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USING CONCAVITY INDEX FOR MANUFACTURING FEATURE RECOGNITION

ZASTOSOWANIE INDEKSU WKŁĘŚŁOŚCI W ROZPOZNAWANIU CECH TECHNOLOGICZNYCH

Abstract

The paper presents the usage of the concavity index for the effective recognition of the concave, open manufacturing features like open pockets, through slots and steps. The determination of this index using B-Rep representation is presented in detail. This is a fragment of an algorithm for the recognition of manufacturing features defined in the STEP-NC standard.

Keywords: manufacturing feature recognition, STEP-NC, CAD/CAM integration

Streszczenie

W artykule przedstawiono zastosowanie indeksu wklęsłości do efektywnego rozpoznawania wklęsłych cech technologicznych typu otwartego, jak kieszenie otwarte, rowki przelotowe czy uskoki powierzchni. Szczegółowo omówiono procedurę wyznaczania tego indeksu w oparciu o reprezentację B-Rep. Jest to fragment algorytmu rozpoznawania cech technologicznych zdefiniowanych w standardzie STEP-NC.

Słowa kluczowe: rozpoznawanie cech technologicznych, STEP-NC, integracja CAD/CAM

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1. Introduction

CNC machine tools are now basic manufacturing machines. One of the key tasks to automate the CNC machine tool programming is the manufacturing feature recognition. Manufacturing feature recognition groups geometrical elements into the information units significant from the point of view of the manufacturing process planning, i.e. manufacturing features. So, it groups faces, edges, points, etc. into the manufacturing features like pockets, slots, holes etc.

Three commonly used recognition methods for the B-Rep format are graph-based algorithms [4], volumetric decomposition techniques [1] and hint based geometric reasoning [9]. There is no doubt that the up-to date functionality of the feature recognition, both in commercial software as well as in the research works, still requires further development. The main problems are the recognition of interacting manufacturing features and the use of the manufacturing knowledge during the recognition process [5, 8].

The paper presents the concavity index developed by the author of this paper. This index allows for the efficient recognition of the open, concave manufacturing features like open pockets or through slots. In contrast to the graphs approaches [4], it allows for the recognition of the manufacturing features regardless of the number of the faces constituting the features. This index allows also for the automatic determination of the feature orientation, which is necessary to determine the machining set-up or to select the suitable machining tool. This index is also used in the STEP-NC manufacturing feature recognition algorithm [7, 8]. The input data is the part model in the STEP standard [2, 3]. After processing this input data, the algorithm generates the set of STEP-NC manufacturing features, which can be directly used by the system for automatic CNC machine tool programming in the STEP-NC standard.

2. Algorithm for manufacturing feature recognition in STEP-NC standard

2.1. B-Rep data structure

The input data is the B-rep structure encoded in ISO-10303-21 standard [3]. This data can be output using most of commercially available CAD systems.

In the B-Rep representation, the faces creating the shape are stored (faces $f_1 \dots f_{11}$ in Fig. 1b). These can be plane, cylindrical, conical, b-spline faces, etc. Each face has one external loop defining its boundary. The faces can have optionally the internal loops. The face has internal loops when it is the base for the concave (for example pockets) or convex features (for example boss) (Fig. 1b). The direction of each loop, both external as well as internal is so, that during the movement along the loop, the material remains on the left side. Each loop has an edge list. For each edge, the start point, end point and the edge type are stored. The edge types are lines, arcs, `b_spline_curve`, `b_spline_curve_with_knots`, etc. Each edge is shared by exactly two faces. Fig. 1b shows the edges shared by f_1/f_3 and f_1/f_8 faces.

If the two neighboring faces form a convex angle (as the angle between faces f_1 and f_3), the edge between these faces is called a convex edge (Fig. 1c). If the two neighboring faces form a concave angle (as the angle between faces f_1 and f_8), the edge between these faces is called a concave edge.

