching methodology for variant approach CAPP systems is presented. The research proposes a new methodology based on a coding system in order to identify the shape of the
part from the geometrical information available in the CAD model. Database-based model matching is also covered by the system which, by means of a score system and the previously mentioned coding system, reaches a high level of accuracy in the identification of the part within the database.

![Diagram](image)

**Fig. 1** Simplified scheme of a CAPP system with the proposed methodology for shape recognition and database-based model matching implemented as the main processes. The 4 main elements can be easily recognized: the input data (target shape), the output data (NC code and process plan), the database and the algorithms.

The considered CAPP system is shown in Fig. 1. The input data to the system is the 3D CAD model of the part only. This CAD model has been generated previously, and it can be a simple part or a complex product made of several simple parts. From now on, the input CAD model of the part will be referred as **target shape**, as the target of the system is to manufacture it. Despite being out of the scope of this research, the NC code and process planning generation step is also included in the scheme. These steps may be performed by an external CAM system. As it can be noticed from the scheme, the shape recognition and model matching processes, whose input-output flow can be observed in Fig. 2, is divided in 3 stages, namely: the **shape recognition** stage, the **component identification** stage and the **database-based model matching** stage. Following in this paper, the three stages of the proposed methodology are explained in detail.

However, before that, some nomenclature affairs should be considered. The system has been developed using in the SolidWorks Application Programming Interface (API), while the implemented algorithms have been programmed using Visual Basic for Applications (VBA). Therefore, the nomenclature used in this paper is based in the one used by the SolidWorks API.

A mechanical component that can be completely designed by the CAD software in one unique file is named **part**. Therefore, a part is the most basic component that can be built by a CAD program. Two or more parts can be used in order to obtain more complex mechanical components, leading in what has been traditionally called **product**. In this paper, each of the parts making up a product are called **bodies**. For instance, a part is made only by one body. Nevertheless, a body is usually a complex entity in terms of pockets, slots or holes. As it can be observed in Fig. 3, a body is made up of one or more **faces**, and one or more **edges**. Please note that the concepts of **face** and **surface** are commonly used as synonyms, although surface is used when referring to the mathematical entity and its properties and parameters. Also, one face is delimited by a closed contour called **loop**, which is in turn made up of one or more edges. Figure 3 also shows that loops can be **internal** or **external**. An accepted criterion to distinguish them is the following: if the loop can be scrolled clockwise with the face remaining in the right side, then the loop is an external loop of the considered face; otherwise, if the face remains in the left side, then it means the loop is internal for that face.

The reader should note that bodies without edges or loops and only one face actually exist, i.e. a sphere or a torus. As for the concept of **feature**, usually in the literature is used to refer to slots, pockets or holes existing in the part. Following the nomenclature provided by the SolidWorks API, a **feature** is the entity or operation that originated a certain face and, consequently, owns that face. According to this definition, a face of a certain body belongs to one feature only. However, a loop in the body can be owned by more than one feature as long as the edges making up the loop belong to different faces originated by different features.

In order to have a better comprehension of the developed methodology, the target shape shown in Fig. 4 will be used as example, explaining in detail each of the three stages.

![Fig. 2 General input-output flow of the proposed methodology for shape recognition and model matching. The three stages of the process can be clearly identified: (I) shape recognition, (II) component identification and (III) database-based model matching. There is only one input data (the target shape) and two output files (the shape recognition file and the comparison file).](image)

### 3.1 First stage: shape recognition process

The first stage of the proposed methodology is a shape recognition process which extracts all the information available in the CAD model of the target shape, being this CAD model the only input in the stage as it can be seen in Fig. 2. The information extracted includes the number and type of surfaces, loops and edges, the features owning these surfaces as well as geometric data and parameters. All this information is exported in only one excel file that will become the input for the next stage.

Therefore, the shape recognition stage has three main objectives: first objective consists on identifying the bodies, faces, surfaces, loops and edges of the target shape and extracting their geometric parameters (e.g. lengths, radius, area, etc.); the second aim is renaming each body, face, loop and edge of the target shape in order to create a unique nomenclature naming system that allows the user to easily refer to a particular entity in the CAD model; finally, the stage also generates a unique identification sequence for the target shape by means of a coding system. This coding system, as well as the score system that later will be explained, are the novelty this research tries to introduce. Though the use of a coding system is not a new idea, the process to create the identification sequence making use of the information in the CAD model only is a new way to simplify the model matching task in this kind of systems.

