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Similarity-Based Product Search for Next Generation Process Planning

Juergen Lenz*a, Timo Dennerb, Michael Lickefett*a,b, Thomas Bauernhansla,b

*aInstitute of Industrial Manufacturing and Management (IFF), University of Stuttgart, Nobelstrasse 12, 70569 Stuttgart, Germany
bFraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstrasse 12, 70569 Stuttgart, Germany

* Corresponding author. Tel.: +49 711 970-1994, e-mail address: Juergen.Lenz@ipa.fraunhofer.de

Abstract

The main challenges for companies in today’s environment are an increased demand for customized products, shorter product life cycles and the resulting higher amount of variants. This leads to significant growth in existing production data. Additionally, improved ICT-systems and networks enable production planners to access a broader range of data, containing previous solutions and best practices and therefore the required knowledge and experience. Currently this knowledge and experience is not sufficiently used, as the process planning, work scheduling and route sheet generation is often a manual process, relying on the personal experience of the planner. This paper presents an approach to support the process planning with the help of an innovative method and corresponding digital tool. The digital tool gathers the master data records and numerical control code from previous products. It provides a library of attributes describing the products and the production processes. Through the employment of the developed method and digital tool, process planning can be sped up and standardize by eliminating or reducing manual search. Double work can be avoided. In total, the method and digital tool enable process planners to react faster and more accurately while gaining a competitive edge in dealing with the challenges on the global markets.

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1. Introduction

Nowadays, the increased demand for customized products and the shorter product life cycles result in higher amount of variants and in higher complexity in process planning [1,2]. This leads to significant growth in data and information required for the successful operation of factories. In parallel, improved ICT-systems and networks enable production planners to electronically access a broader range of data. It contains previous design solutions and best practices. Reusing this data can be one of the key factors for the future success in the increasingly competitive market, but is inhibited for instance by heterogeneous data bases originating from the different types of data. Types of data themselves can differ, due to their origin in different types of machines with different machine controls and the different programing control languages.

That’s why there is a need for the preparation of the existing information of previous products. This paper presents an approach and concept to support the process planning with the help of an innovative method and a corresponding digital tool in order to bridge this gap and provide process planners with pre-processed information.

2. Motivation

The main task of a process planner is to generate a route sheet which is economical and technically reasonable for each new part. Afterwards, the process planner stores the data of the route sheet and the technical details of each step in the production into an Engineering Data Management (EDM) system.

This task can be assisted by a Computer-Aided Production Planning (CAPP) system. The area of CAPP is promising to benefit small and medium-sized enterprise (SME) but CAPP systems are still under development [3]. That’s why the exiting data and information can’t be used sufficiently. As a consequence, the design process is heavily relying on the personal experience of the responsible planner. Due to the lack of available digital tools, the task is mainly performed
manually. This task can be performed in two different ways: Either being generated from scratch or based on a previously planned part. If the process planner is using the existing route sheet of a previously planned part, the process planner can use more existing data in case the previous part is similar to the part, which needs to be planned. The preferable option is to identify the route sheet of the most similar part in comparison to the part which needs to be planned. Facing this search problem the process planner can only rely on personal knowledge and either remember already planned similar parts or stumble across a similar part or ask a co-worker.

This leads to the need and the goal of a system which reuses existing data efficiently and creates numerous benefits:

- Reduction of planning time needed
- Eliminating work redundency
- Learning from existing solutions done by other co-workers
- Quick cost estimates based on manufacturing costs of previous parts
- Identify a part, which belongs in a part family
- Unique parts may be eliminated at the design stage reducing inventory
- Avoidance of repeated mistakes and errors
- Other variants costs such as increased administration effort

The idea to access NC-files instead of the CAD-Files has advantages such as the known orientation of the part, which results in less degrees of freedom and additional information such as tools that were used. Another advantage is the use of actual manufacturing data from the shop floor. Data from the planning phase may differ from the manufacturing data.

CAD-files are good for the design phase, but have restrictions for the usage in the manufacturing phase. CAD-files can’t represent intermediate process steps. Additionally, all information about which tools or processes, were used to manufacture the parts, are not stored in the CAD-file.

