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Construction of Ontology-based Fault Knowledge Base of Aerospace TT&C Equipment

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Abstract

This paper studies the construction of ontology-based fault knowledge base of aerospace TT&C equipment. Firstly, knowledge base and fault knowledge of aerospace TT&C equipment are researched. Then we construct an ontology-based knowledge base model, and the process of construction is given in detail. After that, the rule-based semantic reasoning is tested and analyzed. The research in this paper can offer some help and reference for the construction of knowledge base in other domain.

Keywords

Ontology, aerospace TT&C equipment, fault, knowledge base.

1. Introduction

Aerospace TT&C is an activity of tracking, measuring and controlling different kinds of spacecraft by using TT&C equipment. With modern war's increasing dependence on the aerospace industry, aerospace TT&C equipment as an indispensable part has been integrated into the joint combat. Maintenance support of aerospace TT&C equipment determines the recovery and regeneration of combat effectiveness of aerospace forces to a large extent. The scale of fault knowledge accumulated in domain of maintenance support of aerospace TT&C equipment is growing rapidly. Simultaneously, fault knowledge of aerospace TT&C equipment has played a more and more important role in fault diagnosis and maintenance support of aerospace TT&C equipment. Thus, it is of great significance to study the construction of fault knowledge base of aerospace TT&C equipment.

The data of aerospace TT&C equipment has three characteristics that make its analysis, management and modeling difficult. First, the amount of data grows very quickly. Second, the data has multiple dimensions. Third, the relationships between data are complex. Traditional fault diagnosis systems of aerospace TT&C equipment which are usually built based on experts' experience require human intervention and have not reasoning engine, so their diagnosis results have the disadvantages of lacking in flexibility and intelligence.

In recent years, with the development of information technology, methods of knowledge-based fault representation and reasoning have emerged. In literature [1, 2], artificial intelligence and knowledge engineering are applied to fault diagnosis, which improves the reasoning speed and diagnosis efficiency. In literature [3], a method of ontology-based fault knowledge representation is proposed, which realizes the sharing and reuse of knowledge. In literature [4], a rule-based expert system is designed to realize the quantification of fault rates. Literature [5] puts forward a method of fault knowledge representation based on description framework, which enables knowledge to reason. Literature [6] constructs an ontology-based medical knowledge base.

According to the characteristics of fault knowledge of aerospace TT&C equipment, this paper imports ontology to the construction of fault knowledge base of aerospace TT&C equipment. Firstly, the

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introduction to ontology is given. Then we put forward the structure of ontology-based fault knowledge base of aerospace TT&C equipment, and build an ontology model of fault knowledge. After that, we analyze the reasoning application of fault knowledge base of aerospace TT&C equipment.

2. Ontology

The word ontology has been taken from Philosophy, and is used to provide a commonly agreed understanding of Existence. Neches et al. [7] defined an ontology as follows "An ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary". In the field of information integration, the definition of ontology had been controversial. In 1993, Gruber [8] uses the < D, R > structure to define ontology, D represents concepts of the researched field; R represents relationships between concepts, and "an ontology is an explicit specification of a conceptualization". Based on Gruber's definition, Borst [9] gives another definition of ontology saying that: "Ontologies are defined as a formal specification of a shared conceptualization". In 1998, Studer et al. [10] conducted in-depth research on these two definitions, and think that ontology is an explicit formal specification of a shared conceptualization. This definition is widely acceptable. This definition contains four meanings: conceptualization, explicit, formal and shared. "Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private to some individual, but accepted by a group.". Ontology is usually organized in taxonomies and typically contains modeling primitives such as classes, relations, functions, axioms and instances [8, 11].

In this paper, ontology is imported to the field of fault diagnosis of aerospace TT&C equipment. On the one hand, computers can encode the fault knowledge that makes convenient knowledge collection and storage. On the other hand, commonly understanding of fault knowledge of aerospace TT&C equipment can be established, which facilitates the sharing and reuse of fault knowledge.

3. Construction of knowledge base of aerospace TT&C equipment

3.1 Fault knowledge of aerospace TT&C equipment

Studying the fault knowledge of aerospace TT&C equipment can make technicians familiar with the mechanism of fault and deal with the fault quickly. Fault knowledge of aerospace TT&C equipment mainly consists of three parts: fault phenomenon, fault source and fault reason. The relationship among these three parts is shown in Figure 1.

Figure 1. Relationship of main parts of fault knowledge of aerospace TT&C equipment

It can be seen from Figure 1 that a certain kind of fault phenomenon is caused by some fault reasons, and some fault reasons will lead to a certain kind of fault phenomenon. A certain kind of fault reason is usually located at a certain fault source.

