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Original Research Article

CAD 3D models decomposition in manufacturing processes

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ABSTRACT

Data exchange between different computer systems in design and manufacturing processes planning is a very important issue of computer aided engineering. Computer Aided Process Planning (CAPP) systems require properly pre-processed design data. Such data refer not only to geometry, but also to additional information such as dimensions, dimensional and geometrical tolerances and surface roughness. This paper focuses on data exchange between a parametric CAD 3D system and a prototype CAPP system. The proposed CAPP system enables realization of main steps of manufacturing process preparation. Special attention is paid to the data transfer from the CAD system to a design database and from the design database to a feature recognition module of the CAPP system. The article presents feature recognition algorithms and the structure of technological features database. Authors developed also graphical user interface which allows displaying a part geometry as well as recognized features and their parameters.

1. Introduction

Nowadays the use of computers in engineering is necessary. Manufacturing companies are forced to put into practice innovative technologies in order to sustain their market positions and customer base [1]. Innovative technologies are applied in all areas of a company production system. There are various computer systems designed to help engineers at their work. The general term Computer Aided ''something'' (CAx) defines all such systems. The most popular and commonly used in the industry are Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems [2]. In the paper [2] authors indicates the important role the exchange of data between CAD and CAM systems in modern production systems. Usually single, standalone CAx system works properly. However, problems appear during data transfer between different CAx systems. There are two main categories of data exchange:

- internal data transfer (within one kind of CAx systems e.g. different CAD systems),
- external data transfer (between different classes of CAx systems e.g. CAD and CAPP).

To ensure proper quality of data transfer between different CAD systems many neutral file formats and standards have been elaborated, for instance STEP (STandard for Exchange of Product model data). In the paper [3] use of one computer

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system PLM DELMIA to manufacturing processes modelling is presented.

The data exchange between different classes of CAx systems is more difficult. This paper focuses on the data exchange between CAD and CAPP systems. It is organized as follows. In the first section a geometrical and design data exchange in context of features is described. Then the relational database designed to keep parameters of machining features is presented. In the third section the algorithm of machining features recognition is outlined. The last section contains some conclusions.

2. Features in manufacturing processes planning

In the area of design and process planning two main classes of features are employed: design and technological features [4–7]. The paper [4] proposes a Web-based and service-oriented approach for distributed machining process planning using machining features in a decentralized and dynamic manufacturing environment.

Two artificial neural networks for feature recognition, one for slots and steps and the other for circular pockets, was designed and described in the article [5]. The use of features to describe manufacturing processes is presented in the paper [7]. However, in this paper four classes of features are distinguished, i.e. functional, design, technological and machining (Fig. 1). This classification of feature is done on a base of their parameters. Each feature class is characterized by an individual sort of data. During processes of new products design certain conditions are taken into consideration. These conditions are described by functional features. The process of building model geometry in modern, feature based CAD 3D systems consists of adding design features. However, to complete a part description not only geometrical data are necessary, but also specific parameters, which describe: dimensions, dimension tolerances, surface finish, geometric tolerances, material parameters.

There are a couple of methods used for obtaining technological features. One of them employs technological features to design a part. This method completely solves the problem of technological features recognition but has some shortcoming. Technological features are not the best way of modelling a part. Design features are much more convenient. Another approach to obtain technological features is based on feature recognition techniques. In this group of methods technological features are recognized in an existing part model. The best known feature recognition techniques are [8–21]:

- part geometry describing languages,
- AAG (Attributed Adjacency Graph) methods,
- syntactic pattern recognition,
- logical approach – rule based algorithms,
- recognition from a neutral file format – STEP.

The paper [8] discusses the problem of feature interactivity and proposes a feature-based approach to generating hole-series machining features from a design feature model. In the article [9] a CAD linked stand-alone computer-based metal-forming process module is presented. In the study [10] the modified attributed adjacency (MAA) scheme is used to define the part which allows more information to be stored in the part representation (graph or matrix), and this allows multiple interpretations to be solved. Another method for obtaining features is presented in the article [11]. The proposed method adopts a hybrid approach, which combines the graph theoretic approach with the logic approach. Methodologies of enhanced multiattributed adjacency graph (EMAAG) and feature-interaction feature graph (FIFG) for automatic extraction of primitive features and complex features of plastic parts, respectively, are presented. The paper [12] presents a feature conversion approach to convert design features used in a design model into machining features. In the article [13], an approach for defining engineering features, like slots, steps and circular pockets is proposed using binary strings. Two artificial neural networks, one for slots and steps and the other for circular pockets, was designed and developed. The article [14] proposes an approach for interlinking CAD and CAPP, and describes the relevant efforts towards it: recognition of machining features, handling of manufacturing information, and implementation of a neutral interface using ISO 10303-224. Another application of neutral networks for machining feature recognition from CAD models is presented in the article [15]. The study [16] presents a mechanism for feature recognition and conversion, feature parameter and constraint extraction, feature tree reconstruction, technical information processing, process planning and automatic process drawing marking and 3D material stock CAD model generating. The paper [17] focuses on developing a feature-based intelligent CAPP system called ST-FeatCAPP. In the area geometrical data processing main purposes of this CAPP system is to integrate a standardized feature-based model with process planning utilizing the concept of STEP-based features. In the article [18] authors propose a hybrid approach that uses volume subtraction and face adjacency graph to recognize manufacturing features from 3-D model data in STEP AP-203 format. In the paper [19], some concepts of graph-based and hint-based approaches are combined providing a more effective solution to recognize interacting features. The article [20] provides a review of various approaches for solving three major automatic feature recognition problems: extraction of geometric primitives from a CAD model, defining a suitable part representation for form feature identification and feature pattern matching/recognition. Except this, in the study a novel, detailed classification of developed automatic feature recognition systems has been introduced.

