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Selection and Sequencing of Machining Processes for Prismatic Parts using Process Ontology Model

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An essential part of process planning is to select the appropriate manufacturing processes and to determine their order from manufacturing knowledge. Ontology technology is considered an effective alternative for knowledge representation. Some studies have suggested a good process knowledge representation model based on heavyweight ontology, but this has inevitably resulted in limited scalability. Other studies have proposed frameworks to reason the appropriate machining processes for a feature, but have not sufficiently taken into account the manufacturing requirements. This paper thus presents an approach to select and sequence the machining processes for features using an ontology-based representation model as well as the corresponding inference rules. The ontology includes concepts including features, machining process, process capability with relevant properties, and relationships between concepts. The reasoning mechanism deduces a set of appropriate machining processes for individual features. Among these is the most appropriate final process determined by matching the accuracy requirements of a specific feature with the capability of the candidate processes. The preceding machining process is then selected so that the precedence relationship constraint between the processes is met until no further precedent processes are required. The proposed approach is neutral in that it is not subject to a specific restriction, such as a particular tool maker, and therefore can provide an interoperable and reusable platform.

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1. Introduction

Process planning bridges design and manufacturing by preparing the instructions necessary for the machining operations. The quick generation of an efficient process plan can contribute to a reduction in both manufacturing lead times and manufacturing costs. Process planning consists of activities that include interpreting the part drawing, identifying machining features, selecting manufacturing methods, tools, jigs and fixtures, and determining the sequence of operations and machining conditions as well as the standard processing time for each operation.

Process planning tasks rely heavily on the knowledge and knowhow of the process planner, and it is difficult to automate such processes since most process planning knowledge is informal or implicit and neither organized nor sharable. Despite much research and effort over the past decades, process planning remains the realm of empiricism and skill. The reason for this is that manufacturing knowledge has not yet been successfully structured and managed.

Recently, the field of ontology has opened a new opportunity to organize, share, and reuse knowledge. Ontology is considered to be capable of providing a platform to represent and share domain knowledge in an explicit and machine-readable form through conceptualization. However, a survey of the literature reveals that previous studies using ontology technology have not yet been able to successfully solve the problem. Therefore, it is necessary to develop a method that can manage complicated manufacturing knowledge. The selection and sequencing of the machining processes are the most fundamental decision-making tasks among all process planning tasks, and are therefore highly knowledge-intensive.

The objective of this study is to suggest a method to select and sequence machining processes for process planning by using a process ontology model that was developed by the authors. This paper presents a knowledge model that incorporates the feature information, the relation between machining features and machining processes, and the process capability to meet the manufacturing requirements. The decision-making logic to select and sequence the appropriate machining processes is also described.

2. Related Research

A good process knowledge model should be rich enough to express the knowledge needed to select the machining process,[1] and it is desirable for it to be compact, natural, and maintainable. A small change in the machining process capacity should require a minimum amount of change in the machining process knowledge model. Various modeling methods have been investigated to develop an efficient feature and process knowledge representation model.

Garcia[2] developed an ontology-based model to address the limitations to using automatic feature recognition when designing sheet metal parts. This model uses design rules and process rules to build a CAD ontology and a feature ontology, respectively, and then constructs a mapping ontology that connects the same features between the CAD ontology and the feature ontology. As such, it recognizes the relevant feature by inferring the number of edge, face, etc. Lemaignan[3] developed an ontology to support process design by defining process information and inferring expenses for processes. Its highest level concept consists of “entities”, “operations” and “resources” that include the geometric information, materials, and machining costs, process information, labor, loading and unloading of equipment, maintenance tools, labor resources, and factory information. Using concepts, sub-concepts and properties of the ontology model, the machining cost can be minimized. Tao[4] built a model to contribute to sharing and exchanging resources among systems by expressing all distributed process information, labor information, and information relevant to the application systems. The model including the concept and the process characteristics is converted to Unified Modeling Language (UML) and Extensible Markup Language (XML) schema. Feng[5,6] proposed a manufacturing process information model that incorporates relevant classes such as workpiece, manufacturing activity, manufacturing equipment, process sequence, and manufacturing cost and time. Despite its wide spectrum of manufacturing attributes, it cannot be considered practical because the model deals with a very preliminary stage of process planning. For instance, it does not take into account the tolerance or surface requirements. The models from Garcia, Lemaignan, Tao, and Feng have limitations in determining a process sequence through inferencing because they deal with only either feature or process information and do not express relationships between the features and processes.

