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INTELIGENTNÉ CAD-CAP ROZHRANIE ZALOŽENÉ NA ROZPOZNÁVANÍ PRVKOV A GENETICKOM ALGORITME

INTELLIGENT CAD-CAP INTERFACE BASED ON FEATURE RECOGNITION AND GENETIC ALGORITHM

Integrácia výroby závisí hlavne od úrovne automatizácie existujúcich výrobných buniek, ktoré budú integrované do spoločného informačného systému. V prípade CIM ide o integráciu CAD a CAM. Táto integrácia tiež vyžaduje brať do úvahy aj CAP úlohy, pretože tvorí medzičlánok medzi spomenutými modulmi. Článok opisuje inteligentné rozhranie na integráciu CAD a CAP. Skladá sa z dvoch častí - rozpoznávač a vyhľadávač. Rozpoznávač preskúma CAD model a rozpozná prvky, z ktorých sa súčiastka skladá. Vyhľadávač využije výsledky rozpoznávača ako vstupnej jednotky a hľadá primeranú technologickú operáciu z databázy. Vyhľadávač použije optimalizačné princípy genetického algoritmu na to, aby našiel optimálny technologický postup pre CAD dáta.

The integration of production depends mainly on an automation level of the existing production cells that will be integrated into a common information system. In terms of CIM it means integration of CAD and CAM tasks. The integration also demands taking the CAP tasks into an account, because of their intermediate position. The paper describes an intelligent interface for integration of CAD and CAP tasks. It consists of two parts, recogniser and seeker. The recogniser scans the CAD model and recognises its features. The seeker uses the results of the recogniser as an input and searches the appropriate work operation from the technological database. The seeker uses genetic algorithm (GA) optimisation principles for finding the optimal machining procedure of the CAD part.

1. Introduction

Connection and integration of individual units into a whole is the basic fact, which seems to be woven into the structure of the world. The principles of integration can easily be detected in the basic concepts of living beings and also in the society. Self-organisation and, hence, integration is a natural phenomenon, which raises isolated activities to a higher level with a new sense on the basis of which the functioning of the whole is more efficient and more intelligent. On the contrary, disintegration means separation, non-coordinated functioning, and isolation.

With a grain of simplification, the meaning of integration can be traced also in production systems. They must act outwards as much coordinated as possible if they want to survive, however, inwards there must be enough space for variety and competition of ideas. Production systems are like large living bodies condemned to deterioration if the destructive forces in them are too great; if, however, functioning is carefully oriented, re-considered and as much integrated as possible at all levels of the company, that is almost a guarantee for successful harvest, welfare, and prosperity.

Information integration plays a very important role in modern Computer-Integrated Manufacture [1,2,3,4,5]. It has a great influence on product cost, quality, time to market and competitive position of enterprises in general. Our interest covers particularly the integration of information flows accompanying various activities in the CAD, CAP, and CAM subsystems in the CIM system. The latter cannot be efficient if there is no efficient information integration among subsystems. Sometimes there is an integration, but it is so weak and imperfect that it is not possible to realise entirely the flow of information to subsystems they would need. In such a case information gaps are in the structure of CIM.

Several analyses of information exchange show that there are decisive gaps just between CAD and CAP. CAP is a subsystem where the CAD model of a future product is changed into the process plan. Since CAP is an mediator between CAD and CAM, not only the efficient connection CAD-CAP-CAM, but also integration of the entire system of CIM depends on a global and smooth transfer of geometrical and technological data from CAD to CAP. Different authors deal with a problem of automation in production process and automation in engineering process but the thorough integration requires more than that. We need to automate the whole process from engineering to production in order to achieve an integrated dynamic environment.

The aim of our research is a design of an integrated environment for feature recognition and an automated search for an appropriate work operation to manufacture a part. Such a tool

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would enable an automated search (recognition) of features on a given model, and a simultaneous proposition of optimal work operation to the CAP system/operator [6]. In order to reach the goal of the research we used advanced techniques such as geometric reasoning and genetic algorithms [2,7,8].

Section 2 gives a short overview of possibilities for CAD-CAP integration. In section 3 an idea of the intelligent interface is presented. Sections 4 and 5 are devoted to a detail description of components of the intelligent CAD-CAP interface. We conclude with the final discussion and synthesis of the results. The guidelines for future work are also given.