3.2 Ontology model of fault knowledge base of aerospace TT&C equipment

Construction of ontology model is the process of transforming concrete things in the real world into abstract concepts. There are many ontology description languages such as Resource Description Framework (RDF), RDF schema (RDFS), DARPA agent markup language (DAML), Web Ontology Language (OWL), etc., which are web-based ontology description languages. Among them, OWL has a fairly good ability of semantic expression and reasoning support. Hence, OWL is recommended by World Wide Web Consortium (W3C) as the ontology description language. In this paper, OWL is

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used to formalize the fault knowledge. At present, there is no standard method to develop ontology. According to the characteristics of fault knowledge of aerospace TT&C equipment, we build an ontology model using the "seven steps method" proposed by Stanford University. Typical components of aerospace TT&C equipment are shown in Figure 2, and the fault collection of these components and their subcomponents forms all the fault cases of aerospace TT&C equipment.

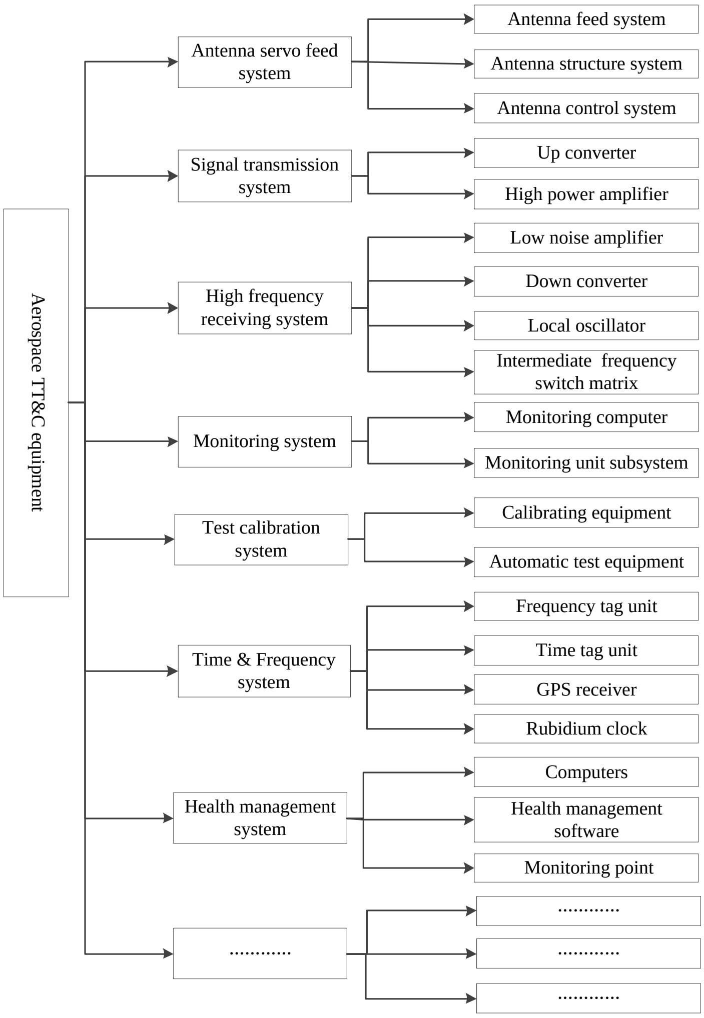

Figure 2. Components of aerospace TT&C equipment

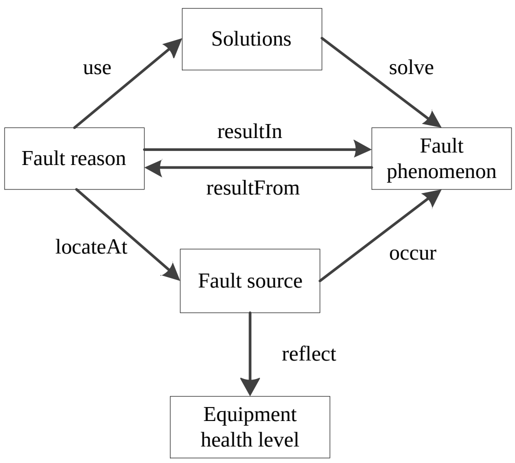

Figure 3. Relationship between classes and object attributes of fault knowledge of aerospace TT&C equipment

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According to analysis of fault knowledge of aerospace TT&C equipment and experience knowledge provided by experts, we divide the fault knowledge into five parts (classes): fault phenomenon, fault reason, fault source, solutions and equipment health level. The relationship between these five classes is shown in Figure 3.

