A survey on methods of design features identification

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Abstract. It is widely accepted that design features are one of the most attractive integration method of most fields of engineering activities such as a design modelling, process planning or production scheduling. One of the most important tasks which are realized in the integration process of design and planning functions is a design translation meant as design data mapping into data which are important from process planning needs point of view, it is manufacturing data. A design geometrical shape translation process can be realized with application one of the following strategies: (i) designing with previously prepared design features library also known as DBF method it is design by feature, (ii) interactive design features recognition IFR, (iii) automatic design features recognition AFR. In case of the DBF method design geometrical shape is created with design features. There are two basic approaches for design modelling in DBF method it is classic in which a part design is modelled from beginning to end with application design features previously stored in a design features data base and hybrid where part is partially created with standard predefined CAD system tools and the rest with suitable design features. Automatic feature recognition consist in an autonomic searching of a product model represented with a specific design representation method in order to find those model features which might be potentially recognized as design features, manufacturing features, etc. This approach needs the searching algorithm to be prepared. The searching algorithm should allow carrying on the whole recognition process without a user supervision. Currently there are lots of AFR methods. These methods need the product model to be represented with B-Rep representation most often, CSG rarely, wireframe very rarely. In the IFR method potential features are being recognized by a user. This process is most often realized by a user who points out those surfaces which seem to belong to a currently identified feature. In the IFR method system designer defines a set of features and sets a collection of recognition process parameters. It allows to unambiguously identifying individual features in automatic or semi-automatic way directly in CAD system or in an external application to which the part model might be transferred. Additionally a user is able to define non-geometrical information such as: overall dimensions, surface roughness etc. In this paper a survey on methods of features identification and recognition is presented especially in context of AFR methods.

1. Introduction
Rule-based automatic design features recognition methods use a general principle which says that if in a product design it is possible to recognize a characteristic structure of a potential design feature this structure is compared, with system inference rules, with design features patterns stored in an AFR
system knowledge base. During the process of an AFR system knowledge base development it is necessary to comply with rules uniqueness condition. In this connection it is not acceptable that two different design features could have the same corresponding pattern or more than one pattern structure definition for a particular design feature. Meeting of rule uniqueness condition allows making AFR systems which can recognize design features with a great precision. But in case of this kind of design feature recognition system is impossible to broaden a store of knowledge stored in a system knowledge base without user participation. As a result it is highly likely that in some cases it could be impossible to match a potential design feature structure with patterns stored in a knowledge base. In such case it is necessary to add appropriate rules and design features structure definitions manually.

Currently, there are many AFR systems worked out with application of design feature recognition logic, which first of all, differ in a manner of a product design representation. In such case the following approaches mostly are used: syntactic pattern recognition, predicate calculus also known as predicate logic, convex hull volumetric decomposition, cell-based volumetric decomposition, hint-based approach and hybrid.

2. Syntactic pattern recognition

In a method of syntactic pattern recognition an element model is made with application of semantic primitives. These primitives are stored with a certain descriptive language. First the set of language grammars, composed of the certain number of rules that allows defining particular syntactic patterns is built. The language grammar is responsible for delivering of detailed models which make distinguishing of characteristic char sequence in a string possible. In a method of the syntactic pattern recognition a sentence (a string generated with a set of rule), a grammar (a set of rules) and parser are given. Parser is used in order to check whether a sentence was properly built according to language grammar. In the figure 1 AFR system architecture with syntactic pattern recognition is shown.

![Figure 1. An AFR system with syntactic pattern recognition.](image)

System form the figure 1 consists of: a design description module, parser and set of language grammars which represent particular design features patterns. At first these kinds of systems were able to recognize design features in 2D product design models, but their development has led to the state where design feature recognition in 3D product design model is also possible. In case of 3D models initial model preprocessing is necessary. Particular model faces have to be projected onto previously defined projection planes. The design product description module is responsible for a design description preparation. The product description is given in the shape of a string which is next examined by a system parser in order to check its correctness from language grammar point of view. If a product string is correct than the subsequent classification process is performed. During a classification process particular product design features are classified to appropriate pattern classes.

One of the latest syntactic pattern recognition methods is edge boundary classification method. In EBC method information about 3D models spatial addressability is used in order to distinguish outer
and inner boundary object sides whilst identified edges loops are sought out in a product B-rep boundary representation. For each identified edges loop an EBC pattern is made. An EBC pattern is made as a result of a classification of points which belong to a test set. Initially the test set points are located in the vicinity of an edge that composes a given loop. A given point of the test set depending on its location according to a reference model is classified as an outer or inner element point. Basis on this information a special code is ascribed to the point. Thus formed for each loop code chain is a base for working out a given loop pattern. This loop pattern next might be used in a process of syntactic design feature recognition. The EBC method allows identifying the following class of objects: pockets, slots, steps, cylindrical and conical holes in rotational and prismatic parts. The most important drawback of syntactic pattern recognition systems is their limited range of application. They are able to identify design features in rotational part such as shafts, sleeves, shields and chosen designs of prismatic parts.