Chungoora[7,8] constructed an ontology model by separating the foundation layer and the domain ontology layer. The foundation layer is a heavyweight ontology-based representation that defines the geometric information for a feature, tolerance, relationships among them, and restriction items. The domain ontology layer defines the location and the process sequence for a feature as well as the process information. Muljadi[9-11] developed a lightweight, semantic wiki-based ontology that expresses features and machining processes. The ontology defines feature, machining process for each feature, and relevant tool instances based on the size and material of a feature to be processed. By drawing on a semantic network, Khoshnevis[12] made a process knowledge model that expresses features, the machining process of relevant features, and the relationships among operating machines. Using an Object Oriented Approach (OOA), this model defines the machining process, machining feature, and machine as the highest level concepts, and slab, step, slot, hole, CNC-Mill, and drill as sub-concepts, and expresses relationships among concepts. The models proposed by Chungoora, Muljadi, and Khoshnevis make it difficult for planners to modify the process conditions of the features and to respond to changes in the process capability in accordance with the advancement of process technology. They also show the shortcomings like covering only a limited range of machining features or pre-defining the relationships between features and machining processes.

Patil[13] proposed Intelligent Feature-based Process Planning (IFPP) system, which consists of a feature-based modeler and an automatic process planner. Gao[14] also shows a framework consisting of a feature-based design system and a knowledge-based process planning system. Both Patil and Gao use a process model that is built on pre-modeled operation sequences. While in Patil the information on feature, its size and tolerance requirement extracted from the modeler is mapped to the pre-modeled alternatives of operation sequence to deduce a process plan, Gao uses a knowledge base containing the rules for process selection and manufacturing routing. The feature model of both Patil and Gao is based on their own taxonomy as well as representation method, which does not conform to the standard like ISO 10303.[15] Their works also have difficulty in managing the inference procedure for the machining process selection and in modifying the rules due to the rigidness of pre-modeling of process sequence and inference rules.

Eum[16] constructed a core process ontology to express the feature and process information. It includes the concepts and relationships of features, and process capabilities. By adding the feature instances of a part into the core process ontology the actual process ontology is created, which is used to infer the machining processes for the relevant features. This model is relatively flexible in the sense that adoption of an advanced technology can be easily done by simply adding a new instance or editing the existing instance in the ontology. The problem of Eum’s model is that the process capacity is tied to the individual tools, which might cause inference result of redundant same processes since a number of individual tools are related to an identical process.

In contrast, the ontology proposed in this research incorporates feature model and process model adopting the international standards, where their relationships are obtained through inference. The process selection and sequencing built on this ontology can be regarded as flexible thanks to non-adherence to a pre-defined rigid relationship as well as non-dependency on specific tools.

3. Process Ontology Model

As previously discussed, the selection and sequencing of the machine processes is crucial during process planning. A process plan includes details of the machining processes that are to be used in addition to their corresponding sequence for all of machined features contained in a part. The process plan for an individual feature may be referred to as a feature process plan, and it typically includes a set of machining processes for which the appropriate machine, cutting tools, and machining condition are to be specified with the corresponding order for the processes. A complete process plan requires knowledge on the features, manufacturing requirements, machining processes, and process capabilities.

The process ontology model that is suggested in this paper is presented in terms of the manner in which this knowledge is modeled and represented. The ontology defines the concepts and relations between the concepts for the specific domain knowledge, and these concepts and relations are defined through a conceptualization where the concept for the objects is formed by abstracting common characteristics of the objects in the given domain. The conceptualization of the features and machining process knowledge results in a formal ontology that consists of concepts, properties, relations between concepts, and individuals, i.e., the substance of the concepts and axioms.

A machining feature describes the volume removed by the machining processes. The STandard for the Exchange of Product data (STEP) AP224 (Application Protocol for Mechanical Product Definition for Process Planning Using Machining Feature) classifies the machining feature and defines the geometric attributes for the individual features.[15] The STEP AP224 convention is incorporated in the process ontology model. As shown in Fig. 1, the ‘Machining Feature’ class includes multi-axis machining features, such as a round hole, pocket, slot, step, and planar face.[17] Each feature is characterized by its primary removal volume shape, qualifying certain types of feasible machining processes to be used depending on their shaping capability. In addition, the bottom condition of a feature is represented in the ‘Optional Removal Volume Shape’ with the ‘Bottom Type’ and ‘Side Corner’ properties. The instances for the ‘Bottom Type’ are conical, flat, through, or spherical while instances for the ‘Side Corner’ are round, flat, or arc-shaped.

Fig. 2 shows fourteen different types of primary removal volume shapes. For example, the ‘Hole’ machining feature has a ‘Primary Removal Volume Shape’ property consisting of a ‘Negative Cylinder’ while in the case of a blind hole, the ‘Optional Removal Volume Shape’ property is a ‘Conical Bottom Shape’. Individual features have their own geometric attributes, and the characteristic attributes are typically the diameter and depth for a hole; width, length, and depth for a pocket; etc. In addition to the geometric attributes, the features may have other manufacturing specifications, such as the tolerance and surface roughness. The tolerance is divided into two types: dimensional tolerance and geometric tolerance (Fig. 1). The former describes the acceptable variation in dimension while the latter determines the permissible variation in correctness of the geometric shapes, including the straightness, circularity, flatness, perpendicularity, and so on. The surface roughness as well as the tolerance sets the requirements for manufacturing, which must be satisfied by the applied machining processes.

