Title:
Multi-level Freeform Machining Feature Characterization

Authors:
Soumiya Bendjebla, soumiya.bendjebla@ens-paris-saclay.fr
Na Cai, ncai@ens-paris-saclay.fr
Sylvain Lavernhe, sylvain.lavernhe@ens-paris-saclay.fr
Charyar Mehdi-Souzani, charyar.souzani@ens-paris-saclay.fr
Nabil Anwer, nabil.anwer@ens-paris-saclay.fr

LURPA, ENS Cachan, Univ. Paris-Sud, Université Paris 13, Sorbonne Paris Cité, Université Paris-Saclay, 94235 Cachan, France

Keywords:
Freeform Machining Feature, Machining Process, Geometrical data, Knowledge extraction

DOI: 10.14733/cadconfP.2018.347-351

Introduction:
During the last decades, Digital Mock-up has been intensively developed. Various information and data are generated in each step of the Digital Chain (CAD, CAM, machining process, etc.). However, these different data haven't been well exploited, especially, in feature modelling. Machining features, defined through their geometrical, topological, and manufacturing characteristics, must integrate the different data generated by the Digital Chain for a better characterization, specially, in the case of freeform shapes. In fact, most reported research deal only with regular shapes while freeform machining features are not well considered at present.

In this paper, we propose a new characterization and definition of freeform machining feature based on digital chain extracted data. The freeform machining feature is represented as a multilevel structure and the mapping between geometrical and machining process knowledge in each level is built. The paper is organized as follows. Section 2 highlights the key points of machining feature technology. Section 3 proposes a hierarchical structure for both geometrical and machining data. The mapping between these data is then explained in Section 4. Section 5 draws conclusions.

State of the art:
In the context of Digital Mock-up and Digital Chain, Feature Technology has become a key technique for knowledge specification and integration. Feature is a concept that was first used as modeling elements in CAx systems for representation of both qualitative and quantitative data related to product development process in the late 70s [12].

During the last decades, many research and applications have been conducted on machining features modeling, which has improved Computer-Aided Process Planning (CAPP). Several definitions exist in the literature which model different data of the part and its manufacturing and which formalize in particular the machining knowledge. Machining feature is defined as a volume, a set of surfaces, or a set of information attached to a geometry form. Fields and Anderson [4] defined machining feature as a set of adjacent faces of a part that correspond to shapes occurring on the surface of machined parts. Lee and Kim [5] defined it as a shape that represents volumes to be removed by machining. Tseng and Joshi [8] defined it as a portion of a part having some manufacturing significance that can be created with certain machining operations. Wu and Liu [11] summarized some definitions of machining features and described them as the mapping between two distinct spaces: the machining feature space and the machining process space.

In an effort to standardize data modeling and develop management and data sharing through the Digital Chain, the international community has been developing a set of standards ISO 10303 (STEP - STandard for the Exchange of Product model data). Feature-based modeling is based on STEP-AP (Application Protocol) 224, which defines different shapes used in manufacturing. Similarly, another standard ISO-14649, considered as an extension of STEP, often known as STEP-NC is being developed to connect all the elements of the Digital Chain from CAD, CAM to CNC machines, based on both geometric and manufacturing data. This connection is specified using an object-oriented data model that associates for each feature, a machining workingstep that encapsulates all the machining process data, such as: program, operations, toolpath, strategies and technologies [13]. These manufacturing features, defined in ISO-14649, are called STEP-NC features. They are organized hierarchically and differ according to their specifications into: machining feature, transition feature, replicate feature, compound feature, turning feature, and region feature. Considering 2.5 axis machining, the feature can be a hole, pocket, etc. Whereas the feature is considered as region in the case of freeform shape. Unlike regular machining feature (hole, slot, etc.), region feature which clusters different kind of freeform shape, has not been well defined, and formalized yet.

