Part Similarity Algorithm Based on Manufacturing Features Similarity

Ramy F. Harik[1] and Fadi G. Barakat[2]

[1]Lebanese American University, ramy.harik@lau.edu.lb
[2]Lebanese American University, fadi.barakat07@lau.edu.lb

ABSTRACT

This paper presents an algorithm for mechanical part resemblance based on manufacturing features similarity. The algorithm is generated from a hybrid variant/generative approach. In a first step the parts are studied and their chaining graph (CG) linking their manufacturing features is generated. In a second step, the CG is compared to other CG available in the study database, thus generating a set of parts with a specified manufacturing similarity percentage. The algorithm is split into three phases: Chaining graph generation, Manufacturing Features graph generation and Similarity Algorithm. The concept is verified through a first draft study case. The paper will end up with a conclusion and perspectives for further development.

Keywords: manufacturing features, PLM, part similarity, chaining graph, EMF, SMF.
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1 INTRODUCTION

Identification of similar mechanical parts can optimize the costs for several trades: Design, Process Planning, Manufacturing … In effect, if the studied part has similar previous ones, the analyst can use the previously generated process plan and manufacturing program to rapidly estimate the manufacturing cost of the new part. This permits a time reduction and helps the industry to establish a knowledge management system to reuse previously studied concepts (in our case part manufacturing). The benefits stated from having a part similarity search algorithm are numerous. This article tries to present a part similarity algorithm based on manufacturing features. It starts from a previous study of ours [8] and further develops it to obtain the algorithm.
The article continues with a state of the art presented in section 2. The state of the art exposes previous methodologies and tries to highlight the need for a manufacturing similarity based algorithm. As a follow up, section 3 presents the general approach of the algorithm that is split into an update of the part chaining graph (section 4), the manufacturing features graph generation (section 5) and the similarity comparison methodology (section 6). The article ends up with a conclusion to the presented work and future perspectives: namely the proposition to implement the proposed concepts on a software platform.

2 STATE OF THE ART

The benefits that can be obtained from part resemblance techniques have affected the production cost, the production time, and have also given cost estimation another approach that does not rely on an expert's rough estimation. In our state of the art we will separate the literature review into: geometrical shape estimation, design features comparison, manufacturing features comparison and cost prediction. This separation is coherent with the proposition of [12] that split techniques into the family of: Global feature-based, manufacturing feature recognition based, graph based, histogram based, product information based and 3D object recognition based. Geometrical resemblance has been the first aspect tackled by researchers because it is the closest to human observation. In [1] a method for partial shape-matching to recognize similar sub-parts of objects is introduced. The technique preserves the geometry and is sensitive to major feature based, its graph is smaller than the one of a B-rep, and it is insensitive to small changes in shape. The resemblance is achieved through a graph-matching technique where the graphs are compared and the sub-parts with similar structure and similar space distribution are highlighted. Another geometrical comparison approach was studied in [6] a similarity assessment of mechanical parts based on the DBMS (dilation based multi-resolutional skeleton). The DBMS technique achieves a high-quality similarity assessment and retrieval of solid models, along with more precise topological and geometric information. The DBMS is claimed to be an efficient technique since it focuses on the essential shape of the model which is usually a small shape. In [11] design feature comparison was tackled by using a shape search system that works on transforming the shape input into feature vectors and a unique skeletal shape. It is close to a B-rep representation with the difference of being significantly smaller. This method preserves the overall geometry and topology of the object, and is insensitive to minor perturbations in the shape while still being sensitive enough to capture major features of the shape. An alternative design feature comparison is presented in [10] the purpose of matching is to reuse existing parts to reduce the time spent in the design process. The matching process is done using B-rep, the overall shape is assessed at first and then the detailed features are compared. If the part was designed by a feature based modeler the modeling history can be used for parametric modeling. The more revolutionary approaches are the methods that compare mechanical parts not according to their geometrical shapes but rather to their similar manufacturing features. In [4] an algorithm for manufacturing feature-based similarity assessment is presented. This technique is limited to 3-axis parts and it utilizes reduced feature vectors consisting of machining feature access directions, feature types, feature volumes, feature dimensional tolerances and feature group cardinality as a basis for assessing machining effort point of view. When comparison is done the group of reduced vectors is transformed in space using rigid body transformation in relation to the other set to minimize the distance between them. The distance between the two sets is used as a basis of comparison and thus the feature based similarity is obtained. In [8] the use of an enhanced B-rep graph is used to recognize manufacturing sequences. The presented method can adapt complex part whose multitude can reach up to a 5-axes orientation. The graph developed in this technique recognizes the faces and the manufacturing features of the part. The faces/features are linked and the graph is used to get the manufacturing sequence of the given mechanical part. One of the motives for creation of mechanical part algorithms is the need to predict the cost of the part with the minimum human intervention. In [13] an interactive GT code is introduced and its main goal is to estimate the cost of a mechanical part. It matches different parts according to their features. The latter are extracted from the 2D draft of the part. When all the information about the part is gathered it is converted into a string code and matched to other codes referring to other parts. The method [4] previously mentioned in this State of the Art has an integrated algorithm that is used to predict the cost of the mechanical parts assessed. Another innovative approach is presented in [16]. In this paper, the focus is on the development of a 3D object retrieval methodology that uses a hybrid shape descriptor providing top discriminative power and has minimal storage requirements. This method is based on previous work done by [15], 2D features are extracted from a depth-buffer based representation of a model and 3D features (spherical harmonic coefficients) from a spherical function based representation as in the work of [14]. To compensate for rotation, two alignment methods, namely CPCA and NPCA, are used while compactness is supported via scalar feature quantization to a set of values that is further compressed using Huffman coding. The superior performance of the proposed retrieval methodology is demonstrated through an extensive comparison against state-of-the-art methods on standard datasets.

