Title:
STEP-NC Feature based Cutting Tool Recommendation System

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Introduction:

In the CNC machining process of parts, suitable cutting tool selection is crucial to machining efficiency and cost. In practice, cutting tool selection still mainly relies on the technicians' experiences by reason of the disconnection between the part design and machining at the process planning stage. The STEP-NC is the next-generation data exchange standard and aims at connecting CAD/CAM design to CNC machining [3]. Cutting tool selection should become automated and even intelligent in future integrated manufacturing [4][6][8].

There are many factors influencing cutting tool selection, including geometry constraint, process parameters, workpiece and tool materials, tool magazine, and toolpath strategies. Different cutting tool combinations bring different machining efficiency, cost, and the final parts' quality. Thus, the multivariate and multi-objective model based on feature is introduced for cutting tools selection. The data structure of the model conforms to STEP-NC and is conducive to achieve intelligent cutting tool selection. A two-step solution is used to solve the model that contains constructing effective cutting tool combinations and choosing optimal tools for high efficiency and low cost.

A STEP-NC feature based cutting tool recommendation system is constructed to validate the feasibility of the method, which is composed of feature based integrated design module and the cutting tool selection module. With UG/CATIA secondary development technology, the integrated design of geometry and process is achieved and suitable tools for each feature are selected in the selection module. In addition, the system can generate the STEP-NC file that contains the geometry, process, and recommended tool information.

Main Idea:

STEP-NC feature based integrated design module

Three kinds of information are defined in the STEP-NC which contains of geometric information, process information, and cutting tool information. Process information and cutting tool information are defined as two properties of the operation that has a one-to-many relationship with the feature. The core of the integrated design is to complete the planning of geometric and non-geometric information as much as possible in the design stage.

A human-computer interaction interface for feature modeling, process parameter inputting, and STEP-NC file generating is provided in this module. The machining features can be quickly created by inputting key parameters through the developed plug-in based on UG/CATIA. The plug-in provides an interface for adding the operation information conveniently. The process parameter is determined by material and the parameter is the input data of the tool selection module meanwhile. In fact, cutting tool selection is closely related to process parameters, such as axial depth, radial depth, feed rate, and spindle speed. A database is established that the process parameter is organized as the tool diameter when the cutting tool material and workpiece material is fixed. The data of the process information comes from the process manual. All the information is stored using the STEP-NC data structure and the read and write functions of STEP-NC file are embedded in the module. The interface of the integrated design platform is shown in Fig 1.

(a) Feature modeling (b) Process parameters inquiry

Fig. 1: The plug-in interface of integrated design.

Milling cutting tool extension model

The STEP-NC cutting tool data for milling in ISO 14649-111 mainly describe three types of static data contain tool type, tool geometry, and expected life [1]. The data structure is not enough to cover necessary dynamic information while considering the tool selection from the viewpoint of non-geometry. Hence, the extended cutting tool model is proposed based on the existing standard and factors of tool selection.

The research result [2] shows that energy consumption varies among different cutting tools. The cutting time, rapid feed time, and tool changing time heavily decide the machining efficiency. The cost can be calculated from the tool expense and energy consumption [7]. Hence, the *tool_selection_extension_data* is extended as an attribute of the *milling_cutting_tool*, which contains *machining_time*, *tool_expense*, and *cutting_force_coefficients*. The non-geometry data provide more reliable evaluation indexes for the cutting tool selection. Fig 2 displays the key entities of the extension model.

The machining expense (C_m) for the single machining feature can be refined as cutting tool expense (C_T), machine tool depreciation expense (C_M), and expense of operations (C_P) [7]. The three expenses can be calculated by machining expense rate (C_k) multiplying machining time (T_m) that the formula is expressed as: $C_m = C_T + C_M + C_P = T_m C_k = T_m(C_{tool}/T + M + C_0)$ The machining time is defined as the sum of cutting time (t_c), rapid feed time (t_r) and tool changing time (t_g). The machining energy consumption (E) is calculated as below, which contains auxiliary system energy consumption (E_0), empty load energy consumption (E_u), cutting energy consumption (E_c) and additional load energy consumption (E_a) .

$$E = E_0 + E_u + E_c + E_{a=}(P_0 + P_u) * (t_u + t_r + t_g) + (P_c + P_a) * t_c$$