In most research dealing with feature modeling, only regular shapes, represented by simple primitives, are considered [3]. Freeform machining feature are not well studied since their definition and processing are more complex than regular feature [10]. They are represented by Bézier, B-Spline and Non-Uniform Rational B-Spline (NURBS) surfaces, defined by a set of parameters, and generally manipulated by control points. Sunil and Pande defined freeform surface feature as a set of connected meaningful regions having a particular geometry and topology which has some significance in design and manufacturing [7]. Thus, they are generally divided into distinct zones using different criteria. The authors in [1], [9] proposed geometry-based decomposition of freeform feature using different parameters such as normal, curvature, edge-exity (concave, convex, or saddle), or shape index. While others [6] use machining data like sets-up, strategies, operations, and cutting tools.

<u>Multi-level freeform feature characterization:</u>

As we have seen above, few works deal with freeform features. Freeform shapes have not been well exploited at present in feature modeling. In our previous work [1], the freeform shape is divided into different regions with ten surface types based on discrete differential geometry indicators. On the basis of our previous work, in this paper we improve the definition and characterization of freeform machining feature considering both geometry and machining process data that benefits from the digital chain information. First, we define a multi-level structure for both geometrical and machining process data. This decomposition makes the manipulation of freeform shapes easier. Then, different attributes are computed for both data. Finally, a level-by-level mapping, between geometrical and machining process data is built to characterize the freeform machining feature.

Hierarchical structure for geometrical data

Due to the unintuitive parametric representation of freeform shapes, it is difficult to extract geometrical properties that define the shape. To solve this problem, we propose to decompose the surface in different levels described with different parameters. First, the freeform surface is sampled and then approximated with triangular meshes. Based on discrete topological structure, the surface is represented with: vertices (V), edges (E), and faces (F). Then, the topology is described with: (n_V) the unit normal vector at the considered vertex, (d_E) the unit direction vector of edge and (n_F) the unit normal vector of face. In order to enrich this new freeform surface representation, different geometrical parameters are computed based on discrete differential geometry and attributed to each vertex or edge. We define here [1]:

- shape index (s): ranged $[-1, 1]$, measures the local surface type at each vertex of the mesh. It is calculated by the principal curvatures.
- edge-xity (m): measures the edge's concavity/convexity, and can be used to decide whether an edge is an obviously sharp edge or not.
- curvedness (c): as a complementary parameter to the shape index, specifies the amount or intensity of the surface curvatures.

Based on the machining data extraction and geometrical properties, different levels can be defined for the freeform surface. Figure 1 shows the hierarchical structure for the geometrical data. First, the *vertices* with the same characteristics are connected together to build a *region*. Based on geometrical and machining data, a set of regions are grouped to form a *sub-feature*. Finally, a set of different sub-features are recognized as a *freeform feature* based on recognition techniques.

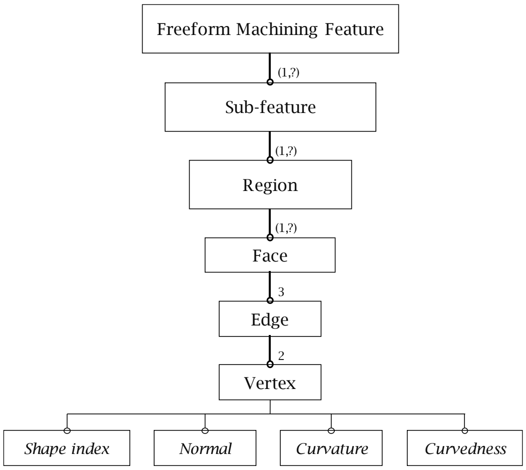

Fig. 1: Hierarchical structure for geometrical data.

Machining process knowledge extraction

In this section, we will develop an extraction and management method of machining knowledge from a digital simulation software for a better characterization of freeform machining feature. In fact, CAD models with geometrical properties are not sufficient for freeform machining feature characterization. Machining process knowledge and different data from the digital chain must be attached to this geometry. Figure 2 shows the hierarchical structure for machining process information, which is based on CAM data and the results of the simulation software.