CAM (Computer-Aided-Manufacturing)-files, would contain this information, but they aren’t considered in this approach, because they are not searchable due to their proprietary data format.

Figure 1 shows the general idea with the three different calculation processes and the necessary information. The CAD-files are only for displaying purposes.

This paper explains the state of the art in 3D-file similarity search, the chosen approach, the method proposed and the implementation of the concept is introduced.

3. State of the Art

The idea of a searchable system of geometry data, is in development for over 15 years [4,5].

3.1. State of the Art in Research

There is no generally accepted definition of a degree of similarity. Similarity is always in the context of the usage domain. Similarity can be either similarity of the whole shape or partial similarity of some aspects.

There are two fundamentally different types of 3D similarity search. There is geometry-based similarity and feature-based similarity [6].

The first one is based on the interpretation of the geometry data. The geometry data can be CAD-file types, vectors (e.g. STEP or IGES), voxels or scatter-plot [7]. Then, only based on the geometry, values are calculated and similarity is detected over these values. Examples for global similarity, presents Keim [8,9], who analyses multiple concepts such as voxel based and Nearest-Neighbor(NN)-Algorithms, Heczko [7] who derives Multi-Scale-Vectors or Stark [9], who uses an approach based on segmentation. A reverse approach is the shape benchmark [10] idea. In this case algorithms are trained to find similar objects which are categorized in advance. This gives the possibility to measure the degree of similarity according to these categories. The algorithm can then be optimized to give results which fit in the categories. One of these benchmarks is the Stanford shape benchmark [11].

The other type of 3D similarity search is the function or feature-based type: The degree of similarity is based on the functions of the part not on the global appearance. This can either be on a technical level [12] or on a partial shape, or the part. These features or functions can be calculated or entered by the user and stored separately [13].

3.2. Existing digital tools

The current state of the art in industry is continuously changing and digital tools are developed rapidly. There are a lot of different commercially available products, which offer different features. The most developed products are CADSeek by iSEEK Corporation, Bingo! by Sconce and Part Browser by ShapeSpace, PARTsolutions by CADENAS GmbH and Geolus Search by Siemens AG. All of these products are either based on CAD-file search ability by analysing
geometrical data or a combination of CAD-file input and some meta-data.

3.3. Gap

The gap is the usage of NC-files, the calculation of attributes and the combination with similarity search.

None of the mentioned searchers or the mentioned products can search production data like NC-files.

4. Approach

The approach is the usage of NC-files in order to get access to production and geometric information. Afterwards, the retrieved information is being used for similarity search. The whole approach is a combination of three different subsequent calculations. The first one is the tool movement re-enactment out of the G-Code. The second is the attribute calculation based on the tool re-enactment and the third is the similarity search based on the calculated attributes.

Figure 2 shows the three different types of similarity defined in the scope of this work for this specific search task. The part shown on the left is given as input. An exact match is done by direct comparison. A similarity by shape deals with alterations like scale or insignificant differences in shape. The third type is the similarity by G-code structure. Here, the similarity is defined through similarity in the G-code commands. In Figure 2 the exemplary process is a turning process, but the definition of the three types stands for all kinds of G-code-based production processes.

The task is to find a similar part to the part which the planned production process needs to plan. This approach aims to enhance this specific search task.

5. Method

For the proposed method, the following underlying premises and required constraints apply:

- Only single parts, no assemblies can be searched
- No alternative or backup processes used for the same part
- Processes have to be G-Code-based

Figure 1 shows the information flow of the proposed method. The following are the considered data sources:
- EDM or PDM (product data management) to retrieve the CAD Files
- File Storage servers to get the NC-Code
- ERP (Enterprise Resource Planning) to get all relevant process planning data such as drawing number, raw material used and information about each process step

In addition to this data input parameter are required in order to start the process to find similar parts. This process consists of three impartial calculations. These sub-processes are:
- NC-Analysis to get the working tool movement
- Attribute Calculation to get certain attribute of the manufactured part
- Similarity Search combines the input parameter and calculated attributes with a search algorithm.