In the definition of class hierarchy, we use three relationships which are “part of”, “instance of” and “attribute of” to represent basic hierarchical relationship between classes.

Class properties include datatype properties and object properties. Datatype properties are used to describe individual’s numerical characteristics. Object properties are used to describe the relationship between instances. From Figure 3 we can see that in the fault ontology model of aerospace TT&C equipment, “fault reason” ‘use’ “solutions”, “solutions” ‘solve’ “fault phenomenon”, “fault reason” ‘resultIn’ “fault phenomenon”, “fault phenomenon” ‘resultfrom’ “fault reason”, “fault source” ‘occur’ “fault phenomenon”, “fault source” ‘reflect’ “equipment health level”, and so on.

We use protégé 4.9 developed by Stanford University to edit fault ontology model of aerospace TT&C equipment. Using experts’ diagnosis experience, we establish fault diagnosis rule knowledge, and build a fault ontology knowledge base. Some codes in the OWL file created are as follows:

```
<owl:Class rdf:about=“#Fault_Reason”/>
<rdfs:subClassOf rdf:resource=“#Fault”>
</owl:Class>
<owl:Class rdf:about=“#Antenna_Structure_System_Fault”/>
<rdfs:subClassOf rdf:resource=“#Antenna_Servo_Feed_System_Fault”>
</owl:Class>
<owl:ObjectProperty rdf:about=“#use”>
<rdfs:subPropertyOf rdf:resource=“#topObjectProperty”/>
<rdfs:domain>
<owl:Restriction>
<owl:onProperty rdf:resource=“#use” />
<owl:allValuesFrom rdf:resource=“#Fault_Reason” />
</owl:Restriction>
</rdfs:domain>
<rdfs:range>
<owl:Restriction>
<owl:onProperty rdf:resource=“#use” />
<owl:allValuesFrom rdf:resource=“#Solutions” />
</owl:Restriction>
</rdfs: range>
</owl:ObjectProperty>
```

3.3 Ontology-based fault knowledge base of aerospace TT&C equipment

Fault knowledge base of aerospace TT&C equipment is a collection of fault feature information and troubleshooting methods. On the one hand, we organize the fault knowledge using ontology to implement its storage and management; on the other side, we analyze the fault mechanism using semantic reasoning to realize fault diagnosis. According to requirements of maintenance support of aerospace TT&C equipment, the knowledge base is divided into fault instance knowledge base and fault diagnosis rule knowledge base, as shown in Figure 4.

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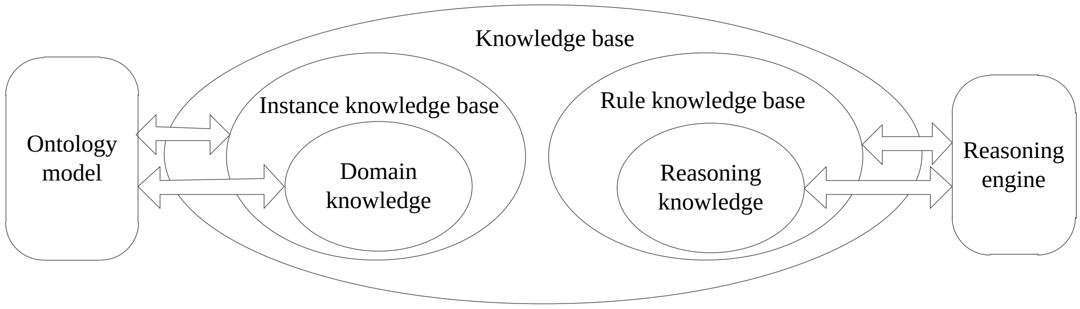

Figure 4. Structure of ontology-based knowledge base of aerospace TT&C equipment

See Figure 4, the instance knowledge base that associates with the fault knowledge ontology model stores relations of concepts and attributes of aerospace TT&C equipment which belong to the domain knowledge. The rule knowledge base that associates with the fault diagnosis reasoning engine stores rules useful for fault diagnosis and semantic reasoning which belong to the reasoning knowledge.

4. Semantic reasoning of diagnosis rules

The aim of semantic reasoning is to use the ontology fault model and rule-based reasoning strategy to infer fault reasons, solutions, etc. The OWL description based on fault knowledge of aerospace TT&C equipment is mainly used to represent the class-based concept knowledge. However, it is difficult to represent the knowledge when it is not class-based (e.g. if…then..., whose semantic reasoning structure is quite common and simple, but OWL is incapable of expressing this kind of rules-based knowledge). Therefore, it is necessary to build a rule knowledge base which can better represent fault knowledge of aerospace TT&C equipment. At the same time, a powerful reasoning engine is needed for semantic reasoning using established rules.

