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Knowledge Modeling of Fault Diagnosis for Rotating Machinery Based on Ontology

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Abstract. For those shortcomings of the current methods of fault diagnosis knowledge representation, it is necessary to use an efficient knowledge model to improve the accuracy of fault diagnosis and realize the reusing and sharing of machinery fault knowledge. In this paper, an ontology-based fault diagnosis model is established. Focusing on fault diagnosis of rotating machinery, the domain-ontology knowledge base and structure definition of the fault diagnosis are demonstrated in detail. The protégé is used to construct the model of ontology-based fault diagnosis. Further more, on that basis, rules are added and Jena is used to realize the knowledge reasoning. The result indicate that the model of fault diagnosis based on ontology is intuitive and efficiency.

Keywords: ontology; fault diagnosis; rotating machinery; knowledge; model

1. Introduction

Rotating machinery is one of the most common classes of mechanical equipment and plays an important role in industrial applications. With rapid development of science and technology, rotating machinery equipment in modern industry is growing lager, more precise and more automatic [1]. Therefore there is lot’s of methods of knowledge representation for rotating machinery fault diagnosis. For example: by using the object-oriented method and expert system in order to improve the fault diagnosis ability [2][3]; building Petri network model to describe fault diagnosis knowledge for solving the universal representation problem of the fault diagnosis knowledge[4]. The transportation information inquiry system based on rule and case reasoning fills up the knowledge gap between the non-expert users and the GIS experts, and provide the more convenient inquiry way for the users[5].However the traditional knowledge representation based on expert system has heavy architecture and requires large scale data and space resource. It provides strong pertinence yet the expansibility is comparatively weak. Petri network is weak in fault diagnosis knowledge mining, it is still insufficient in the semantic support, the validity and completeness of the knowledge base and it can't achieve the knowledge sharing and reuse.

It is significant to deeply explore fault knowledge and formulate a universal fault diagnosis representation model. Introducing Ontology into intelligent fault diagnosis system is a new study topic. An ontology-based knowledge representation has several attractive features and holds the fact that it focuses on the classification and constraints of allowable taxonomies and definitions. It combines the advantages of the traditional method of knowledge representation and has rich knowledge representation languages.

In this paper, a model is proposed for rotating machinery fault diagnosis based on ontology. The background of ontology and its development is introduced in section 2. The ontology model of fault diagnosis for rotating machinery is constructed in Section 3.Section 4 completes rotating machinery fault diagnosis ontology modeling by use of protégé 4 and realizes the knowledge reasoning for fault diagnosis. In the last section, the conclusion and future work are given.

2. Background of Ontology and its application

Ontology is a term borrowed from philosophy that refers to the science of describing the kinds of entities in the world and the relationships that hold between those entities [10]. We can talk about ontology as a theory of the nature of existence in philosophy. In computer and information science, ontology is a technical term denoting an artifact that is designed for a purpose [11]. It is widely used in the fields of knowledge management, knowledge engineering and artificial intelligence. Gruber [12] defines ontology as an explicit specification of a conceptualization. A conceptualization is a set of definitions of metaknowledge in a certain domain. Each knowledge representation follows a certain degree of conceptualization, either explicitly or implicitly. Ontology-based knowledge representation includes fivemodeling primitives: conception, attribute, relation, axiom and instance.OWL (Web Ontology Language) is an ontology language recommended by W3C(World Wide Web Consortium)[13]. It is based on a different logical model which makes it possible for concepts to be defined as wellas described. For instance, an OWL ontology is an RDFgraph, which in turn is an set of RDF triples that can actually be expressed in XML, according to RDF/XML syntax.