The paper [22] presents the two stage approach to the feature recognition for CAPP system. After the presentation of the basic information about the manufacturing features, the definition and the methods of feature acquisition, including the advantages and disadvantages of the particular methods, the analysis of the information flow in process planned-rented product modelling system were carried out.

In this paper authors propose their own feature recognition method. This method is based on the conversion of data extracted directly from the CAD system. Such data are stored in the relational database. Technological features recognition process is divided into two stages [23]:

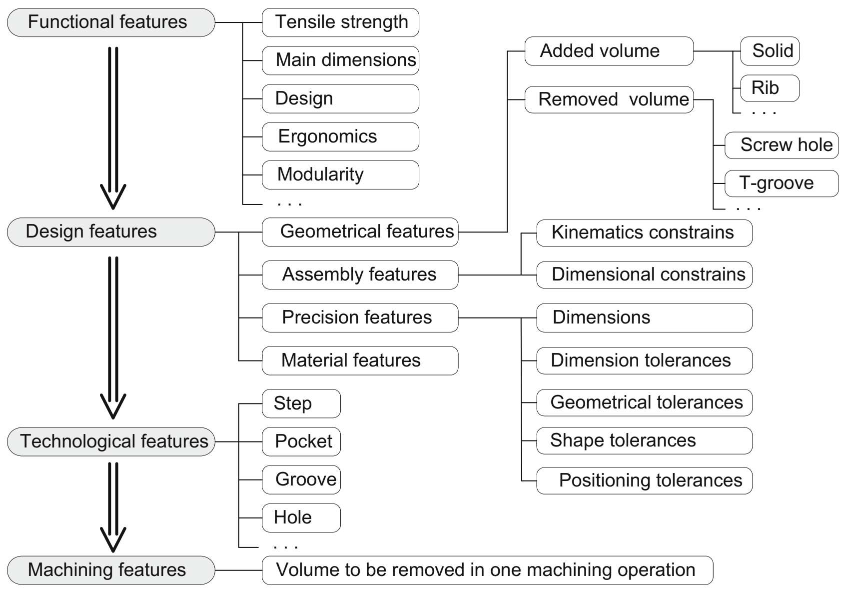

Fig. 1 – Features families.

- reading design and technological data from the CAD system and writing them to the database,
- recognition of technological features and writing their parameters.

The second stage has been implemented as a part of the Computer Aided Process Planning system (CAPP). This system uses parametrical technological features to describe manufacturing process parameters. Technological features are a set of data, which describes geometry, design and technological parameters of a part.

3. Boundary representation of CAD 3D models

Boundary representation is nowadays the most common way of representing three dimensional part models in CAD systems. This representation is employed in SolidWorks CAD system, which is used as a source of part data for the proposed CAPP system. Fig. 2 shows the main structure of 3D part model in SolidWorks system.

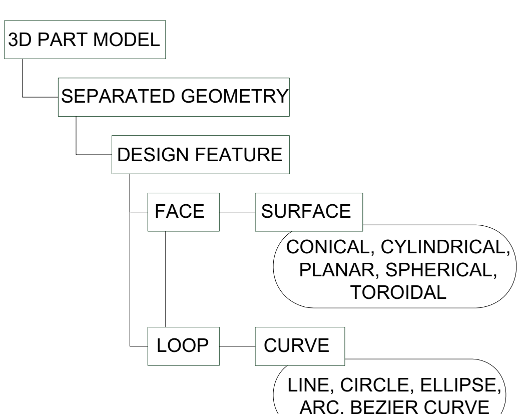

Fig. 2 – The structure of the model in SolidWorks CAD system.

According to this schematic, every model may consist of more than one part. Every such part is defined by a set of design features. Almost every such feature is described by a planar sketch and a 2D → 3D operation e.g. extrusion or revolution. The process of adding new design features usually causes some changes in the part geometry of the designed part. Some new faces may be added or some existing faces may be changed or deleted. Every face can be described as a closed continual area of a surface. According to this definition faces are defined by a surface and a set of borders. Surfaces are defined by a set of specific parameters, which depends on the type of the surface. Borders of faces are called loops, and consist of a set of curves. Every curve has its type e.g. line or circle and specific parameters. A curve in a loop is connected with their predecessor and successor. Every face has one or two outer loops and optionally one or more inner loops.

4. Application Programming Interface of SolidWorks CAD 3D system

API of SolidWorks provides following functionalities:

- reading parameters of parts and assemblies,
- building of new models and modifying existing ones,
- adding and managing of graphical user interface components.