The core of this stage is the algorithm shown in Fig. 5, which is applied to each of the faces found in each body. The algorithm is capable to find five types of surfaces: plane, cylinder, cone, sphere and torus, since these are the surfaces that the SolidWorks API is able to extract geometric information from. The algorithm then will analyze the loops of the face, and whether those loops are external or internal. When an internal loop is found, the feature that originated that loop is determined. This allows the algorithm to differentiate between a hole in a surface, a geometric pocket or a slot, for example. The shape of the loop is also determined, distinguishing between circular loops (commonly originated by holes) or prismatic loop (i.e. a rectangular pocket removing material in the body).

Also the shape recognition algorithm was designed in order to provide with quantitative data that can be later used in other stages of the CAPP system, e.g. when the NC code is generated. This information is measured depending on the surface analyzed, and extracted in the same output file than the identification sequences.
Figure 6 shows the result for the face B1S14 (the name is given by the system automatically, and it is not decided by the designer or related to any geometric aspect of the part; it is completely arbitrary). In Fig. 6, the name of the face, type of surface, surface parameters, area of the face and the feature that created the face can be found in the first two columns, while the information related to the external and internal loops is placed from the third column. For each loop, its name, type and edges are written; the length of each edge is next to its name too. Reader should note that only three of the six total loops are shown in Fig. 6.

Face B1S14 is the main face of the target shape, as it contains information from mostly all of the features existing in the part. The surface is recognized as a plane originated by an extrusion operation, as it can be seen in Fig. 6. Also, the external loop is made up of many edges, while the internal loops are made up of only one edge due to the fact that they represent circular contours.

### 3.1.1 The FaceID as coding system

The proposed research uses a coding system as main point to generate an identification sequence that the authors have named FaceID. A FaceID is a 6-digit and 1-word identification sequence generated in base to a certain algorithm and assigned to each of the faces of a body. This sequence depends only on the geometry of the part, and it is the key for the database-based model matching conducted in next stages, allowing an accurate and fast identification of the components of the target shape and a precise database comparison. Each face is provided with, at least, one FaceID, depending on whether the face has internal loops or not. The FaceID is generated as follows (see Fig. 7):

- 1st digit depends on the type of surface: 1 for planes, 2 for cylinders, 3 for cones, 4 for spheres, 5 for torus and 0 for other type of surfaces.
- 2nd digit depends on the geometry of the external contour of the face: 1 for prisms, 2 for circles.
- 3rd digit indicates the number of internal loops, being 0 when there are none of them.
- 4th digit indicates the internal loop number the FaceID refers to, since there may be more than one internal loop in the same face.
- 5th digit depends on the geometry of the internal loop: 1 for prisms, 2 for circles.
- 6th digit indicates whether that internal loop is all external for the adjacent face (being then 1) or not (being then 0).
- 7th element of the sequence is a word indicating the feature owning that internal loop as indicated by the SolidWorks API, i.e. boss, cut, revolve, etc.
Usually, an additional element is added to the sequence, the 8th element, a word indicating the feature that owns the analyzed face. Also, in case a loop is owned by more than one feature, a different FaceID will be generated for each feature, being then the same FaceID except for the 7th element of the sequence. In section 4 of this research, a practical application of the methodology is developed; the reader is suggested to read it in order to clarify the concept of FaceID.

The use of FaceID is the novelty introduced by this research, and the key to identify later the components of the part in an accurate and fast way. Model matching must be performed based on the components and features of the part, but the shape recognition is performed based on the faces of the body by the CAD. To solve this problem, traditionally an external complex code was required in order to get the features; nevertheless, those codes were not standard, and could be applied to certain parts only, depending on what the research was focused on. That is the novelty of the proposed research: as the employ of FaceIDs links the shape recognition performed according to the CAD software with the model matching based on features and components, the proposed methodology is not application-dependent, so it can be used for any mechanical component.