Ontologies are becoming more popular in academia. There is a tendency both in converting existing models into ontologies and in creating new models. The usage of ontologies for knowledge representation, sharing and high-level reasoning could be seen as a major step towards the area of fault diagnosis.In recent years, many experts propose research on the study of fault diagnosis knowledge representation to a certain degree. Ontology-based knowledge base system has developed rapidly in the fields of transportation, aerospace, communications, forestry, agriculture and so on. For example: ontology-based method employed in the Research of Knowledge Base System, which provided basis for the drilling accident emergency decision[6];ChenSonghanget al.[7]used ontology to investigate related knowledge representation and management for artificial transportation system; Zhang Y et al.[8] build an ontology-based model for blast furnace fault diagnosis; D.Wang et al.[9] construct ontology of power transformers system and study on query and inferring of fault diagnosis knowledge. However verylimitedresearch has been reported on using ontology for diagnosing quality and maintenance related problems in rotating machinery fault diagnosis. As ontology has advantages in hierarchy and semantic relationships expressing, the accuracy and judgment ability of fault diagnosis for rotating machinery based on ontology can be improved.

3. Ontology Modeling for Rotating Machinery Fault Diagnosis

In the field of modeling, the role of ontology is to analyze the domain knowledge and separate the domain knowledge from operation knowledge. To construct ontology is a complex systematic engineering.We need to have master extensible knowledge classification method in the research field and collect a large numbers of fault records. Then the knowledge representation and reasoning are realized, the characteristics of the domain-specific knowledge should be reflected correctly and the need of facts or goals can be quickly found by reasoning. In order to ensure the correctness of the ontology knowledge representation and the unity of cognition about concept and relationship in the field, the flow chart of knowledge modeling process for constructing rotating machinery fault diagnosis ontology is shown as Fig.1.

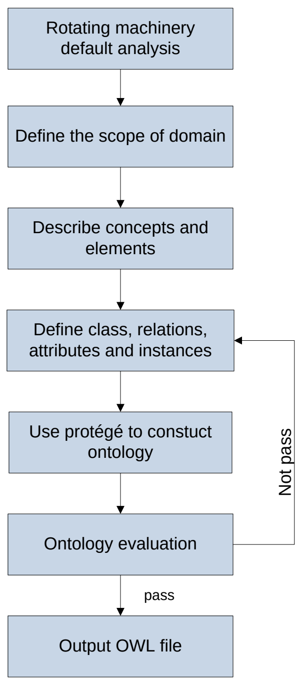

Fig1. The flow chart for modeling of ontology

3.1 Definition of the domain knowledge

Ontology provides a set of terms and concepts to describe a certain domain. Listing the terms of a domain is a very hard work. After analyzing of the information of rotating machinery faults diagnosis, we can describe the information through these aspects such as fault name, vibration characteristics, fault reason and control measures.

For the purpose of facilitating the construction of the proposed rotating machinery fault diagnosis knowledge modeling based on ontology, some definitions must be given as following:

Definition1，rotating machinery fault diagnosis ontology, which can be described as the following formula: O =< C, I, R, A> (1), among them:

1. The factor C: represents a set of concepts in the field of rotating machinery fault diagnosis knowledge, including Fault_name, Vibration_characteristics, Fault_reason and Control_measures.
2. The factor R: represents sets of relationships between concepts in the field of fault diagnosis.
3. The factor A: it is a set of true axioms. The axiom expresses nonrestrictive restraints of a concept and relationship between concepts, which is used to represent the forever valid statements within the territory of fault diagnosis.
4. The factor I: it is a set of instances of concepts and relationships in the field of rotating machinery fault diagnosis.

3.2 Construction of fault diagnosis ontology

Based on the above definitions, rotating machinery fault ontology can be described in four aspects. The four aspects are class, property, relations and instance. The next section expounds the four aspects.

Class：The aim of rotating machinery fault diagnosis (RMFD) is basically to find possible link path from the fault vibration characteristic (Fvc) to fault name (Fna) or even control measures (Com) through fault reasons (Fsn). Rotating Machinery Fault diagnosis ontology class (RMFDClass) can be defined by the following four-topples formula:

RMFDClass = (Fna, Fvc, Fsn, Com) (2)

In the formula, Fna is Fault_name class; Fvc is Vibration_characteristics class; Fsn is Fault_reason class; Com is Control_measures class. Also each class has their own subclasses. Subclass can be defined through inheritance. For example, the Fault_name class includes subclasses: {Rotor bending, Rotor imbalance, Rotor misalignment, Spindle transverse crack, Rotor support parts looseness……}. The table1 displays the classes of rotating machinery fault field knowledge ontology.