The first group of API's functions allow reading all parameters of an opened part model. Beside geometrical parameters, also dimensions and tolerances are accessible in this way. An example of a function from this group is *int Body2::GetFaceCount()*,

which returns the number of faces defining a model. This function is used with

Face Body2::GetFirstFace()

and

Face2 Face2::GetNextFace()

which return the first and the next face of the model. Having the face selected, corresponding surface can be obtained by

Surface Face2::GetSurface().

The type of returned surface can be determined by checking the value returned by following methods:

bool Surface::IsCylinder(), bool Surface::IsSphere() i bool Surface::IsPlane().

When the type of the surface is identified, the parameters of the surface can be obtained by calling appropriate method from the following list:

SafeArray Surface::CylinderParams(), SafeArray Surface::SphereParams(), SafeArray Surface::PlaneParams().

5. Design and technological database

The key issue in processing geometry parameters is collecting and saving the data associated with parts. Considering the fact that every single CAD system has its own standard to store geometry and other design information, it is difficult to process these data. Moreover this internal data format does not allow direct processing of the part data. To solve this problem authors use an Application Programming Interface (API) integrated with a selected CAD system. API allows retrieving different kinds of parameters of a designed part, directly from a CAD system. SolidWorks was applied as a source of a designed part data. Fig. 3 illustrates the main

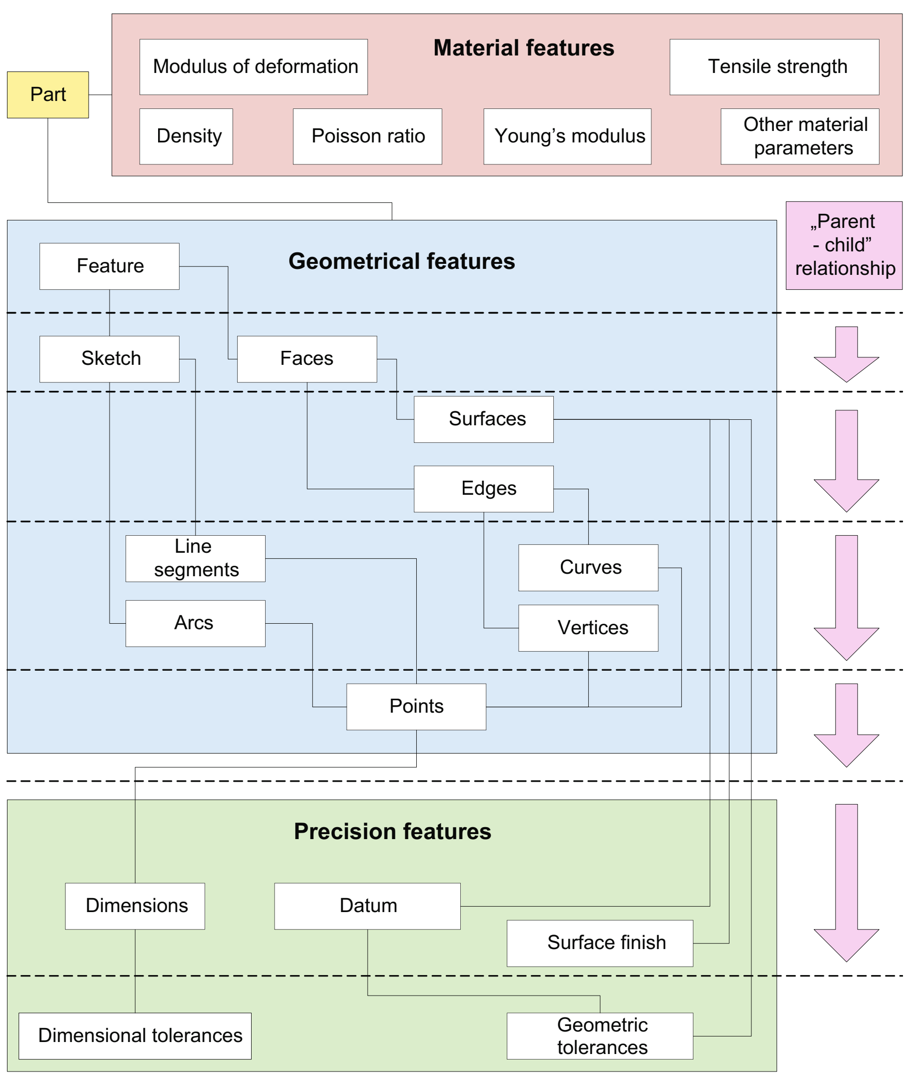

Fig. 3 – Feature based design process in Computer Aided Design system.

structure of design and technological data in SolidWorks CAD system. These data are accessible from the Application Programming Interface integrated with SolidWorks. Access to geometrical, material and other part data is possible from many integrated development environment. Authors chose Borland Delphi. Specific API functions and procedures can be used to read data from the CAD system. Communication between the CAD system and the development environment is possible when both programs are launched and an appropriate kind of document is opened and active in SolidWorks system.

The command syntax Application Programming Interface SolidWorks has the following structure:

destination_object: API_ function (argument_1, . . . argument_n), *destination_object* is a variable of a specific type (integer, float, array, etc.), *API_function* is the name of the corresponding interface functions, the value returned by this function for set values specified by name *(argument _1 . . . argument_n)*. The name will be assigned to a variable named the *destination_object.* In some cases, the interface function takes no arguments, for example. *GetEdgeCount* function returns the number of edges specified object.