2. A short overview of CAD-CAP integration

In conventional methods a technologist is responsible to analyse drawing of the future product and prepare manually the production instruction, whereas modern methods anticipate automatic data transfer from the CAD to CAP system. Modern methods include at least two different approaches:

- feature recognition,
- feature-based modelling.

Definition of features is a difficult task. One definition out of many definitions of features says that they are parts of the body that have a special shape or production property [2]. Features can be classified in several ways. The following division is appropriate: geometrical properties of features and usable properties of features. With respect to geometrical properties the features are: external, internal, explicit, implicit, and various chamfers (Fig. 1). With respect to their use the features can be: design features which are meaningful to the design and manufacturing features which are meaningful to the manufacturing. Usually, the body consists of main shape and features (Fig. 2). Often attributes are connected to features. These can be: dimensions, dimension tolerances, surface accuracies, position tolerances, mutual interaction with other features and topological information about faces, edges and vertices.

Feature recognition is a process generally consisting of two steps:

- detection of features,
- classification of features.

Regarding how the initial solid is represented, the features can be recognised in two ways:

- by means of information about body primitives (Constructive Solid Geometry representation, CSG-rep),
- by means of information about faces, edges, and vertices (Boundary representation, B-rep).

A relatively small and simple data base is the main advantage of a CSG-rep model. In addition, a sequence of machining operations can be modelled by a CSG-rep. Its disadvantage is that an identical body can be represented by different binary trees. For feature recognition the B-rep model is more appropriate than the CSG-rep, since it is independent of sequence of operations during modelling. Its disadvantage is the extensive data base and loss of history of modelling of the component. From [1, 2, 9, 10, 11, 12, 13, 14] it is possible to see the following approaches for feature recognition: syntactic methods, state transition diagrams, decomposition methods, CSG-based methods, graph-based methods, methods of external access direction, logic methods, and feature recognition by means of neural nets.

In feature-based modelling the basic entities that describe the body are already known. Their recognition, which is usually complicated and time-consuming, is no more necessary. Although