Fig. 3 shows an example of the feature specification for a slot represented in the process ontology model. To conform to the STEP AP224 expression, the slot has geometric attributes consisting of the first length, second length, width, two end conditions, profile angle, distance, corner radius, and bottom condition. The ‘Primary Removal Volume Shape’ property of the slot is a hexahedron with two open opposite side faces and an open top surface, and it coincides with both EndCondition attributes for ‘open’. The ‘Optional Removal Volume Shape’ property of the slot is a flat bottom. The ‘HasTolerance’ and ‘HasRoughness’ properties are also specified.

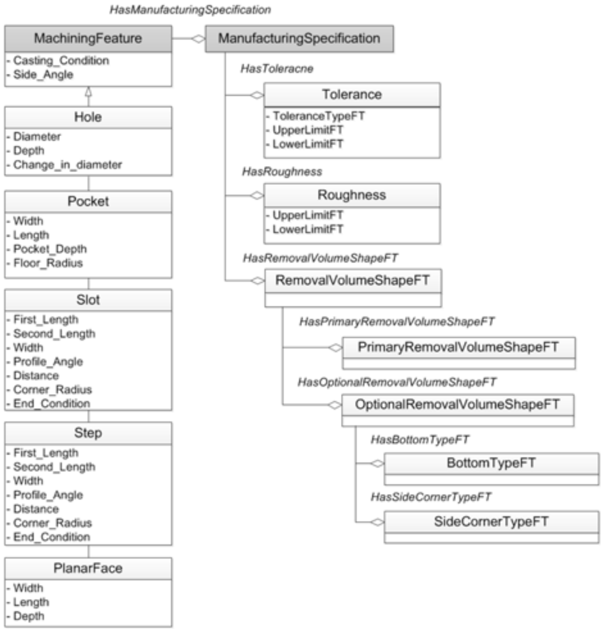


Fig. 1 Feature specification

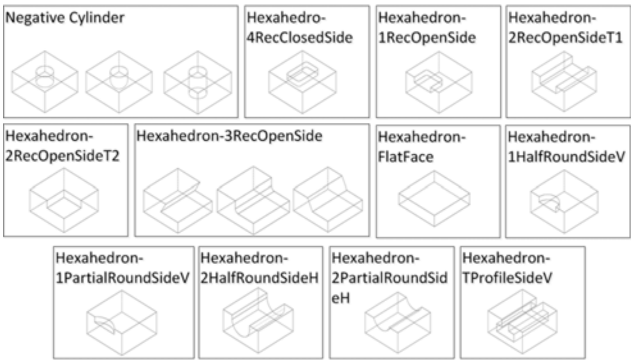
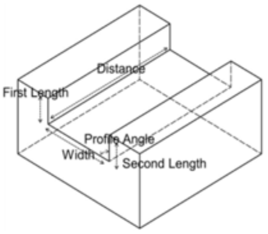


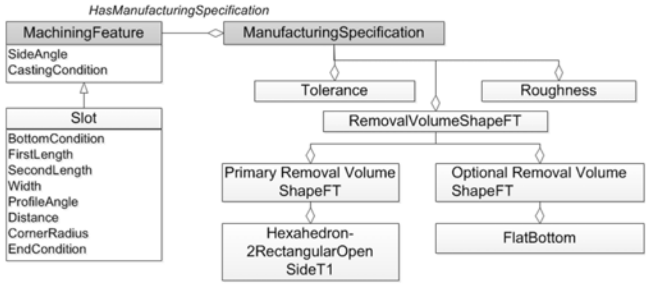
Fig. 2 Primary removal volume shape type

The machining process refers to the shaping method that removes the excess volume from the raw material by using a cutting tool.[18] The different processes, such as drilling, reaming, boring, and milling, belong to the ‘Machining Process’ class. The roughing and finishing operations are distinguished for an identical process type. As a result, the typical instances of the ‘Machining Process’ become drilling, reaming, rough boring, finish boring, rough end-milling, finish end-milling, rough ball-end-milling, finish ball-end-milling, etc. Since some processes cannot be performed before certain other processes have been carried out, the ‘PreOperation’ property is necessary to show the precedence relationship between the machining processes. Each process is capable of machining a certain type of removal volume. For example, drilling or reaming can produce a negative cylinder shape, and milling can produce various forms of flat surfaces. This is indicated with the ‘HasPrimaryRemovalVolumeShape’ relationship shown in Fig. 4.