A piece of code listed below is responsible for reading parameters of geometrical features and writing them down specific database tables.

```
if (feature.GetTypeName = ='Cut') or (feature.GetTypeName = ='Boss') or
(feature.GetTypeName = ='Extrusion') then
begin
    tableFeature.insert;
    tableFeature['feature_id']: = IntToStr(currentFeature);
    tableFeature['name']: = cleanText(feature.Name);
    tableFeature['part_id']: = partNumber;
    tableFeature['feature_type']: = feature.GetTypeName;
    tableFeature.post;
end;
```

The way part data are processed depends on a kind of this data. High level part data e.g. parameters of design features are sent directly from the CAD system to the database. Proper API objects are used to access necessary parameters of a part model.

A different procedure is used for geometric features of the lowest level, i.e. points. Every points are represented as an array of numbers corresponding to point coordinates. Every geometric object like an arc or an line keeps its own points. Considering the fact, that every geometric object has some points common with their neighbour, this way of data representation leads to some data redundancy. Moreover, coordinates of the same point returned by different objects may slightly differ. To solve this problem the part data returned by API need to be transformed to an unambiguous

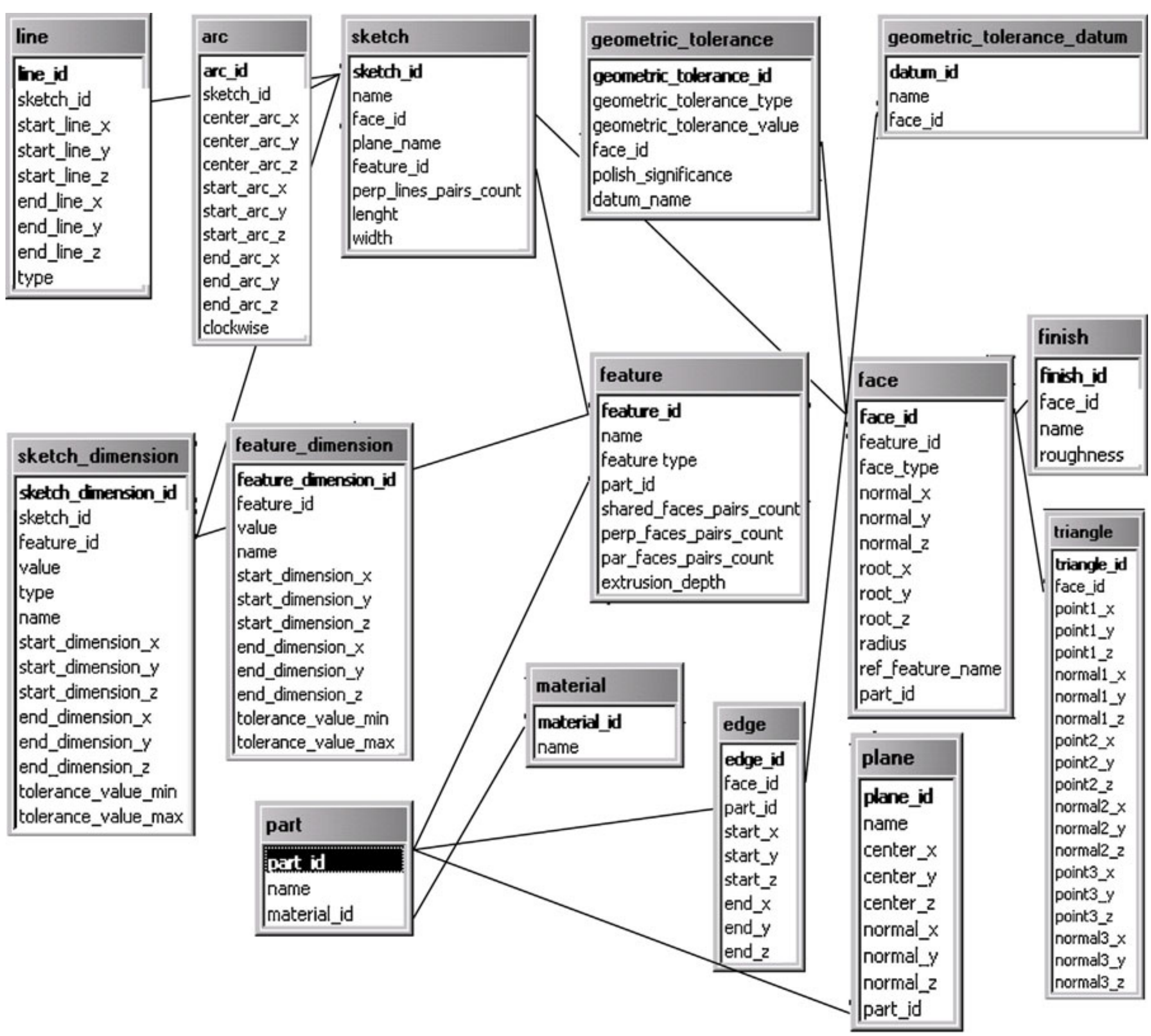

Fig. 4 – Structure of design and technological data in SolidWorks CAD system.