3. Predicate calculus – predicate logic
Predicate calculus design feature recognition systems are usually built with a set of production rules. A single production rule structure could be written in the following way: If $C_1, C_2, C_3, \ldots, C_n$ Then A, where A represents a particular design feature structure. If all conditions it is $C_1, C_2, C_3, \ldots, C_n$ of a production rule premise part are satisfied then a given structure identified in a part description is recognized as a structure compatible with A design feature structure. An example of the AFR system with predicate logic in [1] is presented. In the considered system a part model is represented with IGES format. The product 3D model is next transformed with original software in set of Prolog logic programming language facts. The process of automatic design features recognition begins with part faces extraction and base faces identification. From definition a base face should have at least one adjacent face and faces adjacency character should be a concave-type. In the next stage of the recognition process the product boundary end faces are identified. The main design features recognition criterion is type and the number of a product boundary end faces (excluding design features of the hole-type). In the figure 2 the general structure of the discussed AFR system (a) and the way of design features definition (b) are presented. This system allows recognizing of the following design features: slots, blind slots, holes, countersink holes, reliefs and chamfers.

![Figure 2. The AFR system structure (a), design feature definition (b).](image)

The next example of the AFR system with predicate logic application in the [5] is presented. In this AFR system CSG product model representation is used. The identification process is carried out by a complete review of a text file with a program written in Visual Basic worked out with SolidWorks...
API interface. The recognition process is being performed by comparing of features extracted from a product design with design features structures stored in Oracle database. Thanks to this AFR system it is possible to recognize design features in prismatic parts only excluding those features which intersect each other. The AFR system output information makes input information for a CAPP system planning activities.

4. Graph based design recognition methods
First studies on application of graph theory in design feature recognition were focused on working out of such design representation method which could allow representing both model topology and its geometry. Initially application of an attributed adjacency graph (AAG) in order to transformation of a B-rep product model made in any CAD system into a graph structure was presented. In the AAG graph for each particular graph edge 0 is ascribed if its vertexes satisfy concave adjacency relation and 1 for convex adjacency. In the figure 3 an example of a prismatic element for which design features are being recognized and its corresponding AAG graph structure are presented. A single design feature in the product design AAG graph is represented by the AGG subgraph structure. In this case the recognition process consist in searching, in the AGG graph of a product being processed, of structures which can be matched with those stored in an AFR system database. The subgraph structures are examined with logical rules. This approach known as the graphs isomorphism is characterized by large time-consuming and high computational complexity.

![Graph representation](image)

**Figure 3.** The prismatic part model (left), the product AGG graph (right) (a), the subgraph of the AAG graph representing design feature slot like (b), the subgraph of the AAG graph representing design feature blind slot like (c).

An alternative method to graphs isomorphism is a divided graphs isomorphism method in which the identification process is carried out by an AGG graph syntactic analysis. In such case syntactic analysis is carried out only for these graph vertices for which all product faces are convex.

An original idea of AAG graph application for automatic design features recognition purpose was characterized by identification ability of polyhedral design features only and inability of extracting boundary faces. AAG method limitations have given an impulse to AGG method modification. Based on original AGG graph concept a new Multi-Attributed Adjacency Graph method was worked out. The characteristic for MAAG method is that particular attributes values ascribed to graph edges give a model faces adjacency relation more precisely. For instance if a planar face makes with a curved face a convex angle then the attribute value equals 2. There is also a development of MAAG method for which a graph is presented by means of an adjacency matrix. In such case this AAG takes the name of multi-attributed adjacency matrix MAAM. Design features recognition process is then carried out with
MAAM matrix use, whilst particular MAAM matrix represent a singular design features structure. The most important drawback of graph based AFR systems was inability of design features recognition in case of their mutual interaction. This problem was solved by reconstructing of missing graph edges. These missing edges allow restoring information about mutual product faces connections lost as a result of appearing in a product model two or more design features which interact each other. Summarizing up, all AFR methods that use a graph theory can be characterized by a large number of preprocessing operations which results out of necessity of description of each part feature and geometric primitives. Moreover, most of graph based AFR systems allow recognize design features in prismatic parts only. What is more, there is no guarantee that this information, even if these systems are able to recognize design features efficiently, will be useful from a CAPP system process planning activities point of view.