The faceB1S14 of the example has 6 FaceID sequences in total (5 internal loops and 1 external loop), and they can be seen in Table 1. By looking to the last element of each FaceID, the feature that originated that internal loop can be implied; as it could be expected, there are 4 “Cut” (the 4 holes in the corners) and 1 “Boss” (the central cylinder extruded on the face).

Fig. 4 CAD model of the target shape used in the practical application. The target shape is made up of prismatic and cylindrical volumes only. Image from the GUI of SolidWorks.

3.2 Second stage: component identification process

Once the shape recognition stage has concluded, next step in the process is the component identification stage. As it can be seen in Fig. 2, the only input for this stage is the output file of the previous stage, while the output will be a file called “comparison file”. The considered components are only five, and they have been chosen wisely in order to make the proposed methodology as much general as it could be possible. The components, which can be seen in Fig. 8, are the following: a prismatic volume (it can be a rectangular prism or any other polygonal shape), a cylindrical volume, a conical volume, a spherical volume and a torus. In addition, each of them is classified in PA D when adding material to the part, or POCKET when they remove material. The identification of the elemental components conducted by this stage will become a key factor for the future model matching stage, as this is the process linking the face information contained in the FaceID sequences with the existing features in the part.

In order to perform this identification, a proper algorithm to identify the components based on the FaceIDs of the part is required, and it is explained in the following lines:

- A tabulated list of all possible combinations of FaceID sequences has been created alongside the methodology and stored in a file accessed by the algorithm during the analysis. Each FaceID sequence has been provided with a unique number, which is called tabulated index.
- The FaceIDs of the target shape are compared with the previously mentioned list of FaceID sequences in order to assign a tabulated index to each FaceID of the target shape. The way to carry out such a comparison depends on whether the face is simple (with no internal loops) or complex (with internal
loops). If the face is simple, the 1st, 2nd, 6th and 8th digits of the FaceID sequence are compared; on the other hand, if the face is complex, the 1st, 2nd, 5th, 6th and 7th digits are compared.

- Exactly the same process was conducted for the 5 elemental components shown in Fig. 8 and stored in a file which is also accessed by the proposed methodology every time a target shape is analyzed. Each component owns unique and characteristic tabulated indexes that differentiate it from the other components, as it can be seen in Fig. 8.

For example, the characteristic feature of a cylindrical volume is its cylindrical surface. This cylindrical surface has a characteristic FaceID and, consequently, a tabulated index which is unique and different from, for instance, the conical surface of a cone. In that case, a cylinder is represented by the index no. 38 or 96, while a cone is represented by no. 62 or 108.

However, one volume could be designed using more than one method in a CAD software; for example, the same cylindrical volume could be built by a “Extrusion” tool or a “Revolution” tool, having each of them a different FaceID and tabulated index. Because of that, an elemental component could have more than one unique tabulated index. In Fig. 8, a cylindrical PAD can be no. 38 (when it is made by an extrusion-boss) or no. 96 (when is made by a revolution).

- Finally, the tabulated indexes of the target shape and the five elemental components are compared as follows: if the tabulated index of an elemental component exists in the list of tabulated indexes of the target shape, then it means that the target shape is made up of that elemental component.

- As for the chamfers that may exist in the target shape, they are not considered as an elemental component. These features are analyzed during a pre-process operation at the beginning of the methodology. The result of this pre-process operation is whether the target shape has or not a chamfer, and what kind of chamfer (plane or round chamfer).

The target shape shown in Fig. 4 contains the following tabulated indexes no.: 3, 4, 11, 12, 14, 19, 20, 37, and 38. If these indexes are compared with the tabulated indexes of the elemental components of Fig. 8, it can be observed that only the indexes no. 3 (prismatic POCKET), 4 (prismatic PAD), 37 (cylindrical POCKET by cut-extrusion) and 38 (cylindrical PAD by boss-extrusion) are included in the indexes of the target shape. So, in conclusion, the target shape is made up of the following elemental components: prismatic volumes (both PAD and POCKET) and cylindrical volumes (both PAD and POCKET), which correspond with the slots, cylinder and holes that appear in Fig. 4.