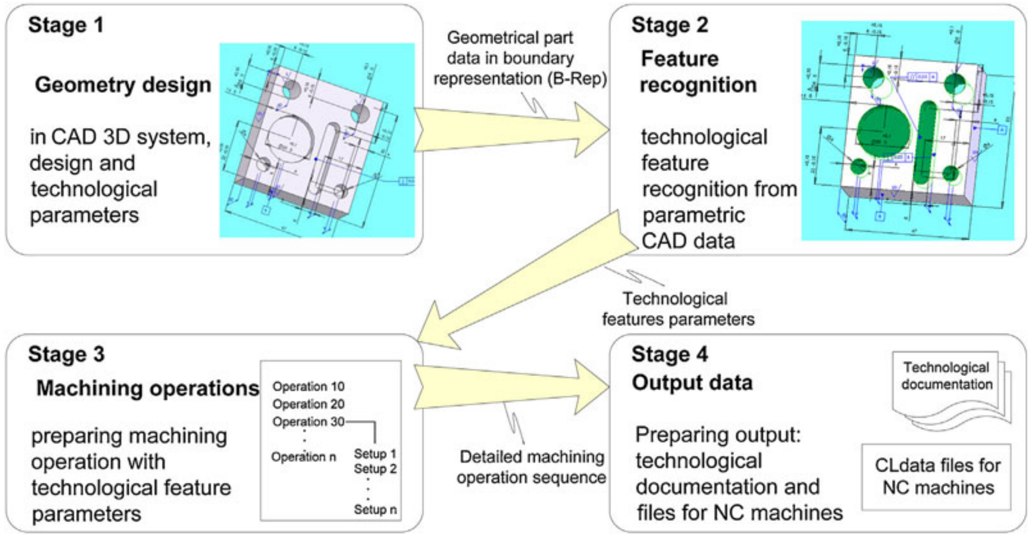

Fig. 5 – Four main stages of planning manufacturing processes in the prototype CAPP system.

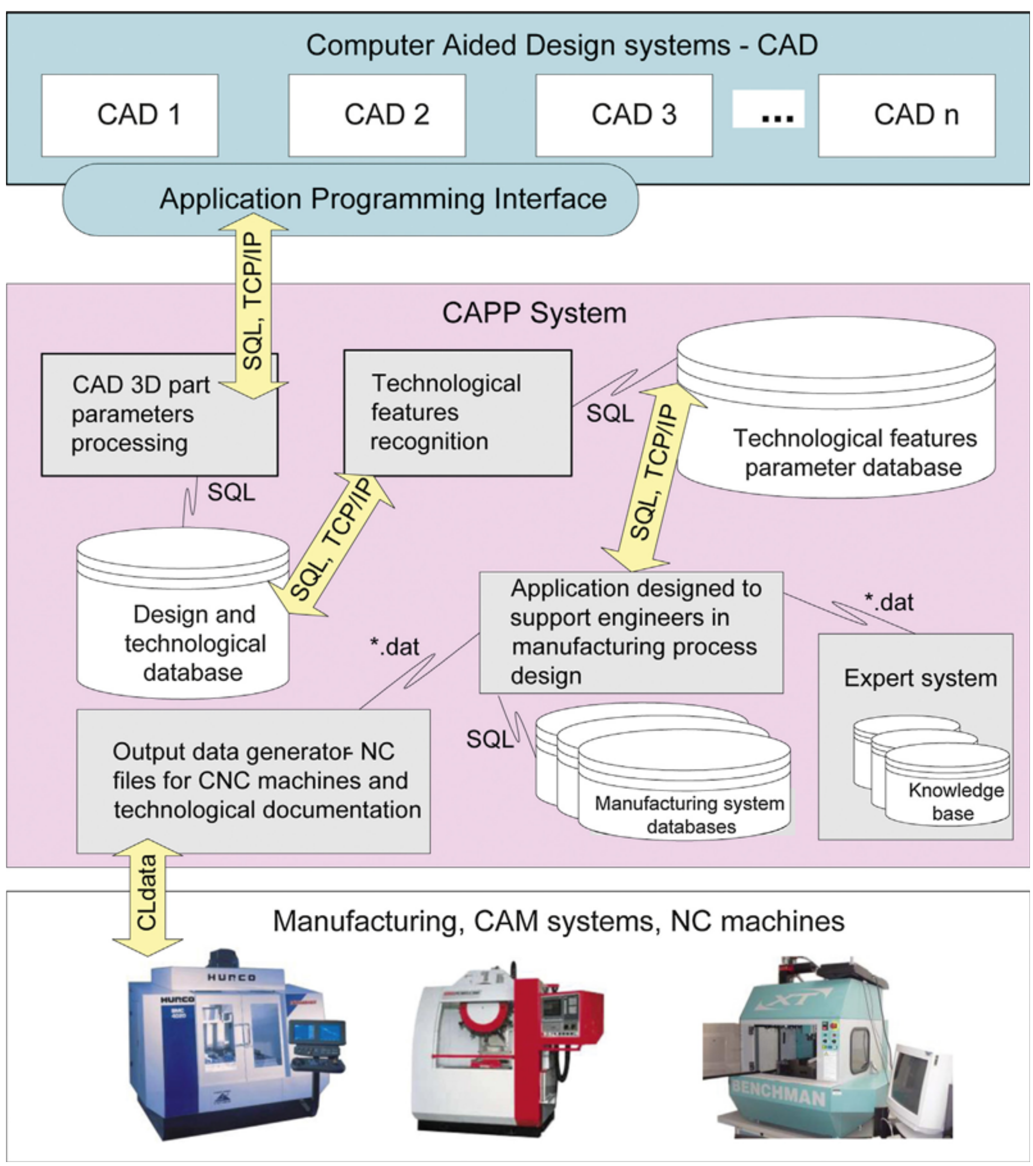

Fig. 6 – Communication between the proposed CAPP system and a manufacturing environment.