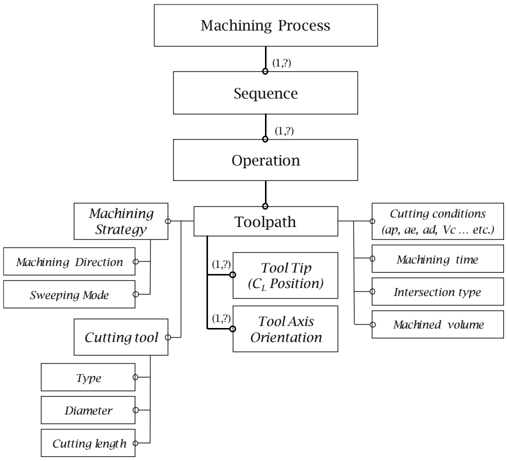

Fig. 2: Hierarchical structure for machining process knowledge.

The first level is related to machining process, which, as defined by Bourdet [2], consists of different attributes required to manufacture a machining feature. *Machining process* is then divided into different levels. Secondly, *machining sequence* is defined as the manufacturing of a sub-feature defined by a set of freeform regions. Thirdly, *machining operation* is the manufacturing of one region

Proceedings of CAD'18, Paris, France, July 9-11, 2018, 347-351

by one cutting tool. Machining operation is then detailed with various attributes: strategy, cutting-tool, and toolpath.

- Machining strategy: a methodology used to generate the machining operation. It is based on a machining direction and a sweeping mode. The machining direction specifies the toolpath plan, such as parallel plane or Z level type. The sweeping mode defines the path direction, such as unidirectional or bidirectional machining.
- Cutting-tool: is characterized by its type (flat endmill, ball endmill or filleted endmill), cutting length, diameter, and corner radius.
- Toolpath: is the sequencing of tool positions on the surface to be machined. It is expressed with both position and tool orientation.

As mentioned above, a simulation software is used to extract additional machining process data. Nowadays, the generated machining process is generally checked using NC simulation software. It is a virtual machining to visualize the material removal, through CNC machine tool and the tool movement, in order to avoid collisions, undercuts, or leaving excess material. In this paper, our machining process is analyzed with NCSimul® software, considering all the aspects of a machining process in order to produce a simulation that reflects the reality. NCSimul® analyzes and optimizes the cutting conditions of the machining process using a time or displacement discretization of each tool path. In fact, the tool path is discretized into calculation segments so as the length is defined as a percentage of the tool's maximum cutting radius. Different parameters are then computed for each point in the discretized toolpath and exported for further implementation:

- Cutting conditions (ap, ae, ad, Vc … etc.).
- Trajectory points coordinates.
- Machined volume.
- Tool/ Part intersection type.
- Machining time.

<u>Definition and characterization of freeform machining feature:</u>

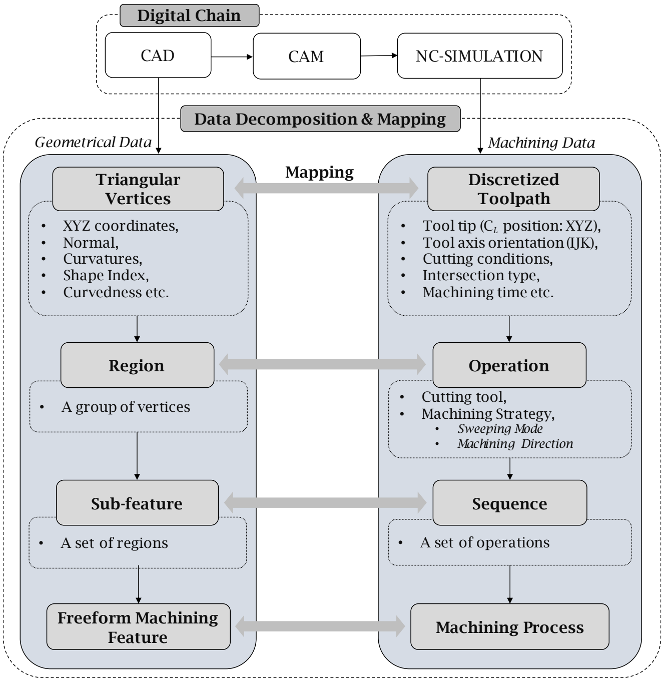

Fig. 3: Structural framework of feature-based NC machining process model.

