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STEP BASED GEOMETRIC AND TOPOLOGICAL SIMILARITY ASSESSMENT OF MECHANICAL PARTS

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Abstract - In this paper, an approach has been developed to assess geometric and topological similarity between 3D mechanical parts using their face-edge relation matrices. The approach relies on the STEP (Standard for the Exchange of Product Data Model) graphic standard to obtain the geometric and topological data belonging to parts designed in a CAD system. The CAD model of any part is automatically translated into a STEP file and entities represented in the STEP file of it are mapped into face-edge relation matrix. Face-edge relation matrix is a square matrix and sized according to number of faces on a part. In the similarity assessment stage, the closest matrix in the database corresponding to matrix of the new part is retrieved and matched as matrix of the candidate part. Similarity factor between the new and candidate parts is calculated with respect to the matched faces and total faces in both matrices. Similarity assessment is useful for many CAD/CAM applications such as especially variant process planning, cost estimation and group technology. The algorithm has been applied to some real parts to demonstrate its efficiency and capability.
Keywords - STEP; Geometric and topological similarity; Face-edge relation matrix

1. INTRODUCTION

Similarity assessment between 3D mechanical parts has recently been an important research topic for CAD/CAM activities such as especially group technology (GT), cost estimation and variant process planning [1,2]. Variant process planning is basically a computer assisted extension of manual process planning. The computer is used as a tool to assist in identifying plans for similar parts, retrieving and editing them to suit the current requirements. The variant approach is based on the concept of group technology. GT can define as classification schemes for identifying and collecting parts into groups based on their similar geometric and manufacturing characteristics. The similar parts are grouped into families and a coding system is used to distinguish each part family. For each part family, a standard process plan which includes all possible operations for the family is produced and stored within system database associated with a family code number. These codes are used to identify the part family associated with the standard plan. A process plan for a new part is generated by retrieving the standard plan for a similar part and making necessary modifications for the new part [3].

Another area for efficiently utilization of similarity assessment is the cost estimation. Total cost of any part to machine can be defined as the material costs, setup costs, tooling costs, and operation costs. Total cost for a part is related to its geometric and topological complexity. Geometric and topological complexity of a new 3D mechanical part designed in any CAD system can be determined by assessing the similarity between its design properties and the design properties of the closest parts stored the database. Since machining processes of a new part will be similar to machining processes of similar one predefined in the database, the new part is easily oriented into manufacturing activities due to its design similarity and all costs of a new part can be determined with respect to process plans of similar parts predefined in the database. The cost of the new part can also be estimated according to machining cost of the retrieved parts in the database [4].

Cardone et al. [5] presented algorithms for identifying machined parts in a database that are similar to a given query part based on machining features. In the system, the parts are restricted as machined on 3-axis machining centers. Reduced feature vectors consisting of machining feature access directions, feature types, feature volumes, feature dimensional tolerances and feature group cardinality is used as a basis for assessing shape similarity. A distance function between two sets of reduced feature vectors is defined to assess the similarity between them from the machining effort point of view. To assess the similarity between the two parts, one set of reduced feature vectors is transformed in space using rigid body transformations with respect to other set such that the distance between them is minimized. The distance between the two sets of aligned reduced feature vectors is used as a measure of similarity between two parts. Mehalawi and Miller [6,7] presented a graph based approach for retrieving and matching similar designs in a database of mechanical components. The retrieval and matching process is based on the geometric and topological similarity between mechanical components. A surface and edge compatibility based similarity factor between the matched designs is calculated in their approach. Elinson et al. [8,9] proposed a graph which includes manufacturing features based systematic similarity assessment approach for solid models. The goal of this work is to develop methods that, given a solid model representing the design of a new product, query a product information database and identify existing designs with manufacturing plans similar to some reasonable plan for the new design or useful as a starting point for creation of a new plan for the new design. Similarity is measured among the graph structures corresponding to two different designs. Ramesh et al. [10] developed an approach for retrieval of similar parts from a part database which in turn requires a method for shape similarity measurement. First, the part is decomposed into simpler shapes resembling machining features. The decomposition method makes use of primitives to generate the shapes. Part characteristics that capture the spatial and dimensional relationships among features are used to measure the similarity. Chu and Hsu [11] developed a search scheme that successfully complements various shape signatures in similarity assessment of 3D mechanical components for design reuse. It considers form-feature, topological, and geometric information in component comparison. Such an integrated approach can effectively solve the feature intersection problem, inherited in any feature-based approaches, and capture the user's intent more precisely in the search, which geometry-based methods fail to accomplish. A set of algorithms are also developed to perform the component comparison in a polynomial time.