However, as mentioned in [12], most manufacturing feature recognition-based techniques are not robust in extracting features successfully and are still a significant challenge for research. Our article connects a comprehensive manufacturing feature recognition technique generated by the French

USIQUICK consortium [2][3][5][7][17] with a comparison algorithm that will assess the manufacturing feature resemblance between the mechanical part studied and parts found in a database of already manufactured mechanical parts.

3 GENERAL APPROACH

In this section we present the complete outline of the methodology and its different steps (Fig. 1):

- **Input**: The input of the algorithm consists of the part in a SOLIDWORKS format. The algorithm current input can be generalized to a neutral format (i.e. STEP) or can be imported from any other CAD system through STEP.
- **Chaining Graph Generation**: In the first step the part is analyzed at the faces and edges level. Each face is set as an elementary manufacturing feature. The links between the elementary manufacturing features are identified and joined. This step generates the chaining graph for the part.
- **Manufacturing Features Graph Generation**: In this second stage the chaining graph is analyzed and further refined to obtain the MF Graph. For this, 20 different types of potential manufacturing features are presented. For each type the corresponding sub-EMF graph is exposed. Following, the different MF are linked and the MF Graph is generated.
- **Similarity Algorithm**: At this level the algorithm is connected to a database containing previously studied parts. This stage identifies similar parts by investigating the different MF, their properties and how they connect to one another.
- **Output**: The algorithm ends up with the identification of the parts that are similar to the input one. For each, a similarity percentage is calculated.

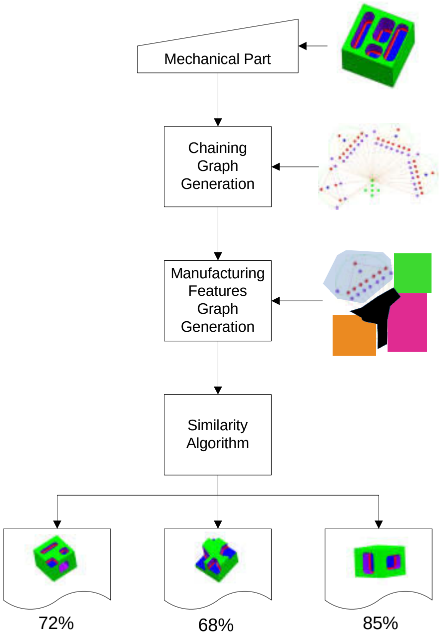

Fig. 1: Part Similarity algorithm general approach.