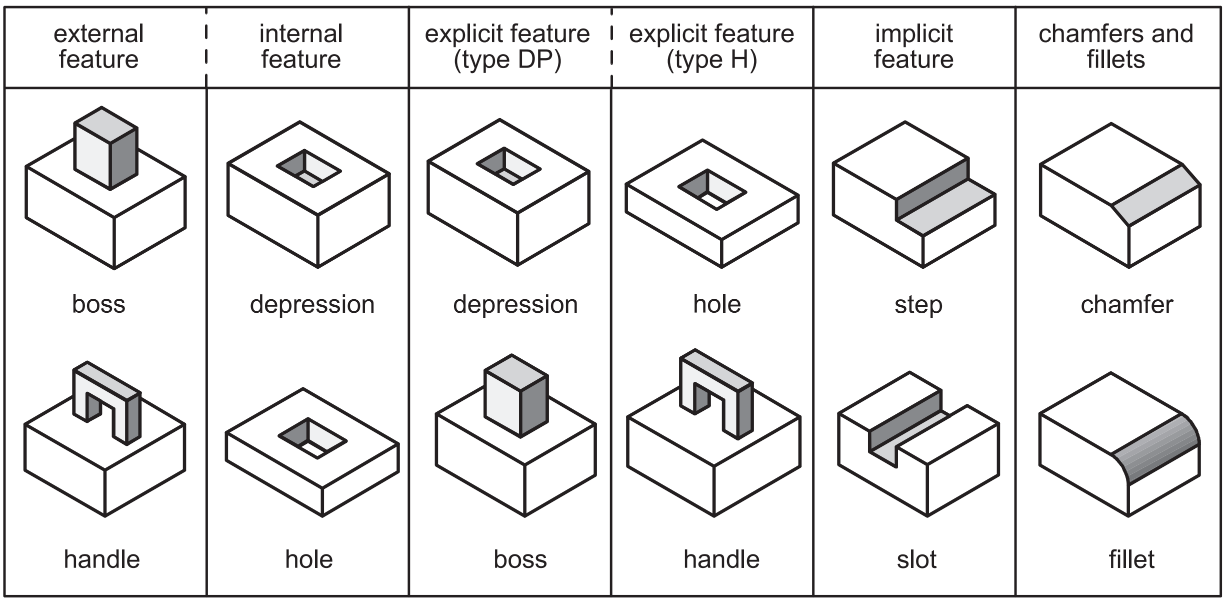

Fig. 1. Different types of features

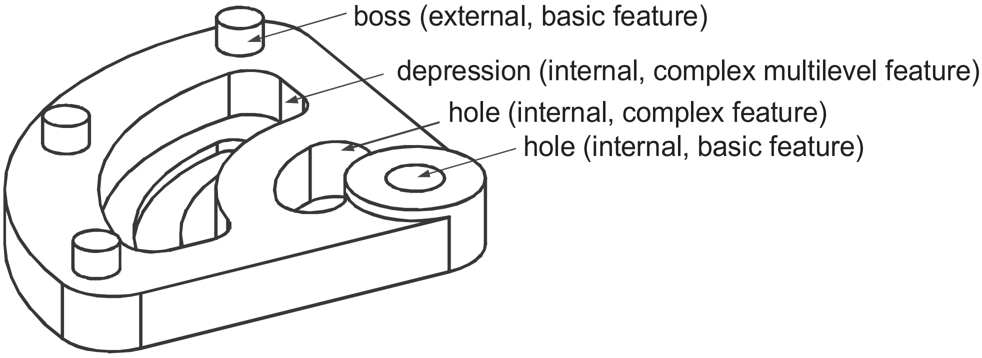

Fig. 2. Main shape of the body and features

feature-based modelling has recently become very popular, the method is not without disadvantages. The main disadvantage is that the designer is usually limited by the library of features, which narrows his concepts and freedom in modelling. In addition, almost unsolvable difficulties occur if two or more features intersect. In this case it is necessary to develop a hybrid system that includes also feature recognition. Basic information on some feature-based systems can be found in [2, 13, 15].

3. Design of the intelligent CAD-CAP interface

Although above mentioned methods for feature recognition and feature-based modelling give possibilities for more or less effective CAD-CAP integration they enable mainly geometrical data transfer from CAD to CAP. In order to achieve more intelligent system which would be able to give us a proposition, for example, which machining processes and tools are appropriate, more advanced CAD-CAP interface with technological database incorporated into decision process has to be conceived. Of course, we also need an algorithm which would be capable to select the best possible set of technological parameters among many sets of parameters available.

Our recognition-optimisation system consists of two main parts, and works in two stages. These two parts are:

1. The recogniser,
2. The seeker.

The process starts with the CAD model processing in order to analyse it's shape and all characteristic features like depressions, bosses, holes, etc. On the basis of recognised features the next part of the system takes over by evaluating the analysed shape and searching through the technological database in order to find an appropriate work operation (Fig. 3).

Main evaluation input data has been stored within the CAD model in a shape of features. In spite of the information wealth of CAD models we still need some technological data that are hidden in an external knowledge of a designer. To add these additional information to the model, we have two obvious possibilities:

- technological data could be added to the model in a form of some special signs or codes within the part file, respectively, or
- they can be added to the part file as an accompanying part definition file.

Output data of the first part, a so-called recogniser, represent the input for the next part, the seeker. It takes the evaluated geometric data from the recogniser and starts the search for the appropriate work operation through the technological database by comparing the original data from the model with the recommended data for disposable tools stored in the production system.

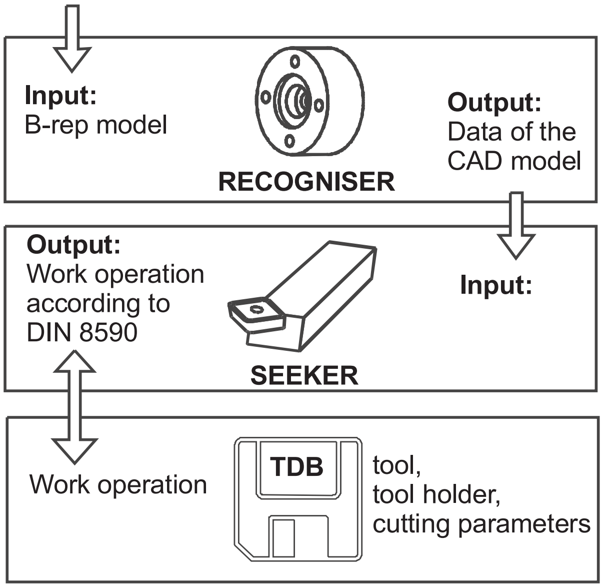

Fig. 3. The idea of the system.