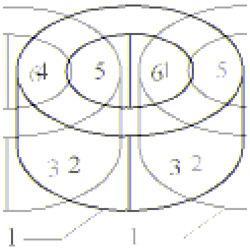
In this paper, an approach has been proposed to measure similarity between 3D mechanical parts. The input to the system is the matrix of a new part modeled on a CAD environment and matrices belonging to candidate parts predefined in the database. The output of the system is similarity factor calculated between most similar parts. The STEP entities are automatically mapped into a mathematical model called face-edge relation matrix. Face adjacency relations and face and edge attributes represented in the new and candidate face-edge relation matrix are used to measure geometric and topological similarity between 3D mechanical parts. The aims of this study are to develop a compact representation in terms of topological and geometric data as input to similarity assessment, to serve CAD/CAM applications such as variant process planning and GT by assessing the similarity between 3D mechanical parts.

2. FACE-EDGE RELATION MATRIX

Many of CAD systems have used some forms of the B-Rep as internal representation structures. The B-Rep in its raw form provides the low level information which is not directly available for many CAD/CAM applications such as similarity assessment, part recognition, feature recognition and computer aided process planning (CAPP). Additional information like face adjacency relationships, face and edge attributes can be needed to support them. Therefore, a STEP based representation scheme named face-edge relation matrix has been developed to support similarity assessment approach and other CAD/CAM applications. This part representation scheme also describes the parts in terms of both geometric and topological data. The approach relies on STEP standard for construction of face-edge relation matrix. A part is represented using the face-edge relation matrix which is a square matrix with face numbers and types representing part surfaces and edge numbers representing part edges. For example, entities $e_{1,}$ $e_{2,}$ $e_{3,}$ $e_{4,}$ $e_{5,}$ ..... e_n represented in the face-edge relation matrix are associated with each edge in the both outer and inner edge loops of each face on the part. Entities $f_{1,}$ $f_{2,}$ $f_{3,}$ $f_{4,}$ $f_{5,}$ ..... f_n represented in it are respectively associated with each face on the part. For each face of the part, a column and row are generated in the square matrix. Therefore, number of surfaces on the part determines the size of the matrix. For example, there are six faces on the ring in Figure 1, dimensions of face-edge relation matrix of it is 6x6 square matrix. Face numbers and their corresponding abbreviations are respectively located from top to down and left to right in the matrix. The abbreviations for the faces are as follows:

cylindrical face	***: cyl***
conical face	***: con***
planar face	***: pla***
spherical face	***: sph***
toroidal face	***: tor***

The cells corresponding to pairs of adjacent or non-adjacent faces in the matrix are generated to determine their face adjacency relations. Then, the generated cells are filled by edge number or zero with respect to face adjacency relations. The approach handles the first face and investigates adjacency relations with other faces on the component. If the first face is adjacent to any face, edge number of edge which shares two surfaces is placed into the cell corresponding to two adjacent faces in face-edge relation matrix. If the first face is not adjacent to a face, the value zero is placed into the cell corresponding to two non-adjacent faces in face-edge relation matrix. Then, attributes belonging to that face are associated with first face in face-edge relation matrix. In this way, face attributes and adjacency relations are extracted, and face-edge relation matrix is constructed for all faces on the component.



		f_1	f_2	f_3	f_4	f_5	f_6
pla	f_1	0	e_1	e_2	0	e_3	e_4
cyl	f_2	e_1	0	e_5	e_6	0	0
cyl	f_3	e_2	e_5	0	e_7	0	0
pla	f_4	0	e_6	e_7	0	e_8	e_9
cyl	f_5	e_3	0	0	e_8	0	e_{10}
cyl	f_6	e_4	0	0	e_9	e_{10}	0

Figure 1. A ring and its matrix

In the STEP file, cylindrical, conical, spherical and toroidal surfaces are represented by two equivalent surfaces. For the ring shown in Figure1, the cylindrical surface is represented by the surfaces 2 and 3. A circle and an ellipse are also represented by two equivalent edges. These surfaces and edges are individually handled in the system. The ring can be defined from its face-edge relation matrix as follows:

- The face 1 (f_1) is adjacent to four cylindrical surfaces (f_2, f_3, f_5, f_6) via four circular edges (e_1, e_2, e_3, e_4).
- The face 2 (f_2) is adjacent to two plane surfaces (f_1, f_4) and one cylindrical surface (f_3) via two circular edges (e_1, e_6) and two linear edges ($e_5, e_{5'}$).
- The face 3 (f_3) is adjacent to two plane surfaces (f_1, f_4) and one cylindrical surface (f_2) via two circular edges (e_2, e_7) and two linear edges ($e_5, e_{5'}$).
- The face 4 (f_4) is adjacent to four cylindrical surfaces (f_2, f_3, f_5, f_6) via four circular edges (e_6, e_7, e_8, e_9).
- The face 5 (f_5) is adjacent to two plane surfaces (f_1, f_4) and one cylindrical surface (f_6) via two circular edges (e_3, e_8) and two linear edges ($e_{10}, e_{10'}$).
- The face 6 (f_6) is adjacent to two plane surfaces (f_1, f_4) and one cylindrical surface (f_5) via two circular edges (e_4, e_9) and two linear edges ($e_{10}, e_{10'}$).

A cylindrical surface is connected to another equivalent (symmetrical) one through two linear edges. But one edge has been represented in the matrix. For example, face 2 is connected to face 3 through two linear edges ($e_5, e_{5'}$). Edge 5' is not represented in the matrix. Since all cylindrical surfaces are identically represented in both new and candidate matrices in the database. This is not any problem for similarity assessment. Attributes belonging to each surface on the part are associated with surface number ($f_1, f_2, f_3, \ldots. f_n$). Attributes of a plane surface are surface type, direction of *z* axes of local coordinate system, edge loop and adjacent faces belonging to that plane surface. Attributes of a cylindrical surface are surface type, direction of *z* axes of local coordinate system, radius of cylindrical surface, edge loop and adjacent faces belonging to that cylindrical surface. Attributes belonging to each edge on the part are associated with edge number ($e_1, e_2, e_3, \ldots. e_n$). Attributes of a circle are curve type, *z* direction of local coordinate system, radius of circle. Attributes of a line are curve type, direction of line vector, length of line vector. Surface and edge data for face 4 and edge 5 represented in the face-edge relation matrix for similarity assessment is given as follows:

Surface no	***: f_4***	***Edge no***	***: e_5***
Surface type	***: planar***	***Curve type***	***: circle***
Direction_Z	***: (0,0,1)***	***Direction_Z***	***: (0,0,1)***
Edge loop	***: e_6, e_7, e_8, e_9***	***Radius***	***: 10 mm***
Adjacent faces	***: f_2, f_3, f_5, f_6***		

The direction of x axis of the local coordinate system is the same as direction of x axis of the global coordinate system. The direction of z axis of the local coordinate system is pointer to the normal of the planar and spherical surfaces and, is pointer to the axis direction of the cylindrical, conical, toroidal surfaces. The origin, direction of x, and z axis of the local coordinate system for face 4 on the ring is shown in Figure 2.