4 CHAINING GRAPH (CG) GENERATION

In this section we will present an update of the CG algorithm presented in [8]. At first we will present separately the attributes required for the generation of the Elementary Manufacturing Feature (EMF) [9] representing the nodes, as shown in the basic CG in Fig. 1., as well as the attributes of the connecting edge linking two EMFs together.

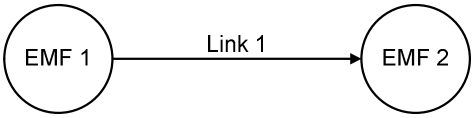

Fig. 2: Basic CG showing two *EMF1* and *EMF2* linked through *Link 1*.

In the presented chaining graph, fillets in the CAD model are considered even though they should be omitted and replaced by a singular edge holding the fillet attributes (fillet dimension due to the tool corner radius). This proposition will further simplify the proposed CG. In future perspectives, fillet subtraction from the CG should be performed.

4.1 Elementary Manufacturing Features (EMFs)

An EMF is composed of one and only one elementary face which boundaries are solidified. It is associated also to at least one finishing process, identified, validated, and independent of the other processes [9].

The attributes of an EMF are:

- Manufacturing Accessibility, containing the manufacturing directions that enables the tool to access the face in consideration
- Manufacturing Modes, specifying the manufacturing process to be applied (Flank, End or Sweep Milling)
- Manufacturing Tools, the parameters of the potential manufacturing tool.

An EMF is represented as **EMF**(*Accessibility*, *Mode*, *Tool*), where the element Mode constitutes the base of separation in between EMFs. In the following, we will present the various EMFs (Fig. 3.):

- Flank EMF: **EMF1**(Accessibility: *Face Contained*, Mode: *Flank Milling*, Tool: *Torus [R,L,r]*)
- End EMF: **EMF2**(Accessibility: *Perpendicular to the Face*, Mode: *End Milling*, Tool: *Torus [R,L,r]*)
- Open EMF: **EMF3**(Accessibility: *General*, Mode: *General*, Tool: *Torus [R,L,r]*)
- Fillet EMF: **EMF4**(Accessibility: *Simultaneous End/Flank*, Mode: *None*, Tool: *Torus [R,L,r]*)
- Thin EMF: **EMF5**(Accessibility: *General*, Mode: *Obtained during Roughing*, Tool: *Torus [R,L,r]*)
- Unspecified EMF: **EMF6**

Fig. 3: Schematic representation of EMF.

It is to mention that the Open EMFs are generally obtained while roughing the billet. And the further defined manufacturing features are to be processed for obtaining the finished part from the near net shape (generated from the roughing operation).

4.2 Chaining Graph Links

A CG link connects two EMFs together. It is supported by an edge and defined by the combination of three elements: the sharpness of the concerned edge (SE) and the nature of the two surrounding EMFs. In the following table we will expose the potential links and attribute a parameter for each (visually a color will be defined).
The sharpness of the concerned edge (SE) is split into [8]: Tangent Closed (TC), Tangent Open (TO), Closed (C), Open (O), and Others (Z).

In Tab. 1, the three presented elements are:

- Links: a set of potential links {(EMFx1,SE1,EMFy1), (EMFx2,SE2,EMFy2)…}
- Color Code : a color depicting the visual link in the CG
- A Probable MF: the links potential participation in the formation of a MF
- X, when mentioned it represents all possibilities

Link	*Color Code*	*A Probable MF*
(EMF1,C,EMF1), (EMF1,TC,EMF1)		Chain of Pocket Walls (Flank)
(EMF1,O,EMF1), (EMF1,TO,EMF1)		Flank Contouring
(EMFx,X,EMF3)		Free MF
(EMF1, C, EMF4), (EMF1, TC, EMF4)		Pocket Wall
(EMF2, C, EMF4), (EMF2, TC, EMF4)		Pocket Base
(EMF1,O,EMF5), (EMF1,TO,EMF5)		Thin Walls
(EMF4,C,EMF4), (EMF4,TC,EMF4)		Fillet Chain
(EMF5,X,EMF5)		Thin Walls' Top

Tab. 1: Chaining graph links.

4.3 Chaining Graph

In this paragraph we will present an application result of the CG algorithm. Figure 4 presents the concerned part whereas figure 5 presents the obtained CG.