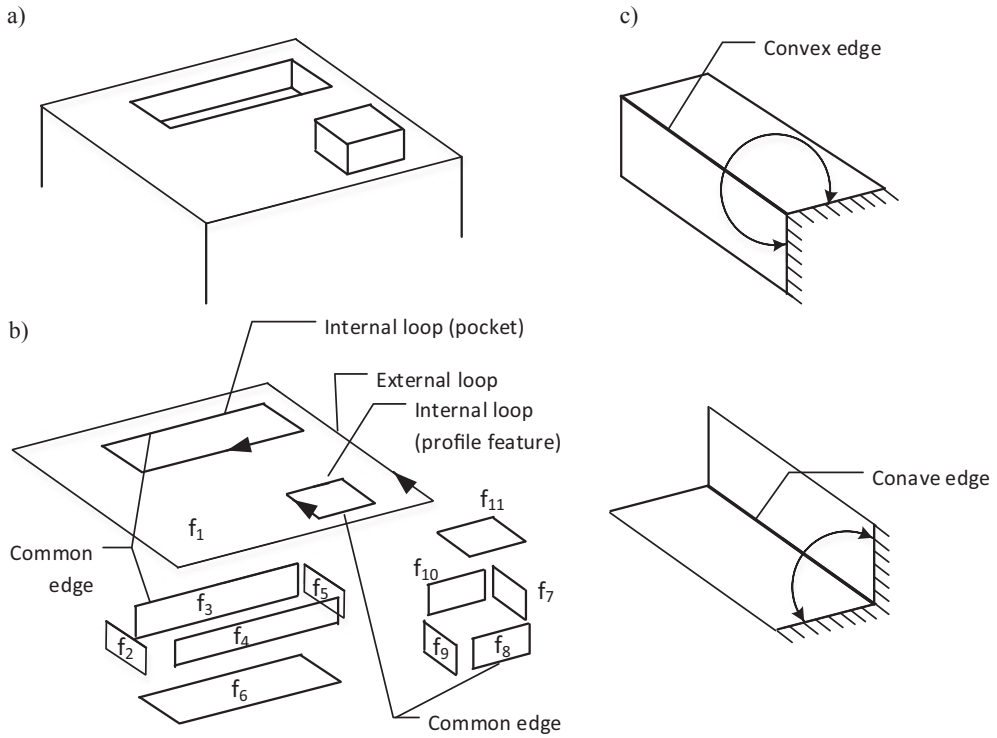


Fig. 1. B-Rep representation: a) Part, b) B-Rep representation, c) Convex/concave edges

2.2. Determination of the type of edges (convex/concave)

As already mentioned, the classification of the edges (concave or convex) (Fig. 1c) depends on the angle between the faces sharing the given edge. Let e be the edge between f_1 and f_2 faces (Fig. 2). To determine the angle between these faces, first the vector product c using n_1 and n_2 perpendicular to the faces f_1 and f_2 is calculated.

$$c = n_1 \times n_2 \quad (1)$$

If the coordinates of n_1 vector are $[n_{1x}, n_{1y}, n_{1z}]$, and the coordinates of n_2 vector are $[n_{2x}, n_{2y}, n_{2z}]$, the resultant c vector has the coordinates:

$$\begin{aligned} c_x &= n_{1y}n_{2z} - n_{1z}n_{2y} \\ c_y &= n_{1z}n_{2x} - n_{1x}n_{2z} \\ c_z &= n_{1x}n_{2y} - n_{1y}n_{2x} \end{aligned} \quad (2)$$

The resultant c vector is perpendicular to the face created by the vectors normal to the f_1 and f_2 faces, so it is parallel to the e edge. The direction of this c vector can be determined

using the right-hand rule. If the directions of the c and e vectors are the same, the angle between the f_1 and f_2 faces is concave so we have the concave edge. In the other case, if the direction of c and e vector are different, we have the convex edge. The order of the faces in the equation (1) should be noted. The direction of e edge determines that order (from right to left).

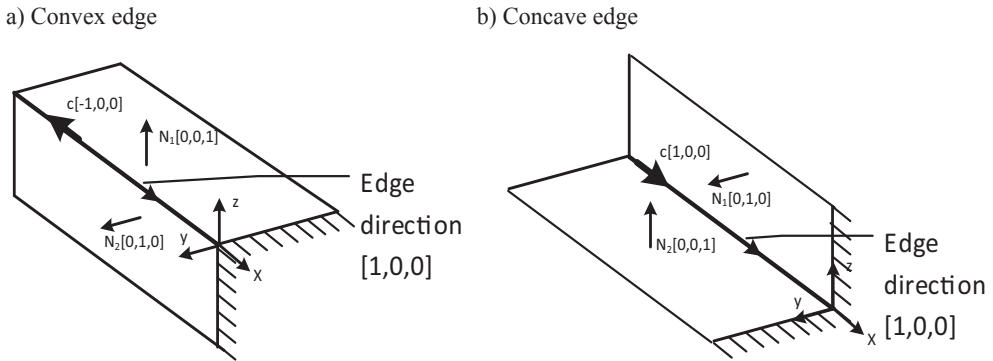


Fig. 2. Vector product of the vectors normal to faces

To determine if the e and c vectors have the same direction, the scalar product d between e and c vectors is calculated.

$$d = c \cdot e \tag{3}$$

If the coordinates of c vector are $[c_x, c_y, c_z]$, and the coordinates of e vectors are $[e_x, e_y, e_z]$, then:

$$d = c_x e_x + c_y e_y + c_z e_z \tag{4}$$

Taking into account that the scalar product between c and e vectors is:

$$d = c \cdot e = |c| |e| \cos(\alpha) \tag{5}$$

A negative value of this scalar product means that the angle between these vectors is 180° , so the vectors have opposite directions. If the directions are the same, the angle is 0° , $\cos(0^\circ)$ is equal 1, so the scalar product has the positive value and the two faces share the concave edge.

