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Ontology-Based Automatic Generation Method for Dimensional Parameters of External Cylindrical Surface Processes of Shaft Parts: Postprint

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Abstract

To address the problems of low efficiency and uncertainty in manual selection of external cylindrical machining process dimension parameters for shaft parts, as well as the difficulty in sharing and transferring relevant process knowledge among heterogeneous CAPP systems, an ontology-based automatic generation method for external cylindrical machining process dimension parameters of shaft parts is proposed. According to the process knowledge involved in the generation of external cylindrical machining process dimension parameters for shaft parts, including design feature analysis, machining scheme reasoning, and process dimension parameter selection, a knowledge representation model composed of the part structure layer, design feature layer, feature mapping layer, and machining feature layer is constructed. The Web Ontology Language (OWL) is used to ontologically represent the knowledge model, constructing a meta-ontology model for external cylindrical machining process dimension parameter generation. The Semantic Web Rule Language (SWRL) is adopted to construct reasoning rules related to the generation process of external cylindrical machining process dimension parameters, an automatic generation algorithm for external cylindrical machining process dimension parameters is designed, the automatic generation is implemented using the Jess reasoning engine, and the feasibility of the method is verified through examples.

Full Text

Automatic Generation Method for Cylindrical Process Dimension Parameters of Shaft Parts Based on Ontology

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Abstract:
Aiming at the inefficiency and uncertainty of manual selection of cylindrical process dimension parameters for shaft parts, and the difficulty of sharing and transmitting related process knowledge between heterogeneous systems, this paper proposes an automatic generation method for cylindrical process dimension parameters of shaft parts based on ontology. A knowledge representation model consisting of part structure layer, design feature layer, feature mapping layer, and machining feature layer is constructed for the generation process of cylindrical process dimension parameters. The Web Ontology Language (OWL) is used to represent the knowledge model ontologically, establishing a meta-ontology model for cylindrical process dimension parameter generation. The Semantic Web Rule Language (SWRL) is employed to construct inference rules related to the generation process, including machining scheme reasoning and process dimension parameter selection. An automatic generation algorithm for cylindrical process dimension parameters is designed, and a reasoning engine is used to achieve automatic generation of these parameters. The feasibility of the method is verified through a practical example.

Keywords: ontology; shaft parts; cylindrical process dimension parameters; OWL; SWRL; process planning

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1. Introduction

Process planning serves as a critical bridge between product design and manufacturing, directly influencing production efficiency and final product quality in the mechanical industry. In traditional process planning, the generation of cylindrical process dimension parameters for shaft parts primarily relies on manual consultation of handbooks or empirical determination by designers. Differences in designers' understanding of process planning lead to uncertainty in design results, affecting consistency and limiting the automation level of process planning for shaft parts.

Computer-Aided Process Planning (CAPP) systems are key technologies for achieving product process design automation, connecting Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM). Previous research has addressed partial automation challenges: Zhang et al. proposed a 3D process model automatic generation method based on volume decomposition to solve the inefficiency of manual 3D process model construction; Cai et al. achieved automatic decision-making of process priority numbers and machining route sequencing for shaft parts using forward reasoning strategies and process rule reasoning engines; Ren et al. applied computer development tools to automatically generate process diagrams based on shaft part machining information codes;

Wan et al. solved process dimension calculation using dynamic vector methods, solution tracking, and Gaussian elimination. However, these studies have not adequately addressed the automatic generation of cylindrical process dimension parameters, and their independent systems limit the sharing and transmission of related process knowledge.

Ontology, as an explicit formal specification of a shared conceptual model, is an important means to promote semantic interoperability between heterogeneous systems and enhance knowledge sharing and reuse. This paper introduces ontology technology into the research of automatic generation methods for cylindrical process dimension parameters of shaft parts. Based on the generation process of these parameters, a knowledge representation model is constructed and transformed into an ontology model using OWL. SWRL is used to build inference rules, and a reasoning engine implements automatic parameter generation.