4. The recogniser

In our system the initial 3D-models are represented by boundary representation (B-rep.). Since feature recognition requires symbol manipulation and reasoning, it is natural to implement it in programming languages that are suitable for such kind of processing. The builders of a majority of reasoning systems choose either LISP [e.g. 1,2] or Prolog [e.g. 1,16]. In addition, LISP is convenient for knowledge representation in expert systems [17, 18]. In our system LISP language is chosen for feature recognition. By specially developed algorithms a 3D-model of a future product is examined. Most topological, geometrical, and technological information about a 3D-model that are returned by these algorithms are LISP S-expressions.

The recogniser consists of two main parts. In the first part the features are detected, whereas in the second they are classified into internal and external ones. The detection of features is based on searching for inner loops on faces of the body, while the classification is based on analysing edge properties in the inner loops.

The recogniser is able to recognise many different types of features out of which special attention is given to the recognition and classification of explicit internal and explicit external features. Fig. 4 shows the test parts with some simple (basic) features which were recognised with the recogniser. More detail information about the special developed algorithms for recognition and classification of features can be found in [19].

For recognition of more complicated multilevel features a special algorithm is developed where 3D-model by the use of special functions is examined (Fig. 5). These functions have recursive definitions. For example, the problem of feature recognition for the Feature I can be described by means of recursive definition in LISP pseudo-code as follows:

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(defun depression (arguments)
        (cond ((predicates) boundary_conditions)
                     (depression (new_arguments)))).
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The recursion variables arguments and new_arguments give topological and geometrical information about faces, edges, and vertices of each sub-feature. predicates and boundary_conditions provide that multiplication of function depression has to stop when a face of sub-feature does not contain the next inner loop. In case of Feature I this is happened after the third copy of the function depression (i.e., at sub-feature number 3 which is located at the bottom of the hole hierarchy). If only one-step-depression is located on the part (i.e., Feature II and Feature III) the boundary_conditions terminate the further multiplication of function depression immediately after its first copy.

After the recognition and classification of features are carried out, their geometrical, topological, and technological data are sent off to the seeker. These information involve:

- type of the feature,
- complexity of the feature,
- geometrical data (diameter, depth, starting level, ending level, etc.),
- required accuracy and a state of the surface.

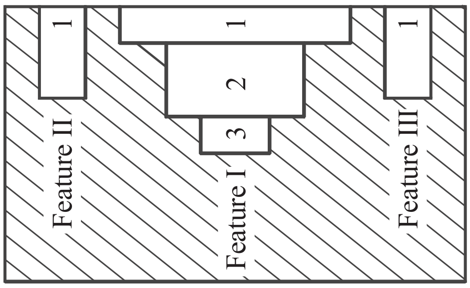

Fig. 5. Two simple features and one multilevel feature

5. The seeker

The seeker takes over the data and carries out a technological evaluation. The evaluation is realised in few steps that narrow the tool search field by defining boundary conditions based on the data gathered by the recogniser.