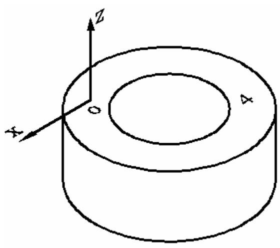


Figure 2. Demonstration of local coordinate system for face 4 on the ring

Similarity assessment is carried out by the geometric and topological data represented in the face-edge relation matrix. Both simple and complex parts are represented in terms of geometric and topological data in matrix. STEP file has a complex data structure. Especially, when the number of surfaces on any part increased, size of the STEP file extremely enlarges due to its complex data structure. Therefore, computational complexity for processing the STEP file is quietly increased. STEP file processor utilizes large amount of computing time for similarity assessment. Representation in the STEP file of face 4 (planar face) on the ring is shown in Figure 3.

```
#132=CARTESIAN_POINT('',(150.0,150.0,50.0));
#133=VERTEX_POINT('',#132);
#149=CARTESIAN_POINT('',(130.0,150.0,50.0));
#150=VERTEX_POINT('',#149);
#157=CARTESIAN_POINT('',(140.0,150.0,50.0));
#158=DIRECTION('',(0.0,0.0,-1.0));
#159=DIRECTION('',(1.0,0.0,0.0));
#160=AXIS2_PLACEMENT_3D('',#157,#158,#159);
#161=CIRCLE('',#160,10.0);
#162=EDGE_CURVE('',#150,#133,#161,.T.);
#172=CARTESIAN_POINT('',(144.46,150.0,50.0));
#173=VERTEX_POINT('',#172);
#182=CARTESIAN_POINT('',(135.53,150.0,50.0));
#183=VERTEX_POINT('',#182);
#184=CARTESIAN_POINT('',(140.0,150.0,50.0));
#185=DIRECTION('',(0.0,0.0,-1.0));
#186=DIRECTION('',(1.0,0.0,0.0));
#187=AXIS2_PLACEMENT_3D('',#184,#185,#186);
#188=CIRCLE('',#187,4.465560989869728);
#189=EDGE_CURVE('',#183,#173,#188,.T.);
#223=CARTESIAN_POINT('',(140.0,150.0,50.0));
#224=DIRECTION('',(0.0,0.0,-1.0));
#225=DIRECTION('',(1.0,0.0,0.0));
#226=AXIS2_PLACEMENT_3D('',#223,#224,#225);
#227=CIRCLE('',#226,4.465560989869728);
#228=EDGE_CURVE('',#173,#183,#227,.T.);
#239=CARTESIAN_POINT('',(140.0,150.0,50.0));
#240=DIRECTION('',(0.0,0.0,-1.0));
#241=DIRECTION('',(1.0,0.0,0.0));
#242=AXIS2_PLACEMENT_3D('',#239,#240,#241);
#243=CIRCLE('',#242,10.0);
#244=EDGE_CURVE('',#133,#150,#243,.T.);
#262=ORIENTED_EDGE('',*,*,#244,.F.);
#263=ORIENTED_EDGE('',*,*,#162,.F.);
#264=EDGE_LOOP('',(#262,#263));
#265=FACE_OUTER_BOUND('',#264,.T.);
#266=ORIENTED_EDGE('',*,*,#228,.T.);
#267=ORIENTED_EDGE('',*,*,#189,.T.);
#268=EDGE_LOOP('',(#266,#267));
#269=FACE_BOUND('',#268,.T.)
#257=CARTESIAN_POINT('',(140.0,150.0,50.0));
#258=DIRECTION('',(0.0,0.0,1.0));
#259=DIRECTION('',(1.0,0.0,0.0));
#260=AXIS2_PLACEMENT_3D('',#257,#258,#259);
#261=PLANE('',#260);
#270=ADVANCED_FACE('',(#265,#269),#261,.T.);
```

Figure 3. Representation in the STEP file of face 4 on the ring

3. SIMILARITY ASSESSMENT

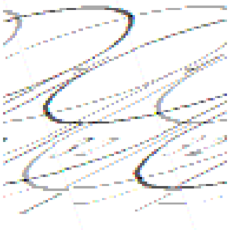
With similarity assessment procedure, a similarity factor is also calculated by evaluating face adjacency relations and all attributes including dimensional attributes represented face-edge relation matrices of similar parts. Since similar parts have similar manufacturing characteristics, similarity assessment is very important for optimal manufacturing costs and machining. In this stage, geometric and topological similarity of mechanical parts is investigated. A similarity factor is calculated between them. Similarity assessment is executed by comparing face adjacency relations and attributes of faces and edges represented in the face-edge relation matrix of new design and the closest face-edge relation matrix of a part represented in the database. Matrix comparison process is to find the most suitable matrix among candidate designs in the database corresponding to matrix of new design. This is achieved by finding matrix of a candidate design with maximum matching surfaces corresponding to matrix of new design. In similarity assessment, geometric information is not only compared, but also topological information and similarity factor is based on the matched surfaces in both matrices. Therefore, if face adjacency relations, face attributes of any surface and edge of new design do not match with ones of another surface and edge of candidate design in the database, it is eliminated and passed to evaluate another surface. A loop continues until the approach obtains a candidate matrix with maximum matching surface in the database. Since exact surface matching processes are performed in similarity assessment algorithm, it is capable of finding the closest part to new part. Similarity factor between two matrices is calculated using the following formula:

$$SF\% = [(2 \text{ x } F_M) / F_{TOTAL}] \text{ x } 100 \quad (1)$$

Where, SF is similarity factor between new design and candidate design. F_M is number of matched faces in the new and candidate matrices. F_{TOTAL} is the sum of number of faces in the both new and candidate matrices.