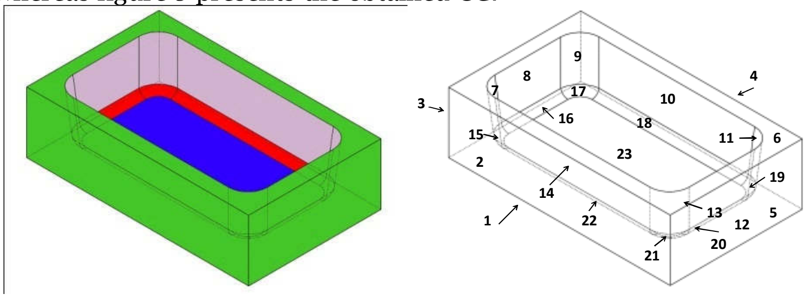

Fig. 4: Study case: (a) Faces colored with respect to their EMF type (b) Face numbered.

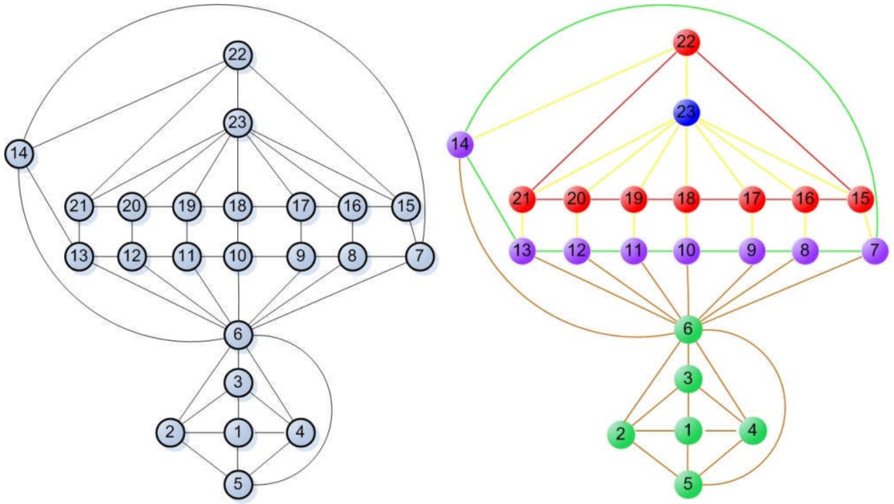

Fig. 5: Chaining graph application: (a) Faces graph (b) Chaining graph showing EMF.

4.4 Comparison between Update and Previous Methodology[8] &[9]

In this section we will highlight the difference between the previous work done in [8][9]and the updated method proposed in this paper. The method proposed in this paper takes the previous work a step further. In the previous work the aim was to extract the elementary manufacturing features from a mechanical part and identify the type of links with the other bordering features using USIQUICK and represented in a CG. The new methodology proposed takes the CG generated from the previous method and groups EMFs that make up a manufacturing feature (MF) passing through sub-manufacturing features (SMF) which will be further explained in section 5.

5 MANUFACTURING FEATURES GRAPH GENERATION

In this part we will reduce the generated chaining graph Fig. 5 from an EMF based graph to a manufacturing feature graph Fig. 8 passing through a sub-manufacturing feature (SMF) graph Fig. 7 that extracts chains of similar EMFs

Fig. 6. The following process does not account for geometric attributes this step will be included in the perspective and will be a continuation of this topic.

5.1 Transition from EMF CG to SMF Graph

The algorithm that transforms the EMF graph to the SMF graph works as follows:

- Identify similar EMFs directly linked together
- If an EMF of a type is not connected to another EMF of the same type it is considered to be a SMF by itself.
- Identify whether the links linking the similar EMFs are of the same type.
- Identify whether the chain formed by the selected EMFs is a closed chain or open chain.
- Consider the chain obtained as a SMF and defines its type and the number of faces it includes (Fillet Chain, Chain of Pocket Walls (Flank), cube-like open flank chain).