Reader should note that there are only nine tabulated indexes even there are around 40 FaceIDs in total. This is completely correct. Though each FaceID is assigned with one tabulated index, one index can appear more than once.
Reader also may notice that not all the tabulated indexes assigned to the FaceIDs of a target shape appear in the elemental components of Fig. 8. For example, the index 19 does not represent the main feature of any of the five elemental components.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>FaceID sequences of face B1S14 of the target shape in the example.</th>
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<tbody>
<tr>
<td>FaceID</td>
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Fig. 6 Results after the shape recognition stage in the face B1S14 of the target shape. The face is recognized as a plane surface with one external loop and five internal loops. Image obtained from Excel and SolidWorks GUI.

3.3 Third stage: database-based model matching process

The third a final stage of the proposed methodology is a database-based model matching process in which the target shape is compared within a database of previously known parts in order to find the most similar one. This similar part is called reference part, and the process plan and NC code of the target shape may be created based on the ones of the reference part. The database used in this stage contains the comparison files of the known parts that will be compared with the target shape. This database must be created previously, and it should be made up of parts that are similar to the analyzed target shape in order to obtain useful information. Reader should note that, the more complex the target shape is, the larger the database should be to get high accuracy in model-matching.

3.3.1 The score system as the core of model matching

The score system has been designed with one objective: analyzing the similarity of each part of the database with the target shape and giving a score according to this likeness. The final score is a percentage indicating the similarity of the part and the target shape, being 100% exclusively obtained when both part and target shape are identical. This score
is given according to three factors: the similarity of the FaceIDs, resulting in the ScoreA; the similarity in the components, resulting in the ScoreB; and the similarity in the total number of faces, resulting in the ScoreC.

\[
\text{Score} = (\text{Score}_A \cdot q_A + \text{Score}_B \cdot q_B + \text{Score}_C \cdot q_C) \cdot 100 \leq 100
\] (1)

The ScoreA measures the similarity of the FaceID sequences of the database’s part and the target shape, particularly the similarity of 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}, 5\textsuperscript{th}, 7\textsuperscript{th} and 8\textsuperscript{th} elements of the sequence. By doing so, the information related to the features, surfaces and loops is compared. For each identical element of the sequence, one point is assigned to the FaceID of the database’s part. Once all FaceIDs have been evaluated, all the scores are added and then divided by the maximum available score, which is the total number of FaceIDs of the part multiplied by 6. The ScoreA results in the expression of Eq. (2):

\[
\text{Score}_A = (\sum \text{IDScore} / 6 \cdot N^{\text{FaceID}}) \leq 1
\] (2)

The ScoreB is given based on the components that make up the part and the target shape. The score system takes into account the five elemental components in both pad and pocket variant, and also the chamfers the part or the target shape may have. For each identical component, one point is given, being 12 the maximum (5 components in 2 variants and 2 kind of chamfers). The expression to get the ScoreB is shown in Eq. (3):

\[
\text{Score}_B = (\sum \text{ComponentScore} / 12) \leq 1
\] (3)

Finally, the ScoreC is assigned depending on the total number of faces of the part and the target shape, getting the highest value when the number of faces is exactly the same. The final score could be defined with the ScoreA and the ScoreB only, as they consider the components and its configuration in the part. Nevertheless, the ScoreC allows to improve the accuracy when the target shape is very similar (but not identical) to the parts in the database. For instance, two parts with same features, shape and components, one with blind holes and the other with through holes, would get exactly the same ScoreA and ScoreB. The ScoreC allows to distinguish them, as the part with blind holes has more faces (one more face per blind hole). Moreover, the proposed algorithm can identify prismatic volumes, but it does not...
differentiate between a rectangular and a hexagonal prism; if the ScoreC is used, differentiation is possible since the total number of faces will be different.

However, ScoreC should be used only when the target shape is very similar to the parts in the database. Otherwise, as the number of faces of two radically different parts could be the same by coincidence, the ScoreC could introduce a fake measure in the final score. In order to control this problem, and to make the system more flexible, the three weight coefficients in the Eq. (1) can be modified by the designer. By doing so, the score system can be somehow calibrated. The problem with the ScoreC can be avoided by giving a null or small value to the weight coefficient of the ScoreC.