3.1. Calculation of Similarity Factor

The algorithm defines similarity assessment between matrix obtained from STEP file of new design and matrix obtained from data base of candidate design. Check whether or not each face in the matrix of new design corresponds to any face in the matrix of candidate design. For each face in the matrix, match face adjacency relations (neighboring faces) and edge loop in both the matrix of new design and the matrix of candidate design. Match all surface attributes in the the matrix of new design and the matrix of candidate design. Match all edge attributes in the matrix of new design and the matrix of candidate design. Group and count the matched surfaces in both the matrix of new design and the matrix of candidate design. If the number of matched surfaces in the candidate matrix is more than other matrices in the database, calculate a similarity factor according to formula (1). If the number of matched surfaces is less than any matrix in the database, for the matrix of new design, find another candidate matrix with maximum number of matched surfaces from the database and calculate a similarity factor between them.



		f_1	f_2	f_3	f_4
pla	f_1	0	e_1	e_2	0
cyl	f_2	e_1	0	e_3	e_4
cyl	f_3	e_2	e_3	0	e_5
pla	f_4	0	e_4	e_5	0

Figure 4. A cylinder and its matrix

The algorithm investigated the matched surfaces for ring and cylinder. It found two matched surfaces (f_2 and f_3 in both matrices). They are shaded as shown in Figure 1 and 4. Therefore, the similarity factor can be calculated by:

SF% = [(2 x 2) / (6 + 4)] x 100 = 40%

Two intermediate samples and their face-edge relation matrices for similarity assessment are sample part 1 in Figure 5 and sample part 2 in Figure 6. The approach has translated the CAD model of sample part 1 into STEP file and generated a STEP file with 777 rows. It has evaluated the STEP file and determined twenty surfaces in the sample part 1. Then, a 20x20 square matrix is constructed by extracting of face adjacency relations from the STEP file of sample part 1.

		f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}	f_{17}	f_{18}	f_{19}	f_{20}
con	f_1	0	0	0	e_1	0	0	0	0	0	0	0	0	0	0	e_2	0	e_3	0	0	e_4
cyl	f_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	e_5	e_6	0	0	e_7	0
cyl	f_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	e_8	e_9	0	e_{10}	0	0
cyl	f_4	e_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	e_{11}	e_{12}	0	0	e_{13}
cyl	f_5	0	0	0	0	0	0	0	0	0	e_{14}	e_{15}	0	0	0	e_{16}	e_{17}	0	0	0	0
cyl	f_6	0	0	0	0	0	0	e_{18}	e_{19}	0	0	0	0	0	0	e_{20}	e_{21}	0	0	0	0
cyl	f_7	0	0	0	0	0	e_{18}	0	0	0	0	0	0	0	e_{22}	e_{23}	e_{24}	0	0	0	0
pla	f_8	0	0	0	0	0	e_{19}	0	0	e_{25}	0	0	0	0	0	e_{26}	e_{27}	0	0	0	0
cyl	f_9	0	0	0	0	0	0	0	e_{25}	0	e_{28}	0	0	0	0	e_{29}	e_{30}	0	0	0	0
pla	f_{10}	0	0	0	0	e_{14}	0	0	0	e_{28}	0	0	0	0	0	e_{31}	e_{32}	0	0	0	0
cyl	f_{11}	0	0	0	0	e_{15}	0	0	0	0	0	0	e_{33}	0	0	e_{34}	e_{35}	0	0	0	0
pla	f_{12}	0	0	0	0	0	0	0	0	0	0	e_{33}	0	e_{36}	0	e_{37}	e_{38}	0	0	0	0
cyl	f_{13}	0	0	0	0	0	0	0	0	0	0	0	e_{36}	0	e_{39}	e_{40}	e_{41}	0	0	0	0
pla	f_{14}	0	0	0	0	0	0	e_{22}	0	0	0	0	0	e_{39}	0	e_{42}	e_{43}	0	0	0	0
pla	f_{15}	e_2	e_5	e_8	0	e_{16}	e_{20}	e_{23}	e_{26}	e_{29}	e_{31}	e_{34}	e_{37}	e_{40}	e_{42}	0	0	0	e_{44}	e_{45}	e_{46}
pla	f_{16}	0	e_6	e_9	e_{11}	e_{17}	e_{21}	e_{24}	e_{27}	e_{30}	e_{32}	e_{35}	e_{38}	e_{41}	e_{43}	0	0	e_{47}	e_{48}	e_{49}	0
cyl	f_{17}	e_3	0	0	e_{12}	0	0	0	0	0	0	0	0	0	0	0	e_{47}	0	0	0	e_{50}
cyl	f_{18}	0	0	e_{10}	0	0	0	0	0	0	0	0	0	0	0	e_{44}	e_{48}	0	0	0	0
cyl	f_{19}	0	e_7	0	0	0	0	0	0	0	0	0	0	0	0	e_{45}	e_{49}	0	0	0	0
con	f_{20}	e_4	0	0	e_{13}	0	0	0	0	0	0	0	0	0	0	e_{46}	0	e_{50}	0	0	0