Proceedings of CAD'18, Paris, France, July 9-11, 2018, 347-351

As mentioned above, we propose a multi-level freeform machining feature, distinguished by an accurate mapping between digital chain data. Our mapping is built level by level. Each geometrical level is mapped to a machining process level.

Figure 3 shows a level-based freeform feature-based NC machining process model. The part vertex and the trajectory point, low level elements, are first mapped together. Each vertex is not only enriched with geometrical data (n, s, c, etc.), but also, with machining process data attached to the toolpath point. Based on all these parameters, vertices are grouped together to form a region. Each region is then mapped to a machining operation defined by a strategy, cutting tool, and toolpath. A cluster of regions, that defines a sub-feature, is then mapped to a machining sequence. Finally, at the high level, the machining process is attached to the freeform feature. Thus, for each feature, a machining process data is known.

Conclusion:

This paper proposes a multi-level freeform machining feature characterization based on digital chain extracted data. First, the extracted data are decomposed in different levels to facilitate their manipulation. In geometrical terms, the freeform feature is decomposed into sub-features, regions, and low-level geometric data such as edges and vertices. The vertex is enriched with different parameters (normal, curvature, etc.). On the other hand, machining process is decomposed into machining sequence, machining operation defined by machining strategy, cutting tool and toolpath. Various attributes extracted from the simulation software are attached to each tool trajectory point. Then, a mapping, level by level, between geometrical and machining process data is built to define the machining feature.

The proposed definition, based on different levels, enables an easy manipulation of freeform features. The different attributes attached to the feature can be used to build a database that structure the digital chain data of each part. The database may be explored later in different applications such as machining process reuse.

References:

[1] Bendjebla, S.; Cai, N.; Anwer, N.; Lavernhe, S.; Mehdi-Souzani, C.: Freeform Machining Features: New Concepts and Classification, In Proceedings of the 11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Naples, 2017.

[2] Bourdet, P.: La gamme automatique en usinage – Introduction générale à la conception automatique de gammes d'usinage, Hermes, 1990.

[3] Bronsvoort, W.F.; Bidarra, R.; Nyirenda, P.J.: Developments in Feature Modelling, Computer-Aided Design & Applications, 3(5), 2006, 655-664. https://doi.org/10.1080/16864360.2006.10738419

[4] Fields, M.C.; Anderson, D.C.: Fast feature extraction for machining applications, Computer-Aided Design, 26(11), 1994, 803-13. https://doi.org/10.1016/0010-4485(94)90094-9

[5] Lee, J.Y.; Kim, K.: A feature-based approach to extracting machining features, Computer-Aided Design, 30(13), 1998, 1019-35. https://doi.org/10.1016/S0010-4485(98)00055-4

[6] Sun, G.; Sequin, C.H.; Wright, P.K.: Operation decomposition for freeform surface features in process planning, Computer-Aided Design, 33(9), 2001, 621-636.

[7] Sunil, V.B.; Pande, S.S.: Automatic recognition of features from freeform surface CAD models, Computer-Aided Design, 40(4), 2008, 502-517. https://doi.org/10.1016/j.cad.2008.01.006

[8] Tseng, Y.J.; Joshi, S.B.: Recognition of interacting rotational and prismatic machining features from 3-D mill-turn parts, International Journal of Production Research, 36(11), 1998, 3147-65.

[9] Tuong, N.V.; Pokorny, P.: A practical approach for partitioning free-form surfaces, International Journal of Computer Integrated Manufacturing, 23(11), 2010, 992-1001.

[10] van den Berg, E.; Bronsvoort, W.F.; Vergeest, J.S.M.: Freeform feature modelling: concepts and prospects, Computers in Industry, 49(2), 2002, 217-233.

[11] Wu, M.C.; Liu, C.R.: Analysis on machined feature recognition techniques based on B-rep., Computer-Aided Design, 28(8), 1996, 603-16. https://doi.org/10.1016/0010-4485(95)00075-5

[12] Xu, X.; Wang, L.; Newman, S.T.: Computer-aided process planning – A critical review of recent developments and future trends, International Journal of Computer Integrated Manufacturing, 24(1), 2011, 1-31.https://doi.org/10.1080/0951192X.2010.518632

[13] ISO 14649 (2002) Part 10: General process data.