On the other hand, each machining process has specific limits in its capability, so the achievable quality level after a given operation, in terms of dimensional accuracy and surface roughness, can be



(a) Geometric model



(b) Ontology model

Fig. 3 Geometric and ontology model of a slot

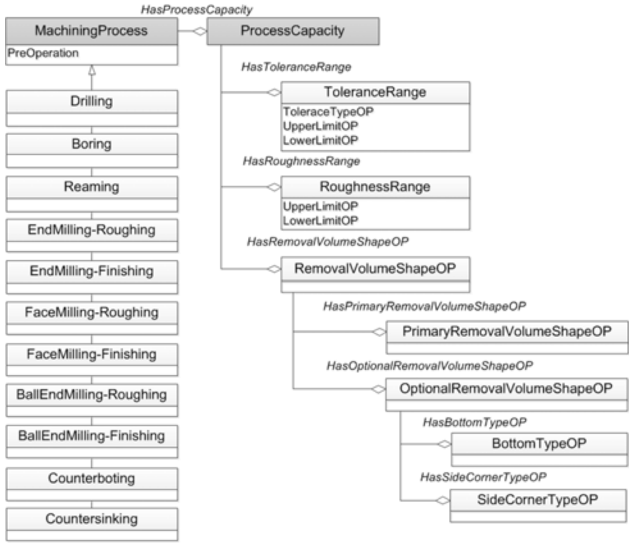


Fig. 4 Representation of the process capability

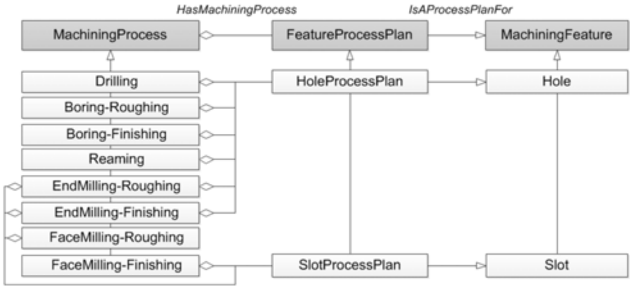


Fig. 5 Concept of the feature process plan

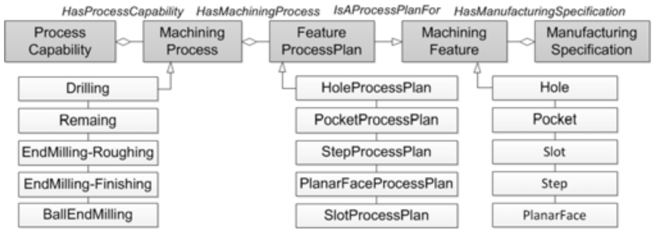


Fig. 6 Overview of the process ontology model

empirically predicted and is represented using the 'Tolerance Range' and 'Roughness Range' of the 'Process Capability' class. Both properties contain the upper- and the lower-limit values to specify the process capability. The 'Tolerance Range' has additional attributes to distinguish the type of tolerance, that is, dimensional or geometrical. The capability of the individual machining processes is based on the corresponding ISO standards (ISO 286, ISO 2768, etc.). Table 1 and Table 2 show excerpts of the tolerance and roughness range for some of the typical machining processes. While explicit values are specified for the roughness, the International Tolerance (IT) grades are given for the dimensional tolerance.

Since machining for a specific removal volume shape can be performed using specific processes and no arbitrary processes, there is a meaningful relationship between the machining features and the manufacturing processes, which is referred to as the feature process plan. Its sub-classes are the 'Hole Process Plan', 'Slot Process plan', 'Pocket Process Plan', and so on. As the number of machining features included in a part to be manufactured are registered, the same number of instances are generated in the "Feature Process Plan' class. The basis for connecting a machining feature with the machining processes is to match the removal of the volume shape. That is, only the machining processes for which the removal volume shape correspond to that of the feature are considered to be feasible. Fig. 5 shows a representation of the feature process plans for the process ontology model. The 'Hole Process Plan' represents the process plan for a hole as an instance of the 'Machining Feature'. The feasible machining processes for the hole include drilling, rough-boring, finish-boring, reaming, rough-end-milling, and finish-end-milling. This means that these processes satisfy the removal volume shape requirements in addition to the manufacturing requirements, and thus they can be regarded as candidate machining processes for the hole.

Fig. 6 depicts an overview of the process ontology model. The top-level concepts are defined as classes, i.e., 'Feature Process Plan', 'Machining Feature', 'Machining Process', 'Process Capability', and 'Manufacturing Specification'. The relevant relationships between the concepts are properties such as the 'HasMachiningProcess' between the 'Feature Process Plan' and the 'Machining Process'; 'IsProcessPlan' between the 'Feature Process Plan' and 'Machining Feature'; 'HasManufacturingSpecification' between 'Machining Feature' and 'Manufacturing Specification'; and 'HasProcessCapability' between 'Machining Process' and 'Process Capability'. The 'Machining Feature' class has sub-classes including 'Hole', 'Pocket', 'Slot', etc.; and 'Feature Process Plan' has sub-classes including 'Hole Process Plan', 'Pocket Process Plan', 'Slot Process Plan', etc., where the relationship between 'Machining Feature' and 'Feature Process Plan' is on-to-one. The 'Machining Process' class contains instances such as drilling,