Figure 3 shows the six steps of the method. The chronological order is necessary due to the required intermediate results. Each step of the six steps of the method is explained in regard of its implementation.

6. Implementation Concept

The implementation concept shows the breakdown of the method into a realizable digital tool. The implementation is intended to be used by SMEs. The standalone application was developed with MATLAB.

6.1. Input and Search Request

The first step is the input of selected attributes and the search request.
As input, new attributes are defined or attributes are selected out of a library of predefined attributes. Alternatively, search parameters from previous search requests can be used. Each attribute is either an exact value or a range, consisting of the interval between two values. The calculation method of an attribute can be modified by the user to enhance the fit to the specific process planning task.

The search request can begin, if at least one attribute is selected in order to create the minimal search base for the successive steps.

6.2. Data Gathering

In step 2 all data relevant for the search is gathered. Due to the different data sources multiple data sources are accessed. Different sources and required file types are shown in Figure 1. The three data sources are all accessed by their individual interface.

6.3. Data Analysis

Figure 4 shows the flow chart of the parsing progress as the main part of the data analysis.

The parsing and re-enacting of the tool movement depending on the control language is written in the NC-file. The re-enacting is necessary due to consecutive dimensioning and the consecutive tool settings. For the purpose of the proof-of-concept, the standard G-code according to DIN 66025/ISO 6983 [14] was implemented.

Other analysis processes are the matching of the heterogeneous data, such as drawing number, CAD-file and NC-program numbers with the route sheet by direct matching of the identifier.

6.4. Calculation of Attribute Values

Figure 5 shows the visualization of the calculation of exemplary attributes. In the figure the attributes length (l) and various diameters (d1, d2) are shown. Also the different feeder types (G0, G1) along the path of the tool are shown. They are relevant to derive the path where the tool is engaged.

The calculation of the full lengths of the considered part is in the first approximation the difference on the Z-axis between the highest and the lowest coordinate with working feeder (G1). A secondary approximation can be calculated when the front side is finished.

Another attribute shown in Figure 5 is the final diameter (d1) of the part: For its calculation the lowest X-axis coordinate of a working feeder is taken for a segment of the Z-axis.

Similar calculation rules can be added at step 1 with the modification of the attributes. Exemplary additional attributes are:
- Specific tool used
- Specific process used
- Combination of diameters to describe the shape
- Specific subprograms (e.g. relief groove / undercut)

All in step 1 selected attributes with or without a range are calculated for each part. After these attributes are stored temporarily the similarity search is started.

6.5. Similarity Search

In this step, the attributes are prepared for the similarity search and a k-NN search algorithm as described by Knuth...
Validation

The CAD-file and the digital drawing from previous parts are shown as well, in order to help the process planner to identify a relevant match.

6.6. Display Search Results

The final step is the visualisation of the search results. A list of similar parts is presented to the process planner. The part with the best match is ranked highest. The parts are presented along with the meta-information from the EDM and ERP in order to ensure fast access to relevant data such as the route sheet. The CAD-file and the digital drawing from previous parts are shown as well, in order to help the process planner to identify a relevant match.

7. Validation

A prototype of the tool with the implemented method was developed and a German SME provided actual production data. The dataset consisted of drawings, NC-files and EPR data exported into an Excel sheet for 40 parts, which are manufactured on an INDEX turning machine. The tool worked and the calculated attributes were matched with the real values of the drawings of the parts.

8. Conclusion and Outlook

The task of a process planner, who has to find previously produced parts, was addressed with a new approach. This approach uses NC-files as additional input. Its implementation combines the NC-analysis with attribute calculation and similarity search and improves the production planning significantly.

The implementation is broken down into six steps and explained. The proof-of-concept was performed with the turning process, but the usage can be expanded to all G-Code based production processes. Further research activities include:

- Expansion to different types of processes
- Refinement of the similarity search rules
- Additional interfaces to ERP-systems

The goal to demonstrate feasibility of the method was achieved. In total, the method with the corresponding digital tool enables companies to react faster and more accurately while gaining a competitive edge in dealing with the challenges on the global markets.

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