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2. Construction of Knowledge Representation Model

Cylindrical process dimension parameters include process dimensions and tolerances, machining allowances, and total machining allowances. Their generation involves design feature analysis, machining scheme reasoning, and process dimension parameter selection. To fully represent the complex relationships among multiple objects in the parameter generation process and describe relevant semantic information, a representation model consisting of four layers is established: part structure layer, design feature layer, feature mapping layer, and machining feature layer.

2.1 Part Structure Layer The part structure layer is the first layer of the representation model. Its primary function is to decompose the part model into several cylindrical shaft segments, providing the foundation for constructing the knowledge representation model of cylindrical process dimension parameter generation.

2.2 Design Feature Layer The design feature layer extracts relevant design features of the part and its cylindrical shaft segments from the part model, describing the affiliation relationships between the part/its shaft segments and design features.

Part-related design features include: - Blank type (BT): Bar, Forging, Casting - Nominal part total length (NTL) - Maximum blank diameter (MBD) - Part material (Ma): Steel, Non-ferrous metal - Heat treatment (HT): Preparatory heat treatment, Stress relief heat treatment, Final heat treatment, Surface heat treatment - Cylindrical shaft segment count (CPSN)

The set of part design features is defined as:
PD = {BT, NTL, Ma, HT, MBD, CPSN}

Cylindrical shaft segment-related design features include: - Blank diameter (BD) - Nominal cylindrical diameter (NCD) - Cylindrical surface roughness (CRa) - Dimensional tolerance grade (DTG) - Geometric tolerance constraint (GTC) - Geometric tolerance grade (GTG)

Geometric tolerance constraints are categorized as form tolerance (FormT), orientation tolerance (OrieT), location tolerance (LocaT), and runout tolerance (RunT), with further subdivisions (e.g., runout tolerance includes CircularRun-out and TotalRun-out).

The set of shaft segment design features is defined as:
SD = {BD, NCD, CRa, DTG, GTC, GTG}

2.3 Feature Mapping Layer The feature mapping layer stores and describes the mapping relationships between features in the design feature layer and machining feature layer. Given a part Si with n cylindrical shaft segments, the mapping relationship matrix DM_{7$×$15} represents the relationships between design features and machining features, where matrix elements indicate the presence or absence of mapping relationships.

2.4 Machining Feature Layer The machining feature layer describes the affiliation relationships between cylindrical shaft segments and their machining features. Machining features include: - Cylindrical machining method (CMM): Rough turning, Semi-finish turning, Grinding, Lapping, etc. - Cylindrical machining scheme (CMP) - Total machining allowance (CPD) - Process dimension tolerance (CPA) - Process dimension deviation (PDD) - Machining tolerance grade (PDTG) - Total machining allowance value (TMA)

The set of machining feature elements is defined as:
SM = {CMM, CMP, CPD, CPA, TMA, PDTG, PDD}

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3. Construction of Ontology Model

The prerequisite for automatic generation of cylindrical process dimension parameters is the information processing and representation of the generation process knowledge. Traditional models cannot adequately describe the complex relationships among multiple objects in the feature mapping layer or transmit complete semantics. Leveraging ontology' s advantages in semantic representation, sharing, and reasoning, this paper introduces ontology technology into this domain.

OWL is used as the ontology language due to its flexible transformation capabilities in modeling. The widely adopted seven-step method is employed for ontology construction.

3.1 Acquiring Domain Knowledge Domain knowledge includes terminology definitions and inter-concept relationships in the cylindrical process dimension parameter generation process for shaft parts, based on standards such as GB/T 4863–2008.

3.2 Defining Classes and Hierarchical Relationships Based on the acquired domain knowledge, unary relationships in the representation model are defined as classes with hierarchical relationships. Main classes include ShaftPart (SP), CylindricalPartSegment (CPS), MachiningFeature (MF), and DesignFeature (DF), with subclasses for specific features like BT, BD, MBD, NTL, Ma, NCD, CRa, HT, CPSN, DTG, GTG, GTC, PDTG, CPA, PDD, CPD, TMA, CMM, and CMP.