Table 1 Dimensional tolerances for the machining processes

IT Grandes / Machining Processes	4	5	6	7	8	9	10	11	12	13	14
Reaming		Finishing									
Boring			Finishing				Roughing				
EndMilling/FaceMilling						Finishing		Roughing			
Drilling								Roughing			

Table 2 Surface roughness for the machining processes

Surface Roughness / Machining Processes	0.025	0.05	0.10	0.20	0.40	0.8	1.6	3.2	6.3	12.5	25
Reaming						Finishing					
Boring					Finishing	Roughing					
EndMilling/FaceMilling						Finishing	Roughing				
Drilling							Roughing				

reaming, rough-end-milling, and finish-end-milling, with the roughing and finishing operations are distinguished to result in separate processes, as explained above.

4. Selection and Sequencing of the Machining Process

The process ontology model is a generic model that can be shared between the process planners. The machining process selection begins by extracting the feature attributes from the STEP file in the AP224 format (Fig. 7). The geometric attributes as well as the manufacturing specifications are extracted, and the removal of the volume shapes for the individual machining features id determined. The extracted feature information complies with the class definition of the process ontology model and, therefore, can be easily added to the generic process ontology, resulting in an actual ontology in the Web Ontology Language (OWL) format. The actual ontology contains the process ontology with added feature attributes, and the inference rules in the Semantic Web Rule Language (SWRL) are imported from a database. RacerPro, an OWL reasoner, is loaded with the actual ontology and is then executed to find the appropriate machining processes and the feasible sequence corresponding to each of the machining features. The results of the inference are obtained through a series of queries and are stored in a proper format.

The reasoning logic is described in Fig. 8. It is first investigated to determine whether a center-drilling process is required as the starting operation. Center-drilling becomes the first process only if the feature is a round hole with geometric tolerance, such as perpendicularity or a true position. Otherwise, the center-drilling process is not necessary. Secondly, the appropriate machining processes are induced by comparing the removal volume shape properties of the ‘Manufacturing Specification’ and ‘Process Capability’. The machining processes, that is, the removal volume shape that corresponds to the feature, are counted as feasible. The primary removal volume shape and the bottom-type and side corner-type are taken into account.

Third, a suitable final machining process is found by comparing the instance values of the ‘Manufacturing Specification’ and the ‘Process Capability’. Among the candidate machining processes, those with a process capability that satisfies the tolerance and roughness range of the manufacturing requirements specified in the feature definition are determined as the final machining processes for the feature. In case no machining process satisfy both requirements, the processes satisfying the more server requirement among the tolerance and the roughness are selected as the final machining processes. Finally, processes that can be applied prior to final machining are induced. A searching is repeatedly conducted for preceding processes of a machining process until no more pre-processes are found. This procedure is performed for all instances of the machining features, resulting in a set of feature process plans that include the sequences of selected machining processes.