In this example we extract several SMFs from the part shown in Fig. 4. All EMFs of the same type that are linked together by the same link type described in Tab. 1 are reduced to one SMF chain; the SMF chains represent the SMF Graph

The procedure is depicted below:

- **EMF3** topological chain **highlighted** on Fig. 6 by the **Free MF** represents a cube-like **SMF3.**
- **EMF1** chained by the **Chain of Pocket Walls (Flank)** links to become **SMF1.**
- **EMF4** chained by the **Fillet Chain** links to become **SMF4.**
- **EMF2** which is a single element that represents the bottom of the pocket to become **SMF2.**

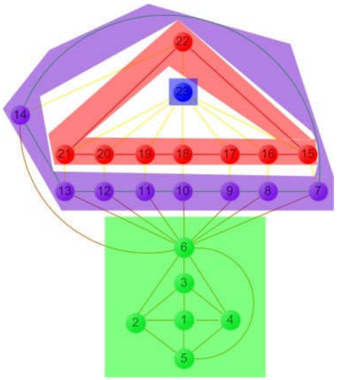

Fig. 6: Highlighting similar EMF chains.

- **SMF1 (8 EMFs)** is linked to **SMF3** by the **Free MF** link on face 6
- **SMF4 (8EMFs)** is linked to **SMF1** by the **Pocket Wall** link

- SMF2 (1EMF) is linked to SMF4 by the Pocket Base link
-

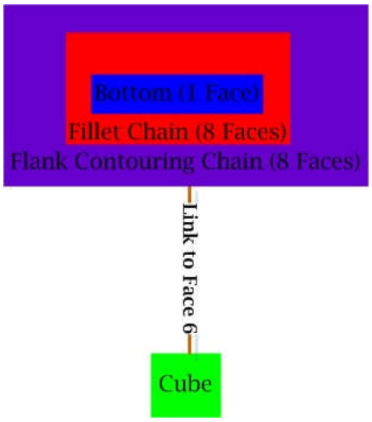

Fig. 7: SMF graph.

5.2 Transition from SMF Graph to MF Graph

The algorithm that transforms the SMF graph to the MF graph works as follows:

- Identify the type of links between the SMFs.
- Identify whether a single face from one SMF is connected to a single or several faces of another SMF.
- Check whether the link between several SMFs contribute to the property on a common MF.
- If the check turns out true the group of SMF is identified as a known MF (Pocket, slot, rib…).
- If the check turns out false the group of SMF is identifies as a Miscellaneous MF.

In this step the SMF graph obtained in

Fig. 6 will be further more reduced to a MF graph represented in Fig. 8.

The listed descriptions below make up a single MF which is in this case a regular pocket on Face 6.

- SMF1 is linked to SMF3
- SMF1 encircles SMF4
- SMF4 encircles SMF2

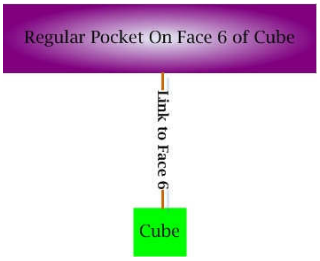

Fig. 8: MF graph.

5.3 Examples on Transitions from EMF CG to MF CG

This section presents two examples of the MF graph generation.

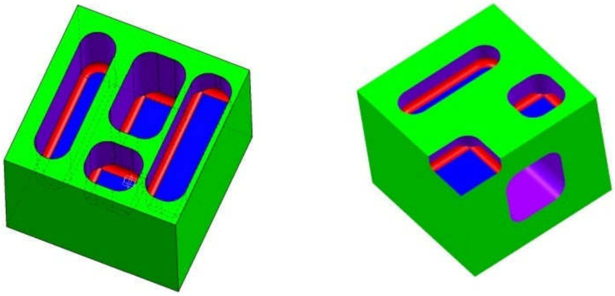

Fig. 9: (a) Part 1 (b) Part 2.

The graphs shown in Fig. 10 are those of Part 1in

Fig. 9. Part 1 has three regular pockets on the same face (face 6) and one 4 faced pocket also on the same face. The MF CG Fig. 10 (c) clearly describes the part.