Figure 5. Sample part 1 and its matrix

The approach has also translated the CAD model of sample part 2 into STEP file and generated a STEP file with 887 rows. It has evaluated the STEP file and determined twenty surfaces in the sample part 2. Then, a 25x25 square matrix is constructed by extracting of face adjacency relations from the STEP file of sample part 2.

		f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}	f_{17}	f_{18}	f_{19}	f_{20}	f_{21}	f_{22}	f_{23}	f_{24}	f_{25}
cyl	f_1	0	0	0	0	0	0	0	0	0	e_{1}	0	0	0	0	0	0	0	0	0	0	0	0	0	e_{2}	e_{3}
cyl	f_2	0	0	0	0	0	0	0	0	0	0	0	e_{4}	0	0	0	0	0	0	e_{5}	e_{6}	0	0	0	e_{7}	0
cyl	f_3	0	0	0	0	0	0	0	0	0	0	0	e_{8}	0	0	0	e_{9}	e_{10}	0	0	0	0	0	0	e_{11}	0
cyl	f_4	0	0	0	0	e_{12}	0	0	0	0	0	0	0	0	e_{13}	e_{14}	0	0	0	0	0	0	0	0	e_{15}	0
con	f_5	0	0	0	e_{12}	0	0	0	0	0	0	0	e_{16}	0	e_{17}	e_{18}	0	0	0	0	0	0	0	0	0	0
cyl	f_6	0	0	0	0	0	0	e_{19}	0	0	0	e_{20}	0	e_{21}	0	0	0	0	0	0	0	0	0	0	e_{22}	0
con	f_7	0	0	0	0	0	e_{19}	0	0	0	0	e_{23}	e_{24}	e_{25}	0	0	0	0	0	0	0	0	0	0	0	0
cyl	f_8	0	0	0	0	0	0	0	0	e_{26}	e_{27}	0	e_{28}	0	0	0	0	0	0	0	0	0	0	0	0	0
cyl	f_9	0	0	0	0	0	0	0	e_{26}	0	e_{29}	0	e_{30}	0	0	0	0	0	0	0	0	0	0	0	0	0
pla	f_{10}	e_{1}	0	0	0	0	0	0	e_{27}	e_{29}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	e_{31}
con	f_{11}	0	0	0	0	0	e_{20}	e_{23}	0	0	0	0	e_{32}	e_{33}	0	0	0	0	0	0	0	0	0	0	0	0
pla	f_{12}	0	e_{4}	e_{8}	0	e_{16}	0	e_{24}	e_{28}	e_{30}	0	e_{32}	0	0	e_{34}	0	e_{35}	e_{36}	e_{37}	e_{38}	e_{39}	e_{40}	e_{41}	e_{42}	0	0
cyl	f_{13}	0	0	0	0	0	e_{21}	e_{25}	0	0	0	e_{33}	0	0	0	0	0	0	0	0	0	0	0	0	e_{43}	0
con	f_{14}	0	0	0	e_{13}	e_{17}	0	0	0	0	0	0	e_{34}	0	0	e_{44}	0	0	0	0	0	0	0	0	0	0
cyl	f_{15}	0	0	0	e_{14}	e_{18}	0	0	0	0	0	0	0	0	e_{44}	0	0	0	0	0	0	0	0	0	e_{45}	0
cyl	f_{16}	0	0	e_{9}	0	0	0	0	0	0	0	0	e_{35}	0	0	0	0	0	0	0	0	0	0	e_{46}	e_{47}	0
pla	f_{17}	0	0	e_{10}	0	0	0	0	0	0	0	0	e_{36}	0	0	0	0	0	e_{48}	0	0	0	0	0	e_{49}	0
cyl	f_{18}	0	0	0	0	0	0	0	0	0	0	0	e_{37}	0	0	0	0	e_{48}	0	e_{50}	0	0	0	0	e_{51}	0
pla	f_{19}	0	e_{5}	0	0	0	0	0	0	0	0	0	e_{38}	0	0	0	0	0	e_{50}	0	0	0	0	0	e_{52}	0
cyl	f_{20}	0	e_{6}	0	0	0	0	0	0	0	0	0	e_{39}	0	0	0	0	0	0	0	0	e_{53}	0	0	e_{54}	0
pla	f_{21}	0	0	0	0	0	0	0	0	0	0	0	e_{40}	0	0	0	0	0	0	0	e_{53}	0	e_{55}	0	e_{56}	0
cyl	f_{22}	0	0	0	0	0	0	0	0	0	0	0	e_{41}	0	0	0	0	0	0	0	0	e_{55}	0	e_{57}	e_{58}	0
pla	f_{23}	0	0	0	0	0	0	0	0	0	0	0	e_{42}	0	0	0	e_{46}	0	0	0	0	0	e_{57}	0	e_{59}	0
pla	f_{24}	e_{2}	e_{7}	e_{11}	e_{15}	0	e_{22}	0	0	0	0	0	0	e_{43}	0	e_{45}	e_{47}	e_{49}	e_{51}	e_{52}	e_{54}	e_{56}	e_{58}	e_{59}	0	e_{60}
cyl	f_{25}	e_{3}	0	0	0	0	0	0	0	0	e_{31}	0	0	0	0	0	0	0	0	0	0	0	0	0	e_{60}	0