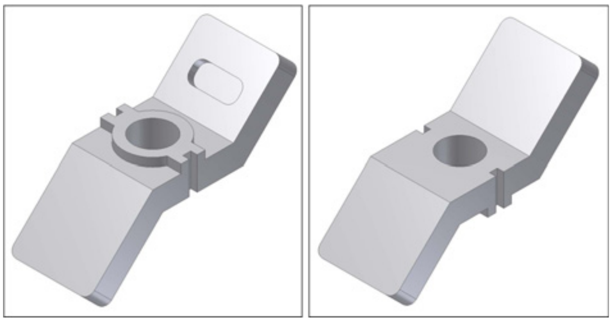


Fig. 7 Overall flow of the process selection and sequencing

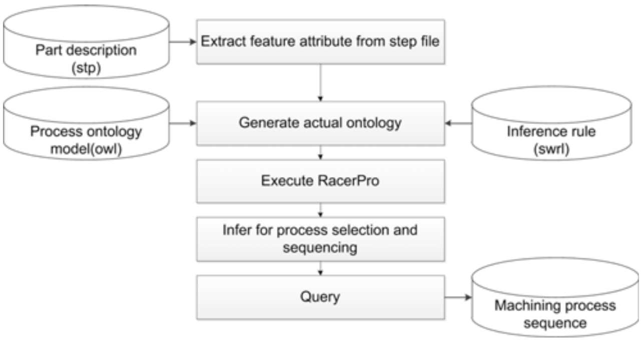


Fig. 8 Reasoning logic for process selection and sequencing

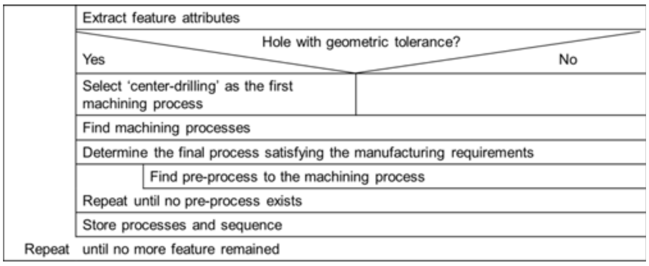


Fig. 9 Engine connector

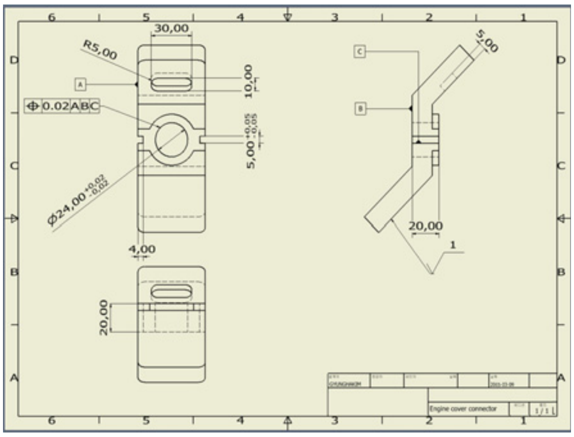


Fig. 10 Part drawing of the engine connector

5. Case Study

The proposed process ontology model and the algorithm for selecting and sequencing the machining processes are verified by applying to two example parts. The example shown in Fig. 9 is a mechanical element that connects an engine and an engine cover. The part contains a hole, a rectangular closed pocket, planar faces, and two slots. The corresponding property information, such as the primary removal volume shape and the manufacturing requirements for these features can be taken from the part drawing, as shown in Fig. 10. The hole has a through bottom, and its geometric and accuracy information are as follows: diameter of 24.0 mm, dimensional tolerance of 0.02 mm, and position tolerance of 0.02 mm. The rectangular closed pocket has a flat blind bottom and round ends of the profile, and no specification is given for the accuracy. In the case of two identical slots, the profile width is 5.0 mm, the profile length is 4.0 mm and the distance is 20.0 mm. Both ends of each slot are open.

The dimensional tolerance of the slot width is specified as 0.02 mm. The planar face has a depth of 3.0 mm, and the surface roughness is given as 1.0 μm. The slot is represented as an instance in the ontology model, as shown in Fig. 11. First, the machining processes that are suitable for the removal volume shape, i.e., a hexahedron with two rectangular open faces at both ends, are selected, resulting in rough-end-milling, finish-end-milling, rough-face-milling, and finish-face-milling. When the dimensions are taken into account, the face-milling processes prove to be inadequate. To select the final processes for the feature in the part, the values of the dimensional tolerance and roughness are taken into account. In the case of the slot, the dimensional tolerance is 0.05 mm, which corresponds to an IT grade of 10. Finish-end-milling is the only process that meets the accuracy requirements from the process capability point of view. Fig. 12 shows the property values for this slot instance in the actual ontology for reasoning. After the final process has been determined, the process that should be prior to the final is selected through the pertinent inference rules, and rough-end-milling is given as the outcome. Then, a feasible preceding process for rough-end-milling is searched in vain. Hence, end milling-roughing is determined to be the process for the relevant feature. As a result, the process sequence for the slot of the part in Fig. 10 is determined to consist of rough-end-milling and finish-end-milling. The reasoning process is applied to all features in the example part, the result of which is summarized in Table 3. The hole requires center-drilling because the geometric tolerance of the 'true position' is specified. The subsequent processes for the hole are drilled, rough-boring, rough-end-milling, reaming, and finish-boring. The process for the rectangular pocket is only rough-end-milling. For the planar face, the process sequence can

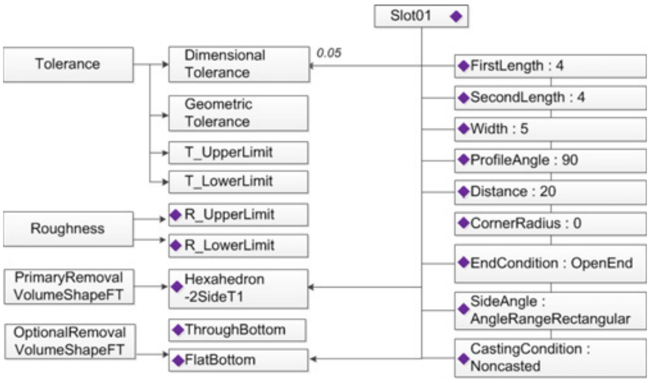


Fig. 11 Representation of the slot in the example part

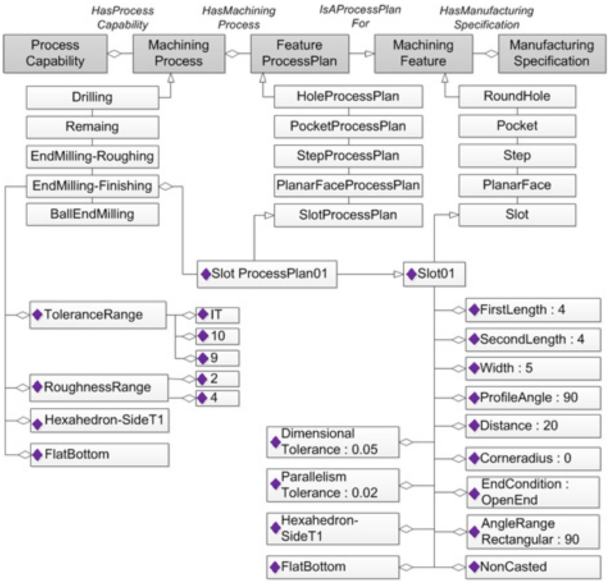


Fig. 12 Properties of the slot represented in the actual ontology after reasoning