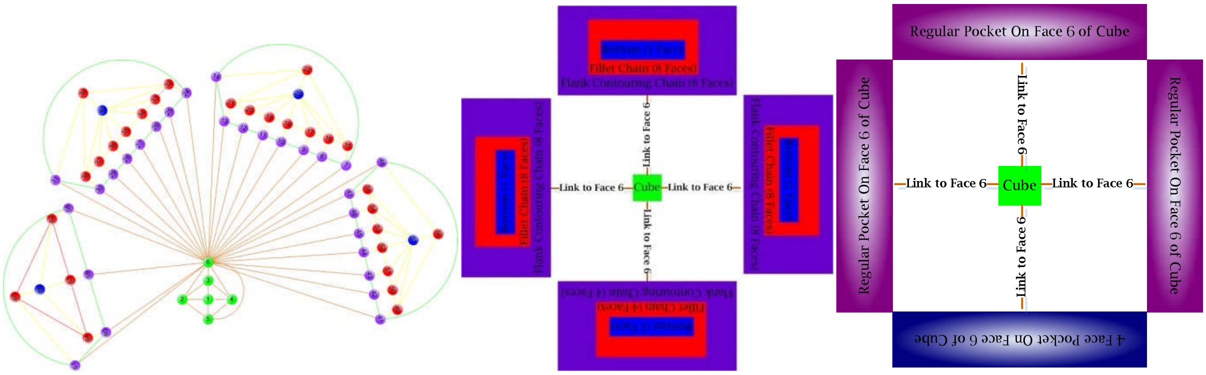

Fig. 10: Part 1(a) EMF CG (b) SMF CG (c) MF CG.

The graphs shown in Fig. 11 are those of Part 2 in

Fig. 9. Part 2 has one regular pockets, one 4 faced pocket, and one 2 sided opened pocket on the same face (face 6). Part 2 has an open ended pocket that extends from face to the other opposite face (Face 3 to Face 5). The MF CG Fig. 11 (c) clearly describes the part.

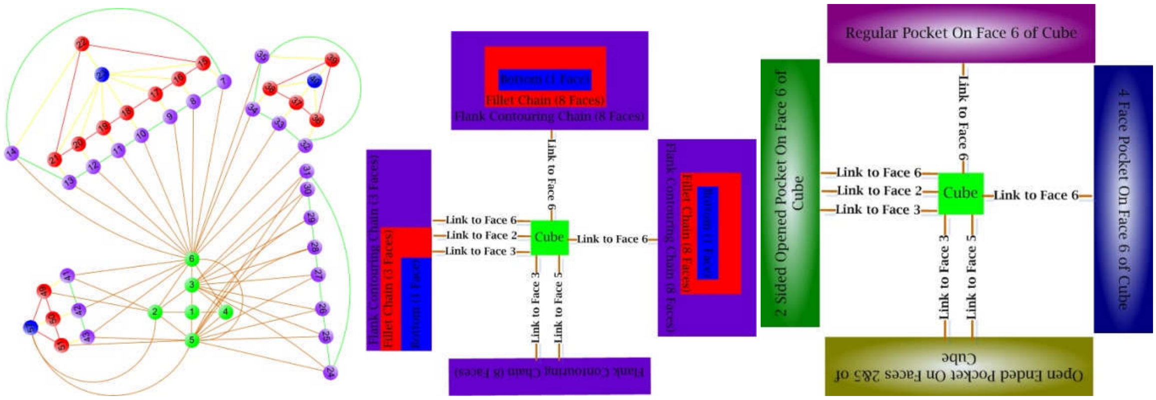

Fig. 11: Part2 (a) EMF CG (b) SMF CG (c) MF CG.

5.4 Interconnected Features

In this section we will present the preliminary work that is being done on the interconnected features. A cube with 4 pockets interconnected will be studied and analyzed. Note that this is part of the work is currently being further investigated.