data structure. The transformed part data are used to design a manufacturing process plan. By dint of the need of making these data accessible to many people at the same time, a relational database system was chosen to store and maintain all manufacturing data in the CAPP system.

Accessing geometrical data from a relational database management system is a few times faster comparing to API. The database of geometrical and technological data was built in a relational database management system – PostgreSQL 8.0. It consists of 15 tables, which are connected by relations [24]. Parameters of relations depend on data character. The database has a Client–Server architecture. Data and the structure of the tables are stored on a server. The communication with the database is possible through a computer network. The proposed database system enables access to data from workstations in different locations and direct access to part data by many users at the same time. Additionally, data stored in the database are protected from unauthorized access. The structure of tables storing 3D CAD parts data is shown in Fig. 4.

The names of the tables and their contents are listed below: part – part data, material – material data, feature – part features, feature_dimension – part feature dimensions, face – part faces, geometric_tolerance, geometric_tolerance_datum, triangle – OpenGL triangles (used for displaying 3D part model), edge – part edges, plane – planes in the part, finish – data regarding face class finish, sketch – sketches in the part, sketch_dimension, line – lines in sketches, arc – arcs in sketches.

Presented data structure allows many different applications, e.g.:

- displaying part geometry,\
- conversion to another data format, e.g. data format of a CAD system,
- application in different CAx systems such as CAPP (Computer Aided Process Planning).

In the following part of the paper the database and data extracting mechanisms are described. Four main stages of

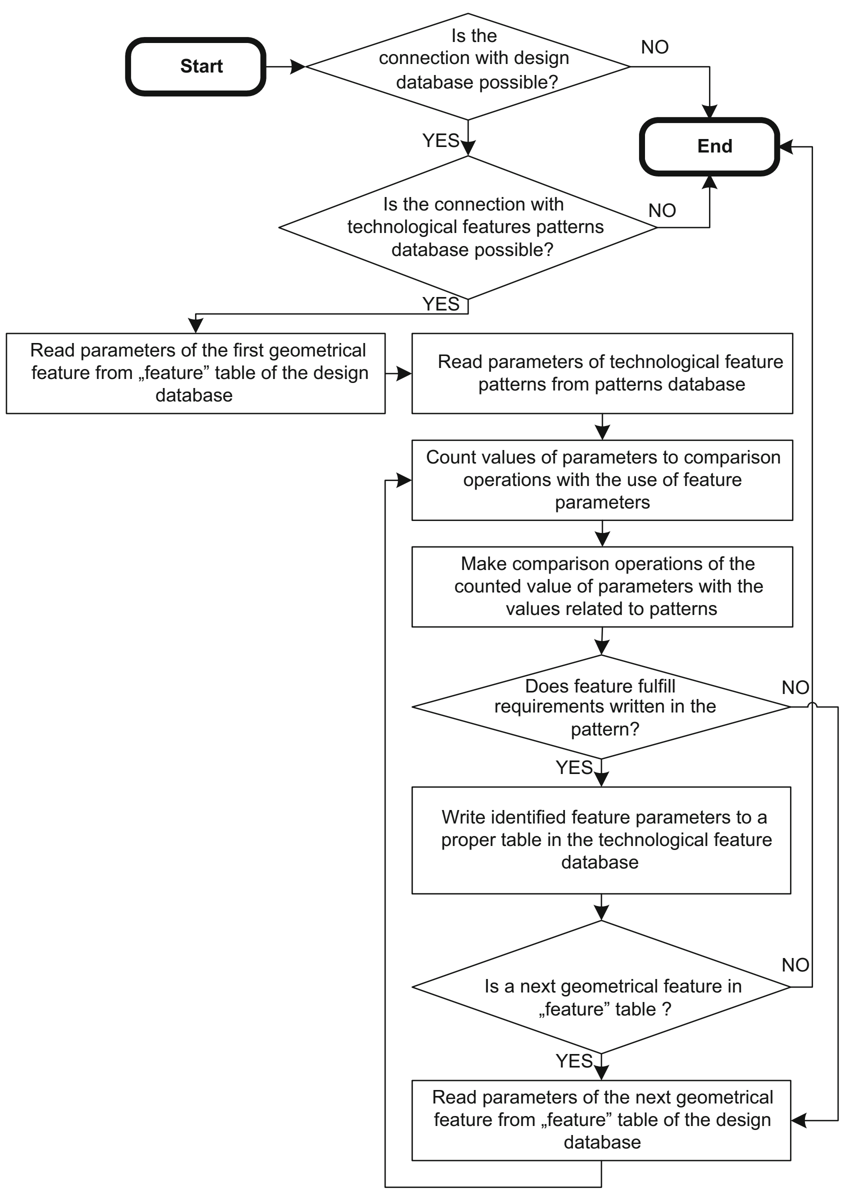

Fig. 7 – Algorithm of technological features recognition.

designing a process plan in the proposed CAPP system are shown in Fig. 5.