Table1. The classes of rotating machinery fault field knowledge ontology

Class	The components of class
Fault_name	Rotor bending, Rotor imbalance, Rotor misalignment, Spindle transverse crack, Rotor support parts losseness……
Vibration_characteristic	Axis Track, Characteristic Frequency, Vibration Stability, Enter Direction, Phase Characteristic……
Fault_reason	Fix Maintain, Design Manufacture, Run Operation, Machine Inferior
Control_measure	Balance, Centered, Rotate, Straightening……

Relations: Fault diagnosis ontology relationship is abstract about interaction between ontology. Generally, the OWL has four basic semantic relationships: {is_a, part_of, attribute_of, instance_of}. Additionally, some relationships such as union, intersection, complementation and inequivalence still exist in the field of rotating machinery fault knowledge. However in the ontology modeling of fault diagnosis knowledge, attribute_of is the mostly use.

Property：Based on above definition of concepts and their classification relationship, it still needs to define properties. In order to define the relationships between classes and express the many-to-many relationships, there are three kinds of properties: {object property, data property, annotation property}.

Object property is the most important property. It describes a relationship between instances of two classes. When a user defines a property, there are a number of ways to restrict the relation. We define six types of object properties:

{ hasCharacter, isCharacterOf, hasReason，isReasonOf，hasMeasure，isMeasureOf }, in this six properties, hasCharacter describes relationship between top level class Fault_name and Vibration_characteristic. IsCharacterOf is the inverse property of hasCharacter; hasReason describe relationship between top level class Fault_name and Fault_reason. IsReasonOf is the inverse property of hasReason; hasMessure describes relationship between top level classeFault_reason and Control_measure. IsMessureOf is the inverse property of hasMessure. The logic mapping between objects through relationships is shown as Fig2. Additionally, the property may have its own subproperty. For example, as the Vibration_characteristics class has subclass: {AxisTrack(AT), CharacteristicFrequency(CF), VibrationStability(VS), EnterDirection(ED), PhaseCharacteristic(PC), Time_domain_waveform(TDW), VibrationDirection(VD), FrequentFrequency(FF)}, the object property hasCharacter has subproperty: {hasAT, hasCF, hasVS, hasED, hasFF, hasPC, hasTDW, hasVD}. We can use them to express relationship between classes exactly and can also use them to reasoning. Data property relates an individual of the subject class and some data type. Annotation property is used to explain some special classes, individuals and properties. The action ranges of object property and data property are limited by their domain and range. Property's domain describes that its subject can be what classes or class instances, while property's range describes that its object can be what classes or class instances. For example, hasReason, its domain is "Fault_name" class, and the range is "Fault_reason" class; hasCharacter, its domain is "Fault_name" class, and the range is "Vibration_characteristics" class; hasMeasure, its domain is "Fault_name" class, and the range is "Control_measures" class. As IsReasonOf is the inverse property of hasReason, conversely, its domain is "Fault_reason" class, and the range is "Fault_name" class. This property related these classes and instances of the former to the latter.