Table 3 Inference result for the engine cover connector

Feature	Option	Process1	Process2	Process3	Process4
Round Hole 01	Option 1	Center Drilling	Drilling	Boring-F	
	Option 2	Center Drilling	Drilling	Boring-R	Boring-F
	Option 3	Center Drilling	Drilling	Reaming	
	Option 4	Center Drilling	Drilling	End Milling-R	Reaming
Slot 01	Option 1	End Milling-R	End Milling-F		
Slot 02	Option 1	End Milling-R	End Milling-F		
Rectangular Closed Pocket 01	Option 1	End Milling-R			
Planar Face 01	Option 1	End Milling-R	End Milling-F		
	Option 2	Face Milling-R	Face Milling-F		

consist of rough-face-milling followed by finish-face-milling, or finish-end-milling after rough-end-milling. Although this example is rather simple, the proposed approach proves the correctness and the practicality of this method for use with more complex parts.

The example in Fig. 13 is a hydraulic cylinder part. The part contains four round holes, four counterbore holes, a pocket, two steps, and a chamfer. Relevant property information related with the example part is taken from the part drawing shown in Fig. 14. Following the same procedure as in the first example above, the reasoning result for all the features contained in the example hydraulic cylinder part is given in Table 4. The result shows the feasible alternatives of process sequence that meets the manufacturing requirements given in the drawing.

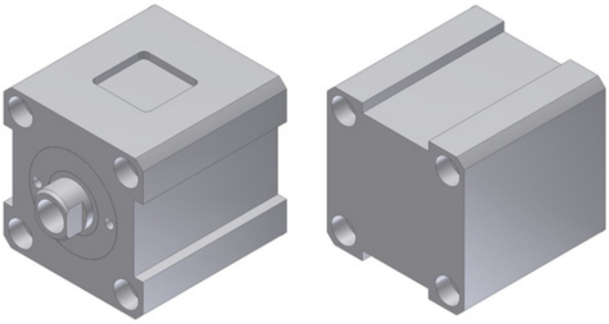


Fig. 13 Hydraulic cylinder part

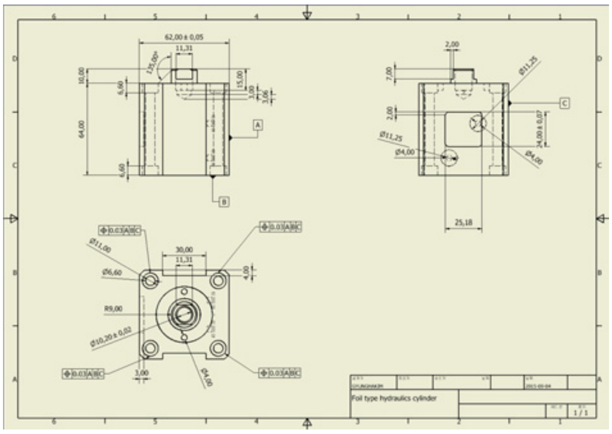


Fig. 14 Part drawing of the hydraulic cylinder part

Table 4 Inference result for the hydraulic cylinder part

Feature	Option	Process1	Process2	Process3
Round Hole 01	Option 1	Drilling	Boring-F	
	Option 2	Drilling	Boring-R	Boring-F
	Option 3	Drilling	Reaming	
	Option 4	Drilling	EndMilling-R	Reaming
Round Hole 02	Option 1	Drilling	Boring-R	
	Option 2	Drilling	EndMilling-R	
Round Hole 03	Option 1	Drilling	Boring-R	
	Option 2	Drilling	EndMilling-R	
Round Hole 04	Option 1	Drilling	Boring-R	
	Option 2	Drilling	EndMilling-R	
Counterbore Hole 05-08	Option 1	Centerdrilling	Counterboring	
Rectangular Closed Pocket 01	Option 1	EndMilling-R		
Step	Option 1	EndMilling-R		
Chamfer	Option 1	Chamfering		

6. Conclusion and Discussion

This paper addresses three issues that are necessary to select and sequence the machining processes for a prismatic part, i.e., description of the machining features, modeling of the manufacturing knowledge, and inference rules to reason the appropriate machining processes. Feature description and process knowledge representation are incorporated in the generic process ontology model. The ontology model adopts the international standards, namely ISO 10303 for feature modeling, ISO 286 and ISO 2768 for process capability modeling, and Web Ontology Language (OWL) for ontology representation, respectively. This significantly enhances the reusability and interoperability of the ontology. In contrast to other researches, the authors' approach is neither based on a pre-defined rigid relationship between the feature and the process nor dependent on specific tools, which assures the flexibility to changes in process capacities as well as application-specific requirements.