3.3 Defining Properties Properties represent relationships between classes and classes, and between classes and data. Two types are defined: - **Object Properties**: Represent binary relationships between classes (e.g., hasCPS for part-segment affiliation, isCPSof for inverse relationship, hasDF for design features, hasMF for machining features) - **Data Properties**: Represent numerical attributes of classes (e.g., hasBDValue, hasNTLValue, hasNCDValue, hasCRaValue, hasDTGValue, hasGTGValue, hasCPAValue, hasPDDValue, hasCPDValue, hasTMAValue, hasCPSNValue)

3.4 Defining Property Restrictions Domain and range restrictions are defined for each property, as specified in Tables 1 and 2 (object properties and data properties respectively).

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4. Inference Rules for Process Dimension Parameter Generation

While OWL provides ontology representation, it lacks the ability to express general-form rules and cannot fully represent the complex constraint knowledge in the feature mapping layer. SWRL (Semantic Web Rule Language) is used to construct inference rules due to its strong logical expression and intelligent reasoning capabilities.

Example SWRL rules include:

Rule 1-1 (Machining Scheme Generation):
If a cylindrical shaft segment belongs to a steel shaft part requiring preparatory heat treatment, with dimensional tolerance grade 6-7, surface roughness 0.16-1.25 m, and circular runout tolerance grade 3-6, then the machining scheme is CMP8 with methods: RoughTurning → Semi-finishingTurning → RoughGrinding → FinishingGrinding.

Rule 2-1 (Process Allowance Selection):
If part nominal total length is 200-400 mm, requires final heat treatment, and

finishing grinding allowance is 50-80 m, then the finishing grinding process dimension tolerance is 0.15 mm.

Rule 3-1 (Blank Diameter Inheritance):
If the blank type is bar stock, then the shaft segment blank diameter equals the part maximum blank diameter.

Rule 4 (Rough Turning Process Dimension):
Process dimension = Blank diameter - Rough turning allowance.

Rule 5 (Total Machining Allowance):
Total machining allowance = Blank diameter - Final machining dimension.

Rule 6-1 (Tolerance Grade Assignment):
If finishing grinding is used, assign corresponding tolerance grade values.

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5. Automatic Generation Algorithm

The automatic generation process involves: 1. Building individual assertions and transforming structured/constrained knowledge into a format recognizable by the reasoning engine 2. Establishing assertion formula sets A_1 (part-segment relationships) and A_2 (segment-design feature relationships) 3. Using the reasoning engine to infer machining schemes for each segment based on A_1 and A_2 4. Building assertion formula set A_3 (segment-machining scheme relationships) 5. Transforming knowledge into JessTab format to construct fact bases and rule bases 6. Reasoning to generate process dimension parameters

The algorithm flowchart is shown in [FIGURE:N].

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6. Case Study and Verification

To verify feasibility, a reducer output shaft is used as an example. Key design features include: - Blank type: Bar stock - Material: 45 steel - Heat treatment: Tempering (28-32 HRC) - Seven cylindrical shaft segments (cps11-cps17)

Step 1: Build assertion formula set A_1 for part-segment relationships.
Step 2: Extract design features and build assertion formula set A_2.
Step 3: For each segment (e.g., cps11), build assertion formula sets for segment-design feature relationships (e.g., SD11).
Step 4: Build assertion formula sets for segment-machining scheme relationships (e.g., MP11).
Step 5: Use the reasoning engine to generate machining schemes and process dimension parameters.

The automatic generation results for process dimensions and tolerances are: - cps11, cps12, cps17: 55 (+0.130/+0.010) - cps13, cps16: 60 (+0.019/+0.002) - cps14: 65 (+0.030/+0.011) - cps15: 70 (+0.021/+0.002)

7. Conclusion

This paper proposes an automatic generation method for cylindrical process dimension parameters of shaft parts based on ontology. By constructing a knowledge representation model and transforming it into an ontology model using OWL, the method employs SWRL rules and a reasoning engine to achieve automatic parameter generation. The case study demonstrates feasibility. This approach reduces human intervention, ensures consistency, and facilitates knowledge sharing and transmission between heterogeneous systems. Future work will focus on developing a plugin for automatic generation of cylindrical process dimension parameters based on this foundation.

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