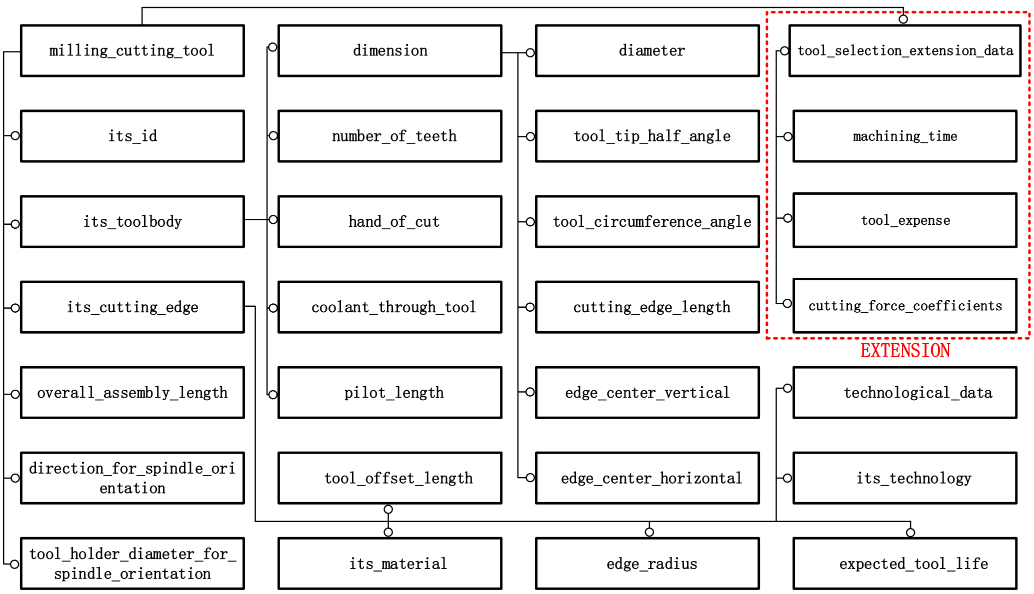


Fig. 2: Key entities of milling cutting tool extension model.

Cutting tool selection module

The STEP-NC feature based cutting tool selection module can be summarized into two parts: constructing effective cutting tool combinations and choosing the optimized cutting tool combination, as shown in Fig 3. The cutting tools which are theoretically feasible and practically owned by the factory are singled out through the feature geometry parameters. There are a lot of possible cutting tool combinations for machining the feature region. One of the achievable discriminating methods is generating a toolpath by selected cutting tools using the toolpath algorithm. The cutting tools are effective combinations if the generated toolpath sweeping region covers the whole machining region without overcutting and remaining material. Then, an optimal solution can be obtained among the effective cutting tool combinations through a multi-objective decision model in which maching expense and energy consumption are considered. The cutting tool combination with the lowest cost and energy consumption will be selected.

Three significant geometry parameters of the machining region are defined as follows to support feasible cutting toolset construction. (1) Minimum Corner Radius (MICR) is defined as the outer contour's minimum radius. (2) Channel tends to occur in machining region that contains boss so Minimum Channel Width (MICW) is defined as the minimum distance between the inner contour and the outer contour or between the inner contour and the inner contour. (3) If a circle is tangent to each edge of a contour, the circle is called the incircle of the contour. Maximum Incircle Diameter MAIR is the maximum incircle diameter among the satisfactory circles. These three parameters provide a reference for the dimension limit of the cutting tool.

The preliminary diameter range of the theoretically feasible cutting toolset is simply determined according to the contour parameters of the machining region. One important determinant of effective cutting tool combination is the area covered by the toolpath. For example, Fig 4 (c) shows the generated toolpath a by 2mm tool which accomplishes the removal of the entire machining region. The larger cutting tool with a diameter of 4mm removes most of the material and the smaller cutting tool with a diameter of 2 mm removes the remaining uncut area in Fig 4 (b). Hence, [2mm] and [2mm,4mm] can be deemed to be two effective cutting tool combinations for machining. It is important to notice that the tool combination takes machining area and toolpath strategies into consideration.

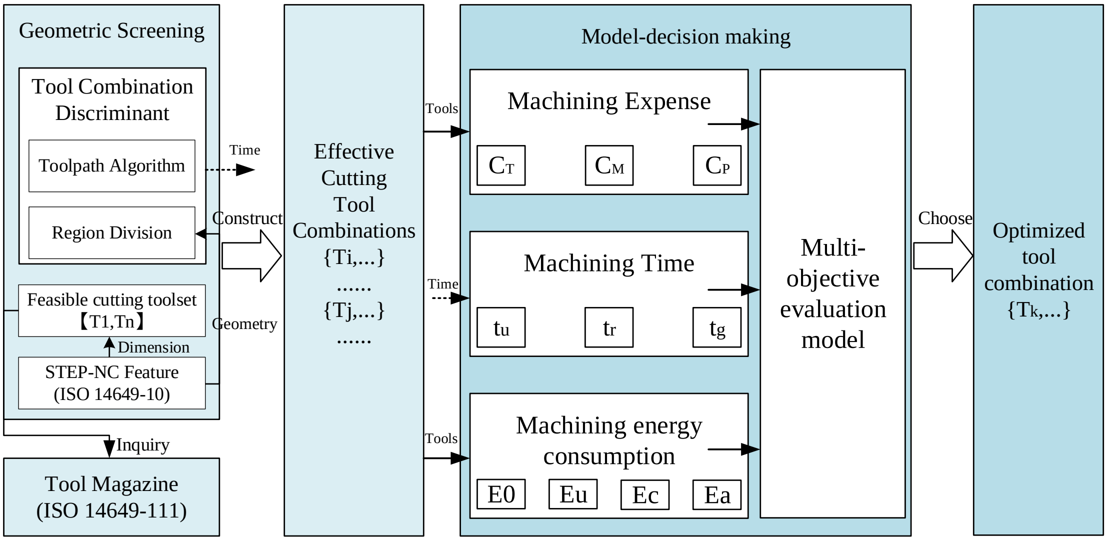
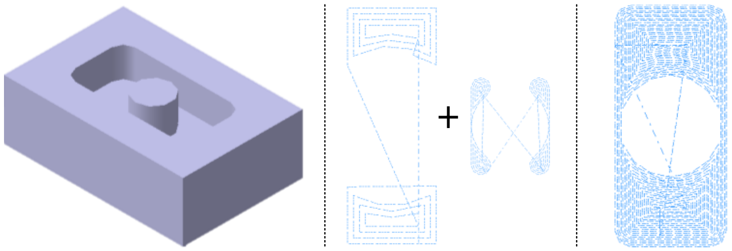