The authors are confident that the proposed approach provides a generic, reusable, and sharable platform for automated process planning since the case study shows the capability of the system to deliver meaningful and practical results for the process sequencing. Despite these promising prospects, the process ontology is not yet complete. Therefore, more effort is needed to make the process ontology model be more comprehensive in terms of the feature types, machining process types, and standards for machinability.

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REFERENCES

1. Poole, D. L. and Mackworth, A. K., “Artificial Intelligence: Foundations of Computational Agents,” Cambridge University Press, pp. 491-548, 2010.
2. García, L. E. R., Garcia, A., and Bateman, J., “An Ontology-based Feature Recognition and Design Rule Checker for Engineering,” Proc. of 10th International Semantic Web Conference, pp. 48-58, 2011.
3. Lemaignan, S., Siadat, A., Dantan, J.-Y., and Semenenko, A., “Mason: A Proposal for an Ontology of Manufacturing Domain,” Proc. of IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications, pp. 195-200, 2006.
4. Tao, F., Hu, Y., Ding, Y., Sheng, B., Song, C., and Zhou, Z., “Modelling of Manufacturing Resource in Manufacturing Grid based on XML,” Proc. of IEEE International Conference on Industrial Informatics, pp. 1261-1266, 2006.
5. Feng, S. C. and Song, E. Y., “A Manufacturing Process Information Model for Design and Process Planning Integration,” Journal of Manufacturing Systems, Vol. 22, No. 1, pp. 1-15, 2003.
6. Feng, S. C. and Song, E. Y., “Information Modeling of Conceptual Process Planning Integrated with Conceptual Design,” Proc. of the 5th ASME Design Engineering Technical Conferences, DETC00/ DFM, 2000.
7. Chungoora, N. and Young, R. I. M., “The Configuration of Design and Manufacture Knowledge Models from a Heavyweight Ontological Foundation,” International Journal of Production Research, Vol. 49, No. 15, pp. 4701-4725, 2011.
8. Chungoora, N. and Young, R. I. M., “Semantic Interoperability Requirements for Manufacturing Knowledge Sharing,” Enterprise Interoperability iii, pp. 411-422, 2008.
9. Muljadi, H., Takeda, H., and Ando, K., “A Feature Library as a Process Planners’ Knowledge Management System,” IJCSNS International Journal of Computer Science and Network Security, Vol. 7, No. 5, pp. 127-135, 2007.
10. Muljadi, H., Takeda, H., and Ando, K., “Development of a Wiki-Based Feature Library for s Process Planning System,” International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, Vol. 1, No. 9, pp. 468-473, 2007.
11. Muljadi, H., Ando, K., Takeda, H., and Kanamaru, M., “Considering Designer’s Intention for the Development of Feature Library of a Process Planning System,” Knowledge Sharing in the Integrated Enterprise, pp. 381-388, 2005.
12. Khoshnevis, B., Sormaz, D. N., and Park, J. Y., “An Integrated Process Planning System using Feature Reasoning and Space Search-based Optimization,” IIE transactions, Vol. 31, No. 7, pp. 597-616, 1999.
13. Patil, L. and Pande, S. S., “An Intelligent Feature-based Process Planning System for Prismatic Parts,” International Journal of Production Research, Vol. 40, No. 17, pp. 4431-4447, 2002.
14. Gao, J. X. and Huang, X. X., “Product and Manufacturing Capability Modelling in an Integrated CAD/Process Planning Environment,” The International Journal of Advanced Manufacturing Technology, Vol. 11, No. 1, pp. 43-51, 1996.
15. ISO 10303-224, “Industrial Automation Systems and Integration - Product Data Representation and Exchange - Part 224: Application Protocol: Mechanical Product Definition for Process Planning using Machining Features,” 2006.
16. Eum, K., Kang, M., Kim, G., Park, M. W., and Kim, J. K., “Ontology-based Modeling of Process Selection Knowledge for Machining Feature,” Int. J. Precis. Eng. Manuf., Vol. 14, No. 10, pp. 1719-1726, 2013.
17. Kang, M., Kim, G., Eum, K., Park, M. W., and Kim, J. K., “A Classification of Multi-Axis Features based on Manufacturing Process,” Int. J. Precis. Eng. Manuf., Vol. 15, No. 6, pp. 1255-1263, 2014.
18. Kim, J. K., Ahn, W., and Park, M. W., “An Implementation of Webbased Machining Operation Planning,” Proc. of DAAAM International Symposium on Intelligent Manufacturing and Automation, Vol. 100, pp. 1062-1067, 2015.