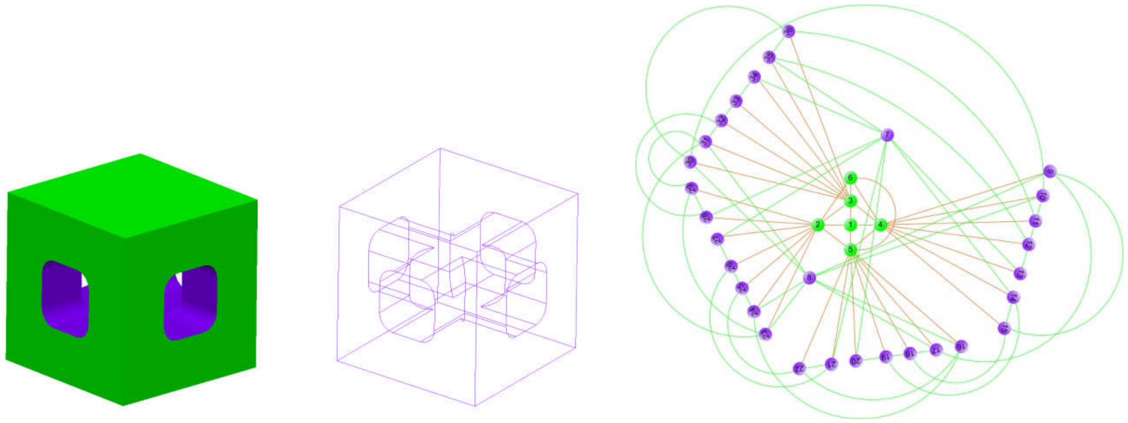

Fig. 12: Part 4 with interconnected features.

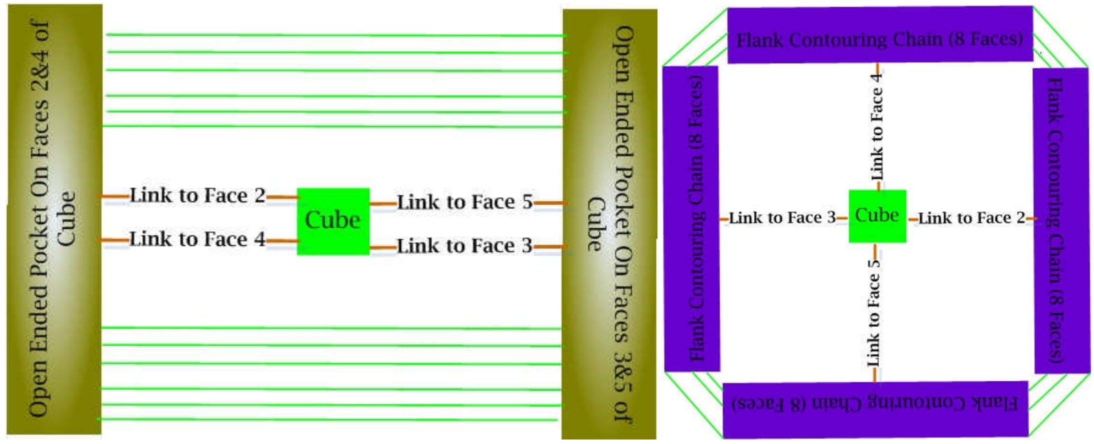

Fig. 13: Part 4 (a) SMF CG (b) MF.

6 MANUFACTURING SIMILARITY

This final section of the algorithm compares MF graphs of different parts and evaluates the manufacturing similarity.

6.1 Micro-level MF comparison

In a first stage Manufacturing Features are compared and coupled along their common attributes. A Pocket MF from part A and a Pocket MF from part B are evaluated based on their similar attributes. This stage requires a proper definition of each potential MF as well as the different attributes.

Tab. 2 lists the manufacturing features with the exception of the revolution ones.

Features
Boss
Axial Features
Slot
Pocket
Shell
Chamfer
Rib
Surfacing
Thin Features

Tab. 2: Manufacturing features.

6.2 Test Case

In this section we will take Part 3 (

Fig. 14 (c)) and compare it to the Part 1 (

Fig. 14 (a)) and Part 2 (

Fig. 14 (b)) based on the generated MF CG (

Fig. 15).

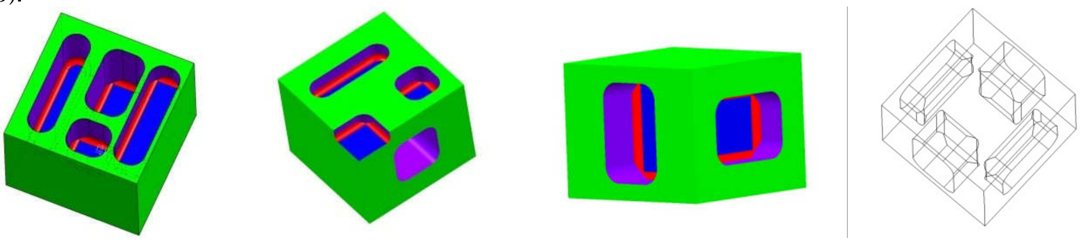

Fig. 14: Test Case (a) Part 1 (b) Part 2 (c) Part 3 (d) Part 3 wire frame.