Fig. 3: The flow of cutting tool selection.

The optimal cutting tools will be selected among the effective cutting tool combinations. The decision-making model is introduced to comprehensively consider machining expense and energy consumption. The weighted summation method is used to transform the above multi-objective optimization problem into a single-objective optimization problem. No direct comparison can be made by weighted sum owing to that the unit of measure is different between machining expense and energy consumption. Dimensional normalization can be carried out first and the weight coefficient is determined by the analytic hierarchy procedure.



(a) A part with pocket (b) The toolpath of [2mm,4mm] tool combination (c) The toolpath of 2mm tool

Fig. 4: Effective cutting tool combinations.

Experiment:
A part that contains a closed pocket with two islands is used to test the cutting tool selection system. The effective cutting tool combinations {[T_4], [T_4,T_5], [T_4,T_6], [T_4,T_7] [T_4,T_8], [T_4,T_9], [T_4,T_{10}], [T_4,T_{11}], [T_4,T_{12}], [T_4,T_{13}], [T_4,T_{14}]} are inferred through geometry parameter when one-or-two tool strategy is adopted. The decision-making model between machining expense and energy consumption works out that [4,12] is the optimal tool combination, shown in Fig 5. The geometry and process parameters of the modeling are used as the input of the tool selection module, then the tool recommendation system based on the CATIA secondary development technology selects the optimal cutting tool and generates a STEP-NC file containing the whole design information at the same time as shown in Fig 6.

Conclusions:

The feature-based programming concept and object-oriented data model of STEP-NC which contains rich data in geometry and process provide a promising idea for the automatic and intelligent cutting tool selection. The milling cutting tool extension model supplements non-geometry information for cutting tool selection and the selection method is validated by the proposed prototype recommendation system. In future researches, emphasis will be paid to the improvement of the tool recommendation system. The range of effective cutting tool combinations will be enlarged and different toolpath strategies will be adapted to search for a better solution. More complex parts are also going to be tested.

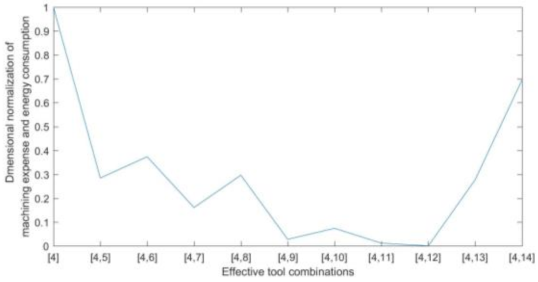
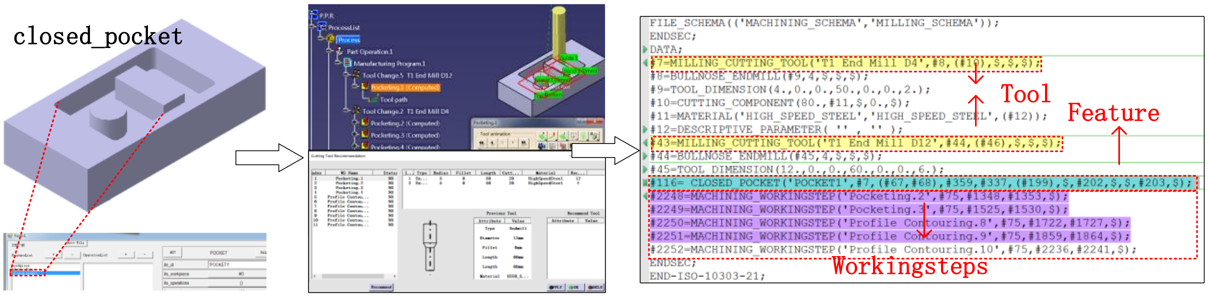


Fig. 5: Optimal result by decision-making model between expense and energy consumption.



(a)Modeling (b)Tool Recommendation (c)STEP-NC File

Fig. 6: Select tools for a closed_pocket using recommend system based on STEP-NC.

Acknowledgements:

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