This system can be fully integrated with a modern feature-based CAD 3D system, through API of CAD system. Fig. 6 illustrates the process of communication between the CAPP system and the manufacturing environment.

The CAPP system communicates via the API with the CAD system and collects geometrical part data. Specific functions and procedures of the API are used to import this data. Design data obtained in this way are sorted, processed and written to the database. In the next stage of data processing technological features are recognized. A module of the CAPP system responsible for that process communicates with the design database through the SQL language and the TCP/IP internet protocol.

Recognized technological features are stored in the database. The computer application designed to ensure this functionality communicates with the technological features database and downloads technological features parameters. Such data will be used in an expert system to support decision process. This process will begin with the selection of a proper manufacturing operation for each technological feature, then operations will be grouped and reorganized to ensure maximum utilization of machines and to reduce the time and costs of manufacturing process. Output data will be presented in a form of technological documentation and files for CNC machines.

6. Technological features recognition

The primary task of the proposed CAPP system is to assist and help process planner in preparation of machining processes. The first stage of data processing in the CAPP system is reading and processing data obtained from the CAD system, and then storing them in the database. The next step is the recognition of technological features. For the feature recognition procedure feature patterns are used. Patterns can by modified and changed by the user. Data necessary to the recognition process are listed below:

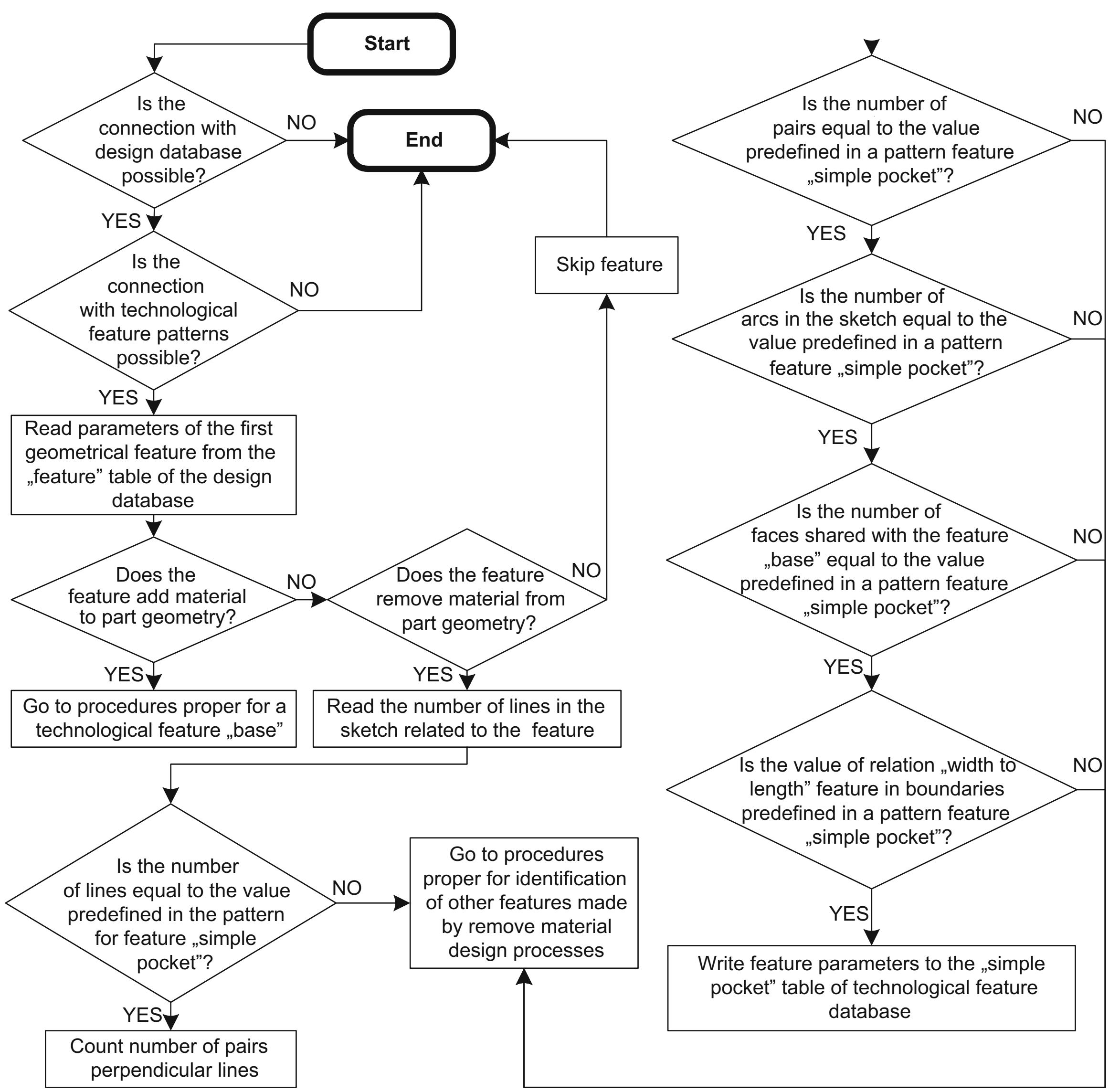

Fig. 8 – Detailed algorithm of recognition of a "simple pocket".