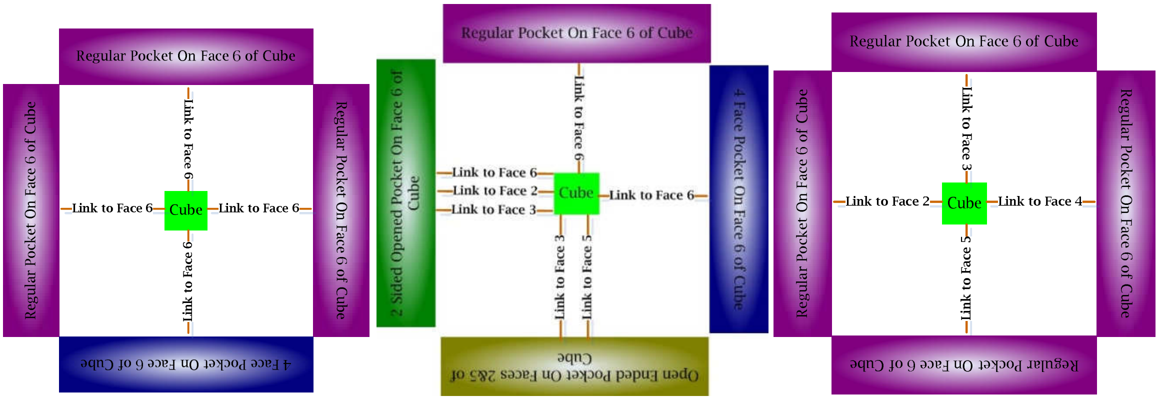

Fig. 15: MF CG (a) Part 1 (b) Part 2 (c) Part 3.

The test case clearly shows that Part 3 has 3/4 identical features to Part 1 making it have a 75% resemblance with Part 1; Part 3 has 1/4 identical features to Part 2 making it have a 25% resemblance with Part 2.

7 CONCLUSION

This article introduced a new approach to identifying similarity between mechanical parts based on manufacturing restrictions. At first, the article presented a comprehensive state of the art that resulted in highlighting the gap of current part similarity algorithms being based on restrictive shape approaches. Following the article introduced the complete methodology and then detailed it through three steps. The first step recalled a previously introduced technique of translating a mechanical part in a graph based network transforming the topological faces into an elementary manufacturing feature object. This network was then transformed into a sub manufacturing features graph linking the several EMF into chains. This sub-MF CG was further refined to generate the MF graph. Lastly, different parts were compared through their MF graph to compute their manufacturing resemblance: a comprehensive test case for 3 different parts is presented.

8 PERSPECTIVES

The MF CG presented in this paper can be further enhanced to perfectly describe the features of a mechanical part along with its manufacturing methods. To begin with, the fillets in the CAD model are considered even though they should be omitted and replaced by a singular edge holding the fillet attributes (fillet dimension due to the tool corner radius). The material of the mechanical part studied should be taken into account in order to better describe the manufacturing process and to better estimate the manufacturing cost and time. Furthermore, the CG should contain geometric attributes of the faces to obtain an exact representation of the mechanical part studied. Also the manufacturing similarity algorithm should be split into two levels: Micro-Level and Macro-Level. The aim behind this split is to study how the different MF are connected to one another and base the similarity value computation on links similarity in addition to feature attributes similarity.

Moreover, the concept presented in this article deserves a prototype to be further expanded. It is interesting to consider the neutrality of the input file (i.e. STEP). The programming platform should be expanded to support CAPP functionalities since proper manufacturing features extraction will automate the definition of fixtures as well as other CAPP functions.

The approach presented in this paper is still in its elementary stage but it is a promising. The aim is to use the method and compare mechanical parts from Shape lab benchmark http://shapelab.ecn.purdue.edu/Benchmark.aspx. More work is needed to find the perfect algorithm that can accommodate all the mechanical features. But it is good to say that the work previously done and that is currently being done is proving to be effective and therefore the we will keep on investing time in that area in specific to produce solid results that can also be used for other applications too.

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