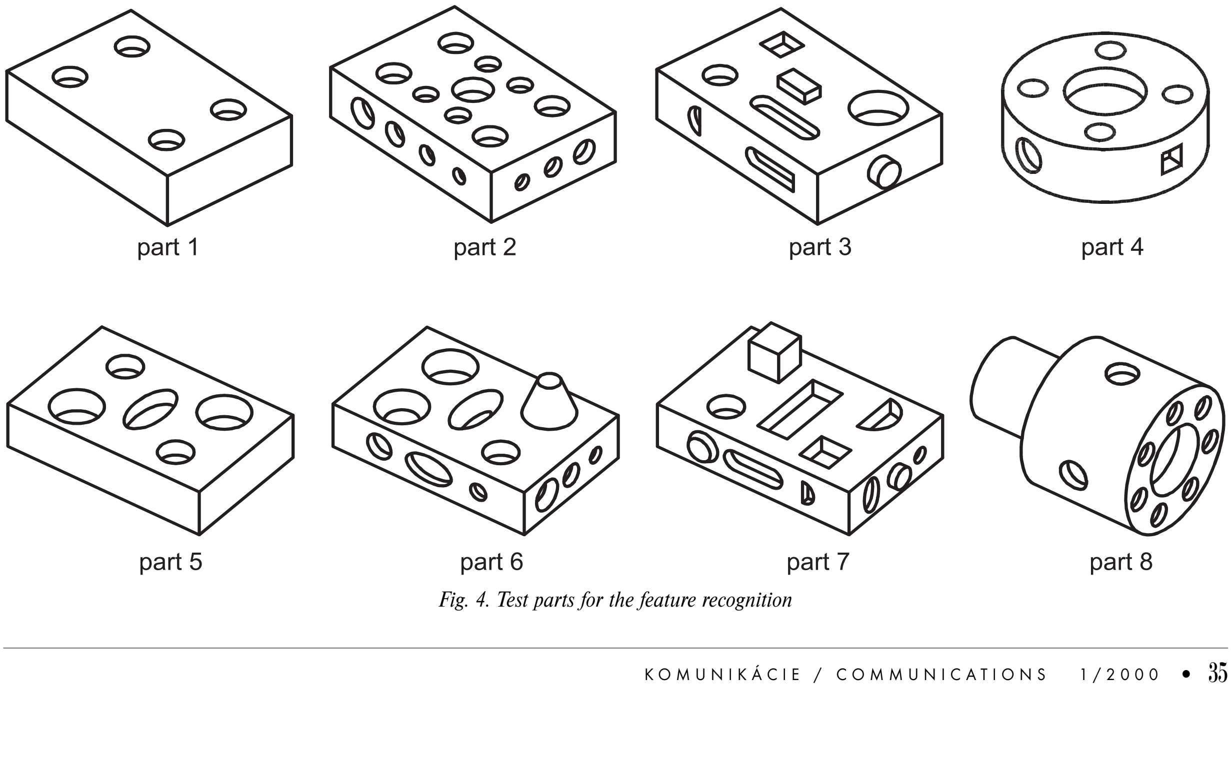

Fig. 4. Test parts for the feature recognition

The first step is a determination phase. On a base of transferred features' data a rough manufacturing procedure is determined (i.e., drilling, milling, etc.) and boundary conditions for the tool search are set (i.e., biggest allowable diameter in a case of milling), (Fig. 6). Further on the features are also checked for possible special finishing requirements. In such a case additional stock allowance condition is set.

A roughing phase is the second step of the evaluation. It checks the geometric data (diameter, depth, etc.) and sets the final geometric boundary conditions for the tool search - required cut length.

The third and the last step is a cutting phase. It prescribes the boundary conditions for the cutting parameters determination with a consideration for possible special finishing requirements. In this phase a wide cutting borders (i.e., allowable cutting depth, feedrate, and cutting speed) are set.

After the evaluation the seeker performs a genetic algorithm search for the appropriate combination of cutting parameters to reach the production demands. Sets of cutting parameters are stored in the technological database (TDB) together with the geometric data of the tool they belong to. To find the appropriate set the genetic algorithm uses known evaluation functions. These are simple functions (1), (2), and (3) that are describing dependence of costs, productivity and roughness from the cutting parameters.

$$t_1 = \frac{S_v}{v}\left(1 + \frac{T_m}{T}\right) \quad (1)$$

$$k_1 = \frac{S_v}{v}\left(K\left(1 + \frac{T_m}{T}\right) + \frac{C_N}{T\,Z_m}\right) \quad (2)$$

$$R_{max} = f\left(\sin\chi_n \cos\chi_n + \frac{r}{f}(1 - \cos\chi_n) - \right.$$

$$\left. - \sin^2\chi_n \sqrt{\frac{2r}{f\sin\chi_n} - 1}\right) \quad (3)$$

Symbols in equations mean:

- t_1 - time needed to produce one piece,
- k_1 - costs to produce one piece,
- v - cutting speed,
- f - feedrate,
- R_{max} - maximal allowed roughness,
- χ_n - tool angle,
- r - radius of the tool tip rounding,
- S_v - length of the tool path,
- T_m - tool changing time,
- T - tool wear time,
- K - operator costs,
- C_N - tool price,
- Z_m - number of cutting edges.