Using the above formulas, the type of edge is determined.

2.3. Manufacturing feature recognition algorithm

The manufacturing features recognition algorithm includes the following steps [6–8] (Fig. 3):

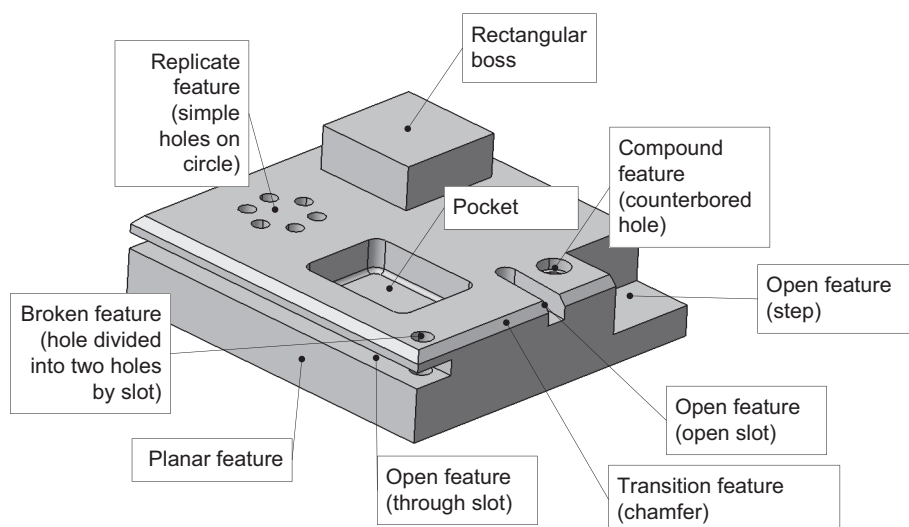


Fig. 3. Different types of manufacturing features

- Preparatory calculations including the reading of ISO 10303-21 file, creation of the internal B-Rep structure and the adjacency matrix;
- Recognition of convex features by analysis of internal bounds with concave edges only. If the face has the loop containing only concave edges, there is the convex feature on this face, like, for example, boss;
- Recognition of concave features by analysis of internal bounds with convex edges only. If the face has the loop containing only convex edges, there is the concave feature on this face, like, for example, close pocket or hole;
- Recognition of concave, open-type features using concavity index. If there are still convex edges, not belonging to the features recognized up to now, there is at least one open, concave feature. This could be open pocket, step, through slot, etc.;
- Recognition of the plane features and transitions features (phases and rounding);
- Combining the broken features, i.e. combining the features divided into more than one feature because of the intersection with other features;
- Grouping features into compound features and replicate features (number of similar features, e.g. a circle of holes or a mesh of holes).

3. Concavity index

One of the steps of the above algorithm is the recognition of the open, concave features. These features are recognized using the unique rule, developed by the author. First, the concavity index is calculated. This index for the given face is the number of concave edges in the external loop of that face. For example, the value of concavity index of the bottom face of open pocket is 7 (Fig. 4). The side cylindrical face of this pocket, pointed to in the figure

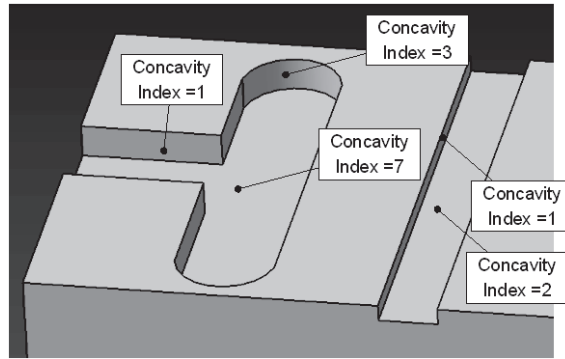


Fig. 4. Concavity index

has the index of 3, because the face has three concave edges (edges shared with the two side faces and one edge shared with the bottom face). In case of the through slot (Fig. 4), the concavity index is 2, because this face has two concave edges (these are the edges between the slot bottom and the two side faces). Of course, index is calculated only for the features not marked as recognized. So, the index is not calculated for the faces of the closed pockets, as such features were recognized in the previous step of the algorithm. All faces with the concavity index are sorted by the decreasing value of this index. In case of the presented example (Fig. 4), the highest value of the index is 7. The face with that index value is selected as the bottom face of the new feature (pocket or slot, the classification takes place later). Knowing the bottom, we can determine the feature orientation and the possible tool access directions (TAD). The faces connected with the bottom face will be included as the side faces. The side face with the greatest dimension in the direction of the vector normal to the bottom is used to select the pocket depth. Bottom and side faces are marked as recognized. This also removes these faces from the list of faces with concavity index. Because of this, during the recognition of the next feature, the greatest index has the bottom face of the through slot. This face will be selected as the bottom face of the new feature.