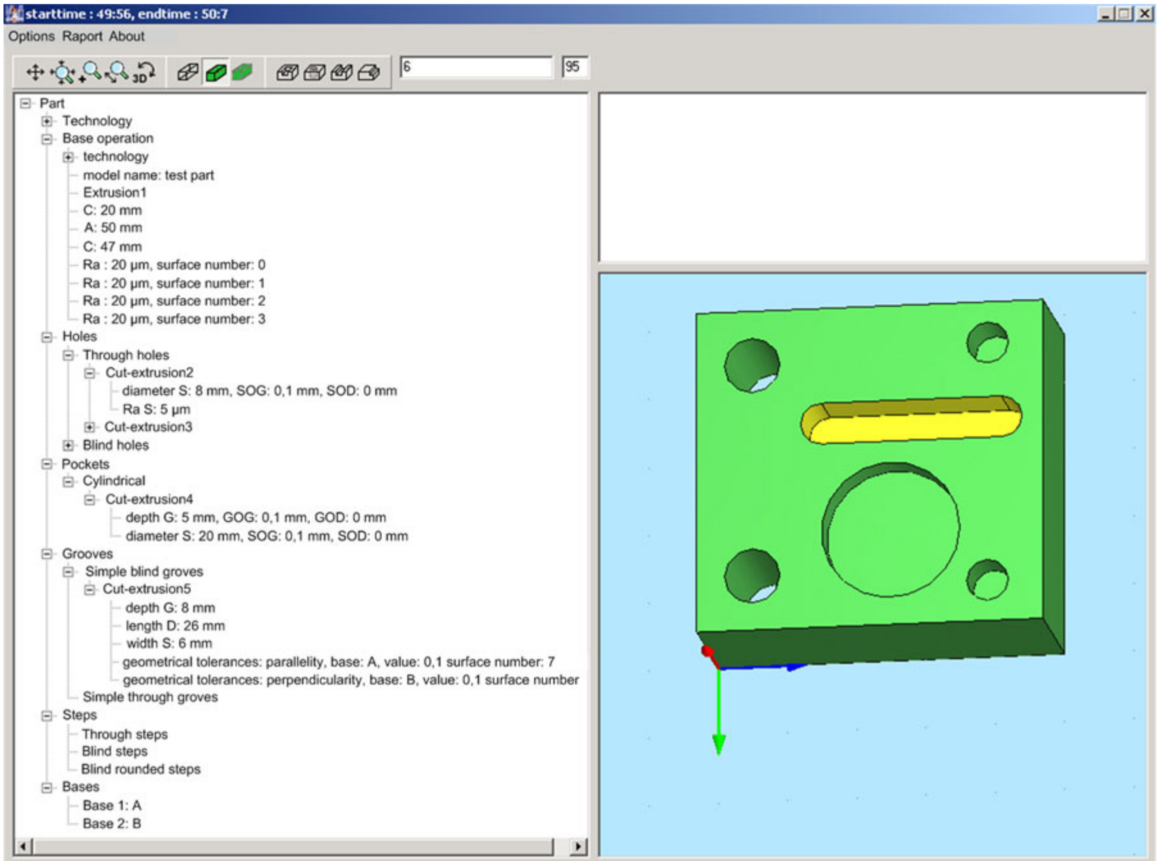

Fig. 9 – The main window of the prototype CAPP system.

- the number of lines and arcs in a sketch (sketch which was used in the design process to make a particular 3D feature),
- geometrical relations between lines and arcs in a sketch (perpendicularity, parallelism etc.),
- depth to diameter ratio (depth and diameter of the 3D part feature), width to length ratio (width and length of the 3D part feature).

The general technological features recognition algorithm is shown in Fig. 7.

The application starts with checking the connection to databases. In case of successfully accomplished connection the first geometrical feature is read from a table called "feature" in the design database. Then parameters of technological features patterns are read. Necessary geometrical feature parameters are calculated to compare them with patterns read from the database.

If the calculated parameters correspond to appropriate parameters of one of technological features patterns, a new technological feature and their parameters are written to the technological feature database. Then another geometrical features are analyzed. If a geometrical feature cannot be recognized because their parameters does not suit to any of technological feature pattern, it is omitted and next geometrical feature is read. In case there is no other geometrical feature, the process is terminated. The detailed recognition algorithm for technological feature "simple pocket" is shown in Fig. 8.

7. Graphical user interface of proposed CAPP system

Parameters of recognized technological features are accessible via graphical user interface of proposed CAPP system. Fig. 9 shows the main window of the prototype CAPP system.

The main window has a menu bar, a toolbar, a feature manager tree and a viewport that lets the user see the model from various directions. When a user selects an item in the feature manager tree, e.g. a hole diameter, the related feature in 3D view becomes highlighted.

The feature manager tree shows all design and technological data of the part. Particular tree branches contain parameters grouped in a "parent–child" hierarchy. Technological features are grouped into five feature families.

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