Figure 6. Sample part 2 and its matrix

Similarity assessment between sample part 1 and 2 has been done by the program. 11 (six cylindrical and four planar) surfaces in both matrices are matched each other. The matched surfaces are shaded in both matrices. The pairs of matched 11 surfaces and their attributes are shown in Table 1.

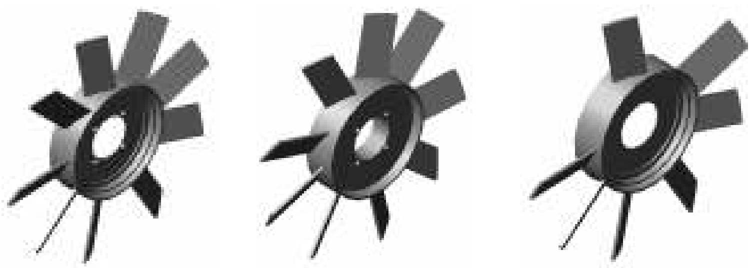
Table. 1. The matched faces of sample part 1 and 2, and their attributes

Face pairs	Face type	Radius	Direction_Z	Edge loop	Adjacent faces
f_5 - f_2	cylindrical	27	(0,-0.17365,-0.98481)	arc, line, arc, line	planar, cylindrical, planar, planar
$f_6 - f_3$	cylindrical	27	(0,-0.17365,-0.98481)	arc, line, arc, line	cylindrical, planar, planar, planar
$f_7 - f_{16}$	cylindrical	27	(0,-0.17365,-0.98481)	arc, line, arc, line	cylindrical, planar, planar, planar
$f_8 - f_{17}$	planar	-	(-0.00658,0.98479,-0.17364)	line, line, line, line	cylindrical, cylindrical, planar, planar
$f_9 - f_{18}$	cylindrical	15	(0,-0.17365,-0.98481)	arc, line, arc, line	planar, planar, planar, planar
$f_{10} - f_{19}$	planar	-	(-0.77026,-0.62805,0.11074)	line, line, line, line	cylindrical, cylindrical, planar, planar
$f_{11} - f_{20}$	cylindrical	27	(0,-0.17365,-0.98481)	arc, line, arc, line	cylindrical, planar, planar, planar
$f_{12} - f_{21}$	planar	-	(0.00658,-0.98479,0.17364)	line, line, line, line	cylindrical, cylindrical, planar, planar
$f_{13} - f_{22}$	cylindrical	15	(0,-0.17365,-0.98481)	arc, line, arc, line	planar, planar, planar, planar
$f_{14} - f_{23}$	planar	-	(0.77026,0.62805,-0.11074)	line, line, line, line	cylindrical, cylindrical, planar, planar
$f_{16} - f_{24}$	planar	-	(0,0.17365,0.98481)	arc, arc, arc, arc, arc, arc, line, arc,line, arc, line, arc, line, arc, arc, arc	cylindrical, cylindrical, cylindrical, cylindrical, cylindrical, cylindrical, planar, cylindrical, planar, cylindrical, planar, cylindrical, planar, cylindrical, cylindrical, cylindrical

A similarity factor between sample part 1 and 2 is calculated according to the matched and total surfaces of sample part 1 and 2 (formula 1) as follows:

SF% = [(11 x 11) / (20 + 45)] x 100 = 49%

In Figure 7, different configurations of the ventilator which has a complex structure according to sample part 1 and sample part 2 are shown. The algorithm has calculated the similarity factor for them. The values in Table 2 are represented similarity factor for each ventilator pairs. The number of matched surfaces on assessed parts is given within parenthesis and next to similarity factor in Table 2. The number of total surfaces is also shown in Table 2.