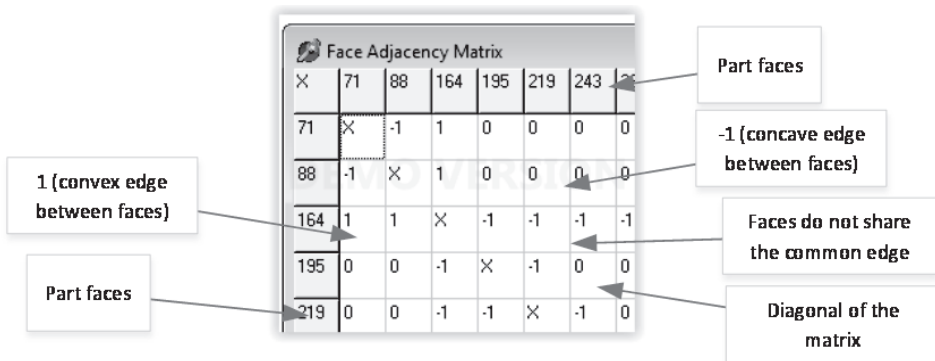


Fig. 5. Adjacency matrix

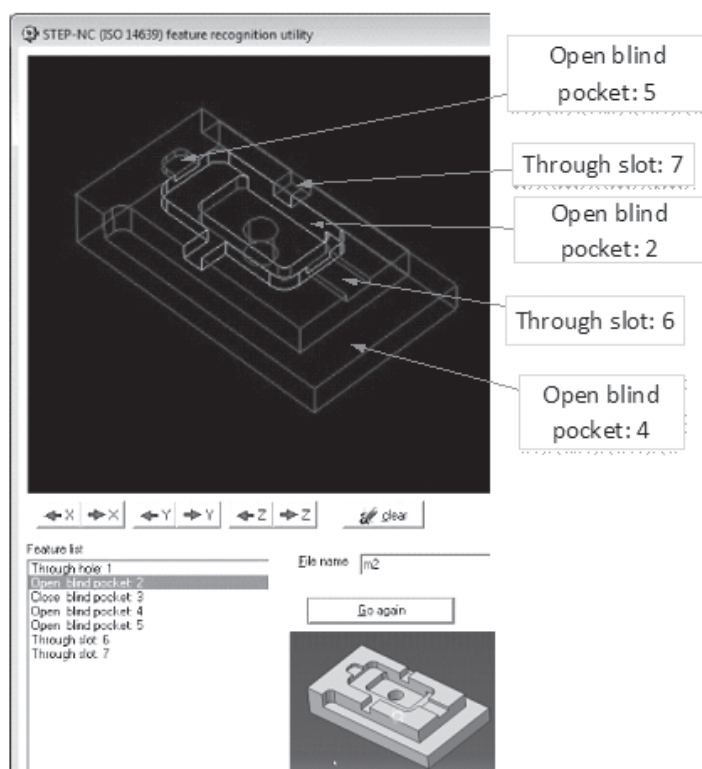


Fig. 6. The screenshot of the developed software showing the recognition results

To calculate this index, the adjacency matrix created during the preparatory calculations is used. It is the square matrix and its dimension is equal to the number of faces. The elements a_{ij} of this matrix describe the type of the edge between faces:

- 0 : face i and j does not share the edge
- $a_{ij} = x$: elements on the diagonal of the matrix
- 1 : faces i and j share the convex edge
- 1 : faces i and j share the concave edge

The procedure for the determination of the type of edges is described in point 2.2. The creation of this matrix speeds up the calculations because the algorithm checks these relations very often. Also the list of all edges is created. Each edge on the list is assigned two faces sharing this edge. Also this list is created to speed up the calculation. Fig. 5 shows the fragment of the matrix created for the test part.

4. Conclusions

The paper presents an algorithm for the recognition of manufacturing features, with special emphasis put on the use of the concavity index for the recognition of open, concave features.

The algorithm was verified through the developed software (Fig. 6). The presented algorithm is part of the works to develop the automatic CNC machine tool programming system in the STEP-NC standard. The presented algorithm does not consider many intersecting manufacturing features. This system uses the back growing approach, i.e. the program is created starting from the finished part and ending on the raw material. The recognition process is called after each transformation on condition that the transformed features interact with other manufacturing features [8]. Such approach allows to eliminate the need for the recognition of the intersecting manufacturing features.

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