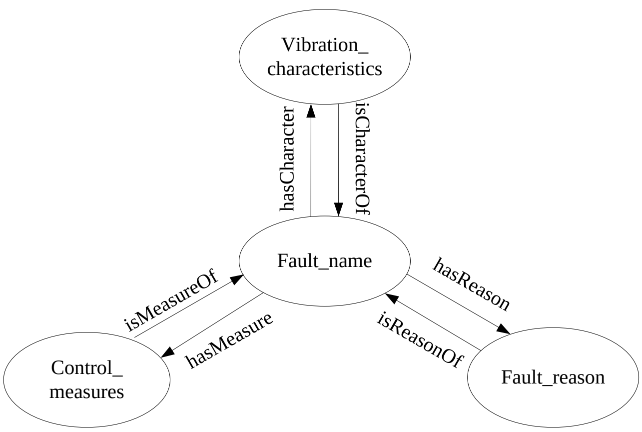

Fig2. The relationship between rotating machinery fault's classes

3.3 Brief structure of fault diagnosis knowledge model

The rotating machinery fault diagnosis knowledge ontology is a foundation to realize the fault diagnosis. OWL and Protégé ontology editor are used to create category and subclass category of ontology domain. The basic attributes restrictions can also be attached to ontology. The field of rotating machinery fault knowledge ontology model is made up of knowledge with fault name, fault vibration characteristics, fault reason and control measures. The structure graphic of fault knowledge ontology class hierarchy is drawn in Fig3. In the Fig3, it shows that the class "Thing" is parent of each fault knowledge class, and the relationship between superclass and subclass is is_a property. However each fault knowledge class has its own subclass. The relevant relation description is defined by the corresponding properties. Part of rotating machinery fault field knowledge ontology properties is shown in Fig4.

The developed ontology model is dynamic, it can store instance of multiple rotor machinery faults. Also it has higher description ability and realizes the knowledge sharing between the users in different fields.

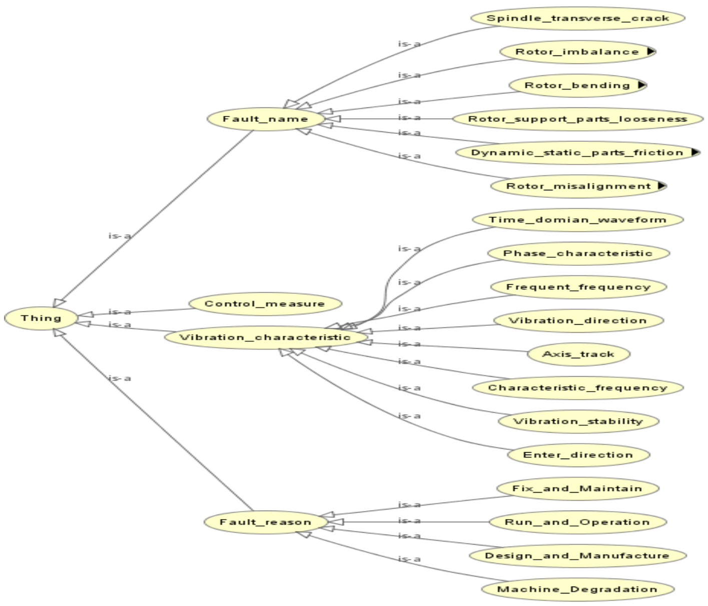

Fig3. The structure graphic of class hierarchy

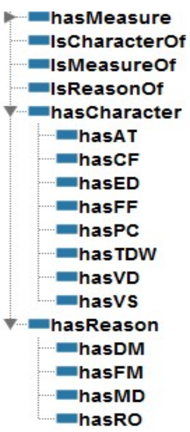

Fig4.Some part of object properties and sub-properties

4. The realization of ontology-based fault knowledge reasoning

4.1 Establishing of the rules

Besides information acquisition and sharing, inferring is another important application of ontology. Describing rules formally with logic languages is helpful to increase the diversity and flexibility of rules during simulation. The participation of rules can improve the operating efficiency of the practical application. As OWL mainly describes the fault knowledge about concept relevance based on category, and difficult to express the general form rules. Therefore, SWRL (Semantic Web Rule Language) is used to describe rules and construct a rule base based on OWL ontology base in order to make up for the OWL language that is imperfect in the ability of expression. SWRL is a regular description language which mixed the OWL and RuleML (rules markup language), and can combine rules and OWL ontology base well, constructing rules by means of existing ontology. It described the knowledge of OWL ontology by highly abstract syntax expression, which realized the combination between the rules and OWL knowledge base.

Based on the constructed rotating machinery domain ontology, a part of judgment rules for fault diagnosis was established as follows:

Rule1: (?x fa:hasAT fa:ellipse)(?x fa:hasCF fa:1x)(?x fa:hasED fa: radial)

(?x fa:hasFF fa:smaller_higher_harmonic)(?x fa:hasPC fa:stability)

(?x fa:hasTDW fa:low_dynamic_balancing)(?x fa:hasVS fa:stable)

-> (?x fa:IsCharacterOf fa:Original_imbalance)

Rule1 means that if vibration characteristics of one’s fault showed the ellipse axis track, 1x characteristic frequency, radial enter direction, small higher harmonic frequent frequency, low dynamic balancing time domain waveform, stable phase characteristic and vibration stability, then this fault name is belong to " Original_imbalance ".