(a) (b) (c)

Figure 7. Three different configurations of the ventilator

Table. 2. Similarity values between three different configurations of the ventilator

Total number of surfaces on the part	83	71	65
Ventilators	**Ventilator (a)**	**Ventilator (b)**	**Ventilator (c)**
Ventilator (a)	100% (83)	79% (61)	82% (61)
Ventilator (b)		100% (71)	69% (51)
Ventilator (c)			100% (65)

4. CONCLUSION

In this paper, a mathematical model based approach for similarity assessment between 3D mechanical parts is proposed. Similarity assessment is based on comparing geometric and topological data represented in the matrix generated from STEP file of a new part and matrix of the candidate part predefined in the database. A mathematical model named face-edge relation matrix has been also developed to represent any part geometry and topology in a compact structure, and to support the similarity assessment of 3D mechanical parts. Face-edge relation matrix is applicable for both simple and complex part in terms of geometric and topological data. It can be used as input for many different CAD/CAM applications such as feature recognition, process planning and part recognition. Since face-edge relation matrix is suitable to computer format and it is easy to decompose than graph based representations. Therefore, the mathematical model based comparison handled in this study is more available than graph based comparisons for geometric and topological similarity assessment between 3D mechanical parts. With similarity assessment, process plans of similar parts can be easily prepared by modifying the process plans of the candidate parts. Since exact surface matching process is applied to new and candidate designs in the system, the approach is capable of selecting the closest part from the database to new one. In the development of the similarity assessment system, solid modeler of AutoCAD™ and Mechanical Desktop™ are used as the geometric modeler. A set of program developed for similarity assessment algorithms were completely written in Visual BASIC programming language.

REFERENCES

1. D. Bespalov, W. C. Regli and A. Shokoufandeh, Local feature extraction and matching partial objects, *Computer Aided Design* **38,** 1020-1037, 2006.
2. W. Gao, S. M. Gao, Y. S. Liu, J. Bai and B. K. Hu, Multiresolutional similarity assessment and retrieval of solid models based on DBMS, *Computer Aided Design* **38**, 985-1001, 2006.
3. M. Gulesin, An intelligent, knowledge based process planning and fixturing system using the STEP standard. PhD Thesis, *Coventry University*, UK, 1993.
4. A. Cardone, S. K. Gupta, A. Deshmukh and M. Karnik, Machining feature-based similarity assessment algorithms for prismatic machined parts, *Computer Aided Design* **38**, 954-972, 2006.
5. A. Cardone, S. K. Gupta, and M. Karnik, A survey of shape similarity assessment algorithms for product design and manufacturing applications, *ASME Journal of Computing and Information Science in Engineering* **3**(2), 109–118, 2003.
6. M. Mehalawi and R. A. Miller, A database system of mechanical components based on geometric and topological similarity. Part I: representation, *Computer Aided Design* **35**, 83-94, 2003.
7. M. Mehalawi and R. A. Miller, A database system of mechanical components based on geometric and topological similarity. Part II: indexing, retrieval, matching and similarity assessment, *Computer Aided Design* **35**, 95-105, 2003.
8. A. Elinson, D. S. Nau and W. C. Regli, Feature-based similarity assessment of solid models, *Proceedings of ACM solid modeling conference* 297–310, 1997.
9. A. Elinson, D. S. Nau and W. C. Regli, Feature-based similarity assessment of solid models, *ACM fourth symposium on solid modeling and applications* 8–11, 1999.
10. M. Ramesh, D. Yip-Hoi, and D. Dutta, Feature-based shape similarity measurement for retrieval of mechanical parts, *ASME Journal of Computing and Information Science in Engineering* **1**(3)**,** 245–256, 2001.
11. C. H. Chu and Y. C. Hsu, Similarity assessment of 3D mechanical components for design reuse, *Robotics and Computer Integrated Manufacturing* **22**(4), 332-341, 2006.