The geometric criteria are simple relations among the geometric factors. For example, the depth of one cut depends of the tool height, the overall machining depth, the demanded surface quality, etc. By joining these criteria together an environment for the search for the tool and work operation is gained. The beauty of the GA approach is in the simplicity of describing the influencing factors' mutual dependence [20]. Mathematically it would represent a tough task which can only be solved by involving some simplification that would lead to a lose of important information. In GA all the dependencies can be written as a set of criteria, and evaluated simultaneously. To perform a search, the GA needs a field to search in. It is hidden in the technological database where the production resource' data are stored.

The search begins with a selection of data sets that fulfil the minimum required condition of geometrical acceptance. In further search only those resources that correspond to the features of the CAD model are taken into account. The search itself is an optimisation process by which the cutting parameters of different tools or operations are evaluated, respectively. Boundaries for the optimisation environment are set on the beginning in the three evaluation phases, when the geometric properties of the feature are technologically evaluated. Further work is a pure GA optimisation

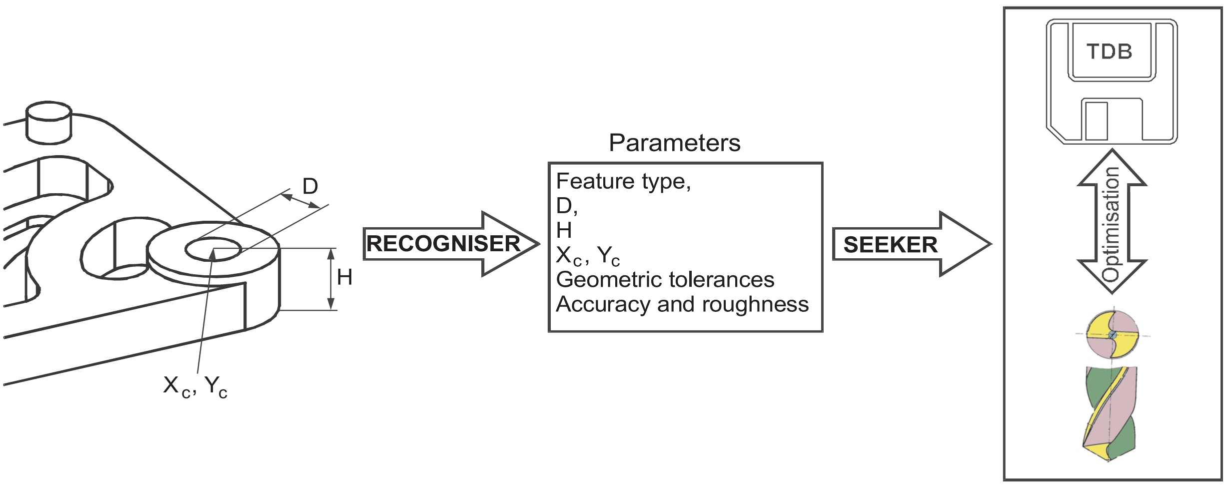

Fig. 6. Tool search procedure

performed over a field of records in the technological database as described in [21] and [22].

6. Conclusion

In market-oriented innovative production systems it is necessary to ensure as great information integration and fast adaptation to market conditions as possible. Any deficient information flow between different activities in the company, in particular between CAD and CAP, in most cases brings a lot of negative influences, which accumulate and cause that the final product is expensive and frequently of bad quality.

The difficulties have been softened by conceiving the intelligent interface between CAD and CAP. It ensures automatic information transfer about a product from CAD to CAP. The interface is based on feature recognition carried out on the solid model of a future product and genetic algorithm optimisation method. The interface intelligently examines a 3D-model of a part and determines the designer's purpose. Results from the interface are rather a preposition to the CAP engineer than an unconditional determination of a further process. As such, our interface is suitable for use in a fully automated environment as well as in conventional production circumstances. The only demand for its functionality is a reasonably high CAD level with incorporated technological database. The genetic algorithm approach used as a search method combined with the technological database becomes a very powerful and robust automation tool. It is capable of simultaneous evaluation of many different influencing factors in real time, what ensures that the results always show the state-of-the art of the production system in which it works. The test results show a great potential of our method, therefore we'll continue our work in this field to improve the interface so it can recognise more features with greater complexity and to broaden its use to other production techniques.

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