Jena [12] is a Java framework developed by HP semantic network laboratory to build semantic web applications. It provides programming environment for RDF, RDFS, OWL, and query language and data acquisition protocol such as Simple Protocol and RDF Query Language (SPARQL). Jena contains a rule-based semantic reasoning engine. In this paper, Jena is used to implement the rule-based semantic reasoning of fault knowledge of aerospace TT&C equipment.

5. Semantic reasoning testing and analysis

Based on construction of knowledge base and semantic reasoning, we take a kind of aerospace TT&C equipment fault as an example, which is "The down converter fault (fault phenomenon) is caused by the down converter (fault source) whose carrier to noise ratio of input signal exceeds the limit (fault reason), and we need to replace the unit (solutions)", to demonstrate the rule-based semantic reasoning. Based on the description above, two diagnosis rules are established:

Rule 1: If the carrier to noise ratio of input signal of down converter is lower than a, the down converter is in fault.

Rule 2: If the down converter has failed, it needs to be replaced.

Rules above can be described using Jena's reasoning grammar as follows:

rule1:(?x rdf:type ttc: Down_Converter),(?x ttc: Carrier_to_Noise_Ratio ?h), lessThan(?h, a),(?f rdf:type ttc: Down_Converter_Fault)->(?x ttc:occur ?f)

rule2:(?x rdf:type ttc: Down_Converter),(?x ttc:occur ?f),(?f rdf:type ttc: Down_Converter_Fault), (?r rdf:type ttc:Unit_Replacement)->(?x ttc:use ?r)

Key codes to implement the semantic reasoning of diagnosis rules are presented as follows:

//Register the URI mapping, define rule prefix

String URI="http://www.owl-ontologies.com/ffcFault.owl#";

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```
PrintUtil.registerPrefix("ttc", URI);
//Create the ontology model and load ontology data
Model model = ModelFactory.createDefaultModel();
model.read("file:d:/ttcFault.owl");
//Establish reasoning rules
String rule="[rule1:(?x rdf:type ttc: Down_Converter), (?x ttc: Carrier_to_Noise_Ratio ?h),
lessThan(?h, a),(?f rdf:type ttc: Down_Converter_Fault)->(?x ttc:occur ?f)][rule2:(?x rdf:type ttc:
Down_Converter),(?x ttc:occur ?f),(?f rdf:type ttc: Down_Converter_Fault), (?r rdf:type
ttc:Unit_Replacement)->(?x ttc:use ?r)]";
//Create the reasoning engine
Reasoner reasoner = new GenericRuleReasoner(Rule.parseRules(rule));
//Create the reasoning model
InfModel infModel = ModelFactory.createInfModel(reasoner, model);
//Create a resource variable and output reasoning results
Resource rs=infModel.getResource(URI+"Down_Converter");
int index=1;
for(StmtIterator i= infModel.listStatements(rs, null, null); i.hasNext(); ){
    Statement stmt=i.nextStatement();
    System.out.println(index+"-"+PrintUtil.print(stmt));
    index++;
}
```

After running the codes above, we can get the output as follows:

1-(ttc: Down_Converter ttc:occur ttc: Down_Converter_Fault)

2-(ttc: Down_Converter ttc:use ttc: Unit_Replacement)

From the first output, we can see that the down converter is in fault. From the second output, we can see that the down converter needs replacement of unit. Output 1 is derived from semantic reasoning of Rule 1, while output 2 is not derived from semantic reasoning of neither Rule 1 nor Rule 2 alone, but from joint semantic reasoning of both Rule1 and Rule2. The output reflects the advantage of using ontology–based semantic reasoning.

6. Conclusions and future work

This paper studies the construction of ontology-based fault knowledge base of aerospace TT&C equipment. Firstly, knowledge base and fault knowledge of aerospace TT&C equipment are researched. Then we construct an ontology-based knowledge base model, and the process of construction is given in detail. After that, the rule-based semantic reasoning is tested and analyzed. The research in this paper can offer some help and reference for the construction of knowledge base in other domain. In the future, emphasis will be put on enriching the ontology knowledge and rule knowledge. Also, efforts are made to develop ontology-based fault diagnosis system of aerospace TT&C equipment, so that fault knowledge base can be easily applied in maintenance support of aerospace TT&C equipment.

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