Rule2: (?x fa:IsCharacterOf fa:Original_imbalance)

->(?x fa:hasDM fa:uneven_material)

(?x fa:hasFM fa:parts_installtion_errors)

(?x fa:hasMD fa:mating _parts_loosen)

Rule2 means that if the fault type is original imbalance, it may be caused by some reasons: the material is uneven in the design and manufacture aspect, some parts on rotor install error in the fix and maintain aspect, the mating parts on rotor loosen in the machine degradation aspect.

Rule3: (?x fa:hasReason fa:mating_parts_loosen)

->(?x fa:hasMeasures fa:remove_loose_parts)

Rule3 means that if the fault reason is that mating parts loosen, then corresponding control measure is to remove the loose parts.

4.2 Fault knowledge reasoning

Due to no special reasoning engine for SWRL at present, we use Jena to realize reasoning process. The Jena is a tool library based on Java programming, which aims at the realization of semantic logic using RDF-API as its core. SPARQL, as the semantic query language, has multi-data source query function and can perform the data retrieval of multi-source heterogeneous ontology. The procedure of fault knowledge reasoning is as follows: basing on the concept level and attribute relationship constructed, using the rule-based reasoning strategy and rotating machinery fault information inputted by users, then introducing user-defined file to realize the query and knowledge reasoning. In fact, reasoning process is a semantic retrieval processing, the constraints and axiom of fault knowledge ontology helps eliminate language ambiguity problem. Ontology-based semantic retrieval has a higher searching speed and accuracy. We propose query requests according to the users' needs, and then the query processor in the application program executes the semantic expansion.

For example, we have acquired the data of one rotor fault vibration characteristic, we want to query which fault type it is, and then through reasoning to find out fault reason. First the monitoring data of vibration characteristic such as axis_track, characteristic_frequency, enter_direction, time_domain_wave…..etc is input. After analyzing the labels and relationships, the instance "Original_imbalance1"of Fault_name class is searched. Then we can get the corresponding Fault_reason. In the example, based on the input vibration characteristic data, we can get the fault name is original imbalance and some fault reason such as unreasonable structure, uneven material, low dynamic balancing and so on. The final outcome of query is shown in Fig5.

```
Problems | @ Javadoc | Declaration | Console
<terminated> test (1) [Java Application] D:\software\jdk\bin\javaw.exe (2014-3-19 下午1:28:42)
-------------------------------------------------------------
| Fault_name               | Fault_Reason                   |
=============================================================
| rotor:Original_imbalance1 | rotor:unreasonable_structure    |
| rotor:Original_imbalance1 | rotor:uneven_material           |
| rotor:Original_imbalance1 | rotor:low_dynamic_balancing     |
| rotor:Original_imbalance1 | rotor:big_error_in_manufacturing |
| rotor:Original_imbalance1 | rotor:cooperate_parts_loose     |
| rotor:Original_imbalance1 | rotor:parts_installtion_errors  |
-------------------------------------------------------------
```

Fig5. The result of query

5. Conclusion

In this paper, a model is constructed for rotating machinery fault diagnosis based on ontology. According to the four elements which are Fault_name, Vibration characteristic, Fault_reason, Fault_measure, the modeling of fault diagnosis knowledge is discussed in details. Basing on the ontology database, the fault diagnosis information and knowledge can be reused and shared. Through establishing the rules and using Jena, we provide realization method to realize the knowledge reasoning and provide the more convenient inquiry way for the users. The last result indicates that this modeling method of fault diagnosis based on ontology is intuitive and high efficiency. In the future, more complicated case studies with more data and more complicated rules will be developed to increase expressivity and test scalability of the fault diagnosis.

6. Acknowledgement

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