The parts which make up the database used for this example can be seen in Fig. 9. Reader should note that, as this is a practical application only, few elements were considered. A larger database is possible and recommended for more advanced applications. The parts E01, E02, E03 and E04 are quite similar to the target shape, while E05 and E06 are not. As there were parts in the database which were not similar to the target shape, the weight coefficient for ScoreC was reduced to 0.05, being the weight of the ScoreA 0.45 and the one of the Score B was raised up to 0.50.

![Fig. 8 The five elemental components. From left to right: prismatic volume, cylindrical volume, conical volume, spherical volume and torus. Each of them can be PAD (adding material) or POCKET (removing material). The numbers represent the tabulated indexes of each component. Image obtained from the SolidWorks GUI.](image)

![Fig. 9 Parts in the database for the model matching stage. As it is a practical application, only six parts were considered. Elements 01, 02, 03 and 04 are similar to the target shape, while 05 and 06 are not. Image obtained from SolidWorks GUI.](image)

The results of the third and last stage of the methodology are shown in Table 2. As it can be seen, the part E02 gets the maximum score, with a 91.66% of similarity respect the target shape. Next E02 and E04 get a score over 90%, which has sense since E04 is identical to the base of the target shape and E01 is identical to the target shape except for
the slots. E03 gets a lower score, as cylinder volume is not included and the holes in the corners do not exist too. E05 gets the lowest score, under 70%. This also has logic, as there are no spherical volumes in the target shape. As for E06, reader could expect it to get a lower score than the one it really obtained, which is around 88%, quite high for a part with a configuration rather different from the target shape. The components are exactly the same (except for the chamfer), while the score for the FaceIDs is also high due to the fact that both E06 and the target shape are made up of a cylinder over a prism, and then a hole in the cylinder. Also, E06 got a high Score C. Nevertheless, the score of E06 is under 90% and is lower than for E01, E02 and E04, so model matching was correctly performed.

<table>
<thead>
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<th>ScoreC</th>
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4. Conclusions

CAPP systems are a powerful tool to automatically manufacture a part from its CAD model state to its final state as mechanical component without needing knowledge or technical experience in process planning. Though the future seems to belong to the generative approach and the use of AI to create human-based algorithms, nowadays these systems are still in a developing state. In this context, the already known variant approach CAPP systems are a feasible option for this quandary. These systems can be upgraded using solid models and more sophisticated algorithms in order to achieve an excellent effort-result relation in terms of precision and cost.

The methodology proposed in this paper tries to simplify the shape recognition and model matching stages, unifying the CAD software and the algorithms in one system with only one input (the CAD model of the part) and two outputs (the shape recognition file and the comparison file). The proposed system presents some advantages with respect to the existing methodologies. First, by means of an original coding system, the proposed methodology is able to link the information extracted of the faces of the part, which is directly obtained from the CAD software programming interface, with the identification of the features and components. In contrast to the existing methodologies, it does not require an external code to identify the features of the model. Second, the coding system is also used in the model matching stage, which is carried out by a score system. By doing so, the accuracy in the database comparison is improved, especially when the parts in the database are very similar, but not identical, to the target shape. This score system can also be calibrated depending on the part that is going to be analyzed. Third, during the shape recognition stage, not only qualitative, but quantitative data is also extracted from the CAD model. This data can later be accessed and used by other stages of the CAPP system, such as the NC code generation, which needs specific data, i.e. dimensional parameters. Finally, the system works with solid components and in a user-friendly environment, so it can be easily applied to the industry without needing other software rather than SolidWorks and Microsoft Excel or similar. While other researches worked with wireframes models of the target shape, this methodology uses the CAD model directly.

The methodology has also some limitations. In contrast to the generative approach systems, the variant approach cannot generate a completely new process plan, so a process planning expert may be needed to properly adapt the process plan of the target shape from the plan of the selected reference shape. Moreover, some aspects such as lengths or the orientation of the volumes are not considered by the methodology at its current state. However, as quantitative data can be already extracted, the implementation of a new module which considers the length or the orientation of the target shape is perfectly possible in the very next future.
References