5. Volumetric convex hull decomposition methods
Method of the volumetric convex hull decomposition consists in transformation of an input model into a set of intermediate volumes. Basis on these identified intermediate volumes design features are being search. This method uses a definition of ASV – alternating sum of volumes understood as the difference between a model volume and volumetric convex hull. On the basis of ASV definition in [2] a new partitioning procedure ASVP – alternating sum of volumes with partitioning was presented. In [4] on of the examples of ASVP use was presented. In this work basic design features and freeform design feature structures are considered. By freeform design features were assumed these features which contain freeform surfaces that could be machined with 2.5 or 3 axis milling operations. In the system [3] a B-rep product model made in any CAD system, exported with STEP or IGES neutral format, makes an input into a process of geometric information extraction. In that case of the ASVP method implementation particular model surfaces take different attribute values depending on whether they are a piece of a blank – SS, a piece of a finished product – MS or pieces of a product at particular stages of a manufacturing process – IS.

In such case a design feature is defined as a unique combination of the model surface with different attribute values it is SS, MS or IS. In the figure 4 the AFR system action schema is presented.

![Figure 4](image)

**Figure 4.** An illustration of design features recognition with ASVP method use [4].

6. Hint based methods
Unsatisfied need of the comprehensive solution of the problem of design features identification in case of features which interact each other has led to development of the new group of AFR methods it is hint-based methods. In a hint-based approach topological, geometric and heuristic information about product being analysed are used as hints on potential appearing of a certain class design features in the product design. There are some AFR systems which use hint approach but the most interesting are these presented in [6, 7]. In [6] system called OOFF from Object Oriented Feature Finder is presented. In this system an approach that consist in searching in a product design precisely defined patterns of
geometric elements such as face, edge or vertex is used. As a matter of fact this approach is completely useless from a practical application angle. But this work introduced one important definition it is the presence rule definition. According to this definition manufacturing operation responsible for performing of a design feature with a machine tool should leave a mark on external surfaces of the machined product even if this design feature interacts with other product design features. The presence rule definition was used in later works giving foundations for working out of a new group of methods so called trace based methods. The introducing of the presence rule allowed working out patterns of minimal marks left by design features on a product external surfaces – boundary surfaces. So if it was possible to state a presence of a certain pattern on an external product surface it would suggest a potential possibility of existence of a certain class design feature in a product design. In [9] a modified hint-based method is presented. In this case as a hint is used additional information introduced by a user it is dimensional tolerances, surface roughness etc.

7. Conclusions
AFR systems were developed with the idea of a complete elimination of an expert presence in a process of design features identification. Despite the fact that AFR systems constantly evolve these systems still have lots of drawbacks and limitations. Among them we could distinguish high complexity of the recognition algorithms, long implementation time, limited application range, information ascribed to particular design features has a limited usefulness from process plan automation point of view, impossibility of design features dimension tolerance information acquiring, impossibility of a complete elimination of an expert presence in the identification process independently of applied method, almost complete lack of AFR methods industrial applications.

Taking into account above a problem of working out of a new efficient method of design features identification it is still valid. This method should be characterized by maximum simplicity and implementation ease. In spite of all the design feature method still seems to be one of the most attractive method that gives a methodological foundations for building of an integrated CAD/CAM/CAE system environment.

References
[1] Babić B and Miljkovic Z 1997 Feature recognition as the basis for integration of CAD and CAPP systems Intelligent Manufacturing Processes and Systems pp 596-601
[2] Kim Y S 1992 Recognition of form features using convex decomposition Computer-Aided Design 24 pp 461-476
[3] Markus A, Vancza J, and Horavath M 1997 Process planning by retrieval and adaptation Computer in Industry 33 pp 47-60
[4] Miao H K, Sridharan N and Shah J J 2002 CAD-CAM integration using machining features International Journal of Computer Integrated Manufacturing 15 pp 296-318
[5] Sadaiah M, Yadav D, Mohanram P and Radhakrishnan P 2002 A generative computer-aided process planning system for prismatic components The I. J. of A. M. Techn. 20 pp 709-719
[6] Vandenbrande J H and Requicha A A G 1993 Spatial reasoning for the automatic recognition of machinable features in solid models IEEE Tran. on Patt. Ana. and Mach. Intell., 15 pp 265-285
[7] Waiyagan K and Bohez E L J 2009 Intelligent feature based process planning for five-axis mill-turn parts Computers in Industry 60 pp 296-316
[8] Xu H Li D 2009 Modelling of process parameter selection with mathematical logic for process planning Robotics and Computer-Integrated Manufacturing 25 pp 529-535
[9] Zheng Y, Taib J M and Tap M M 2011 Implementation of heuristic reasoning to recognize orthogonal and non-orthogonal inner loop features from boundary representation (B-rep) parts Journal Mechanical 33 pp 1-14