

# A Knowledge Modeling Method of Blast Furnace Fault Diagnosis Based On Ontology

Zhang Yajun<sup>1</sup>, Shi Jinliang<sup>2</sup>, Chen Guorong<sup>3</sup>

<sup>1,2,3</sup>Metallurgical Performance Detection and Equipment Engineering Technology Research Center, ChongQing University of Science & Technology, China

<sup>1</sup>yajunzhang76@163.com, <sup>2</sup>Shijinliang@tom.com, <sup>3</sup>cqcrg@sina.com

**Keywords:** ontology; fault diagnosis; blast furnace; modeling method

**Abstract.** There is lots of knowledge in the blast furnace fault diagnosis records and it's useful to guide the fault diagnosis occurred later. But, in fact, such knowledge sharing and knowledge reusing is very low because of a lack of unified, efficient knowledge model. In order to make the furnace operation unification and standardization, an ontology-based intelligent diagnosis model is established in this paper. On the basis of the four elements which are fault phenomenon, fault location, fault cause, fault solution, the author carry out knowledge representation and construction reasoning. Then the author give out a fault diagnosis framework including fault diagnosis class, property, instance, domain, relationship etc. the ontology-based fault diagnosis modeling method is strictly defined and elaborated. Further more, the author quotes the pulverized coal injection system of blast furnace as a case to confirm this modeling method. The results prove that this modeling method is intuitive and high efficiency.

## Introduction

Blast furnace fault diagnosis is a very important part of the metallurgy production process. Any metallurgy enterprise's productivity, effectiveness and competitive ability are closely related to the technique of Blast furnace fault diagnosis. Because the Blast furnace system is very complicated, Including furnace body, material-feeding system, air-blowing-in system, injection system and slag system etc, it's extremely difficult to diagnose the blast furnace fault. There is lot's of knowledge in the blast furnace fault diagnosis records and it's useful to guide the fault diagnosis occurred later. But there isn't a universal model of knowledge representation, it's difficult to fuse most of the knowledge and form a united idea. So it lead to lower ability of fault prediction, fault diagnosis and fault repair. More and more experts gradually recognize that it's significant to deeply mine fault knowledge and formulate a universal fault diagnosis representation model[1]. Such research will improve knowledge sharing and reusing, fault prediction ability and solution-making ability.

At present, many expert Carry out research on fault diagnosis knowledge representation to a certain degree. For example: building fault diagnosis algorithm based on neural network or expert system to improve the fault diagnosis ability[2-3];adapting SDG method, Pelri network model to descript fault diagnosis knowledge for solving the universal representation problem of the fault diagnosis knowledge[4-6]. But there are certain defects in the above methods. For example, neural network and expert system are weak in fault diagnosis knowledge mining. The accuracy of diagnosis is highly dependent on the entries.

In this paper, Ontology is introduced into the fault knowledge representation. The author designs a fault diagnosis knowledge system framework and proposes a knowledge modeling method for blast furnace based-on ontology. In the last section, the author completes the blast furnace fault diagnosis ontology modeling by use of protégé. A case is given in the last section to demonstrate the essence of the blast furnace fault diagnosis model based-on ontology.

## Knowledge analysis of blast furnace fault diagnosis

**Knowledge modeling procedure of blast furnace fault diagnosis.** To construct ontology is a complex systematic engineering. At resent years, many method appeared, such as the TOVE

method, The Skeletal Methodology and SENSUS method[7]. In order to ensure the correctness of the ontology knowledge representation and the unity of cognition about concept and relationship in the field, this paper draws lessons from the advantages of the above method. Further more, based on the facts of blast furnace fault diagnosis, the author design a knowledge modeling procedure for constructing blast furnace fault diagnosis ontology[10]. The flow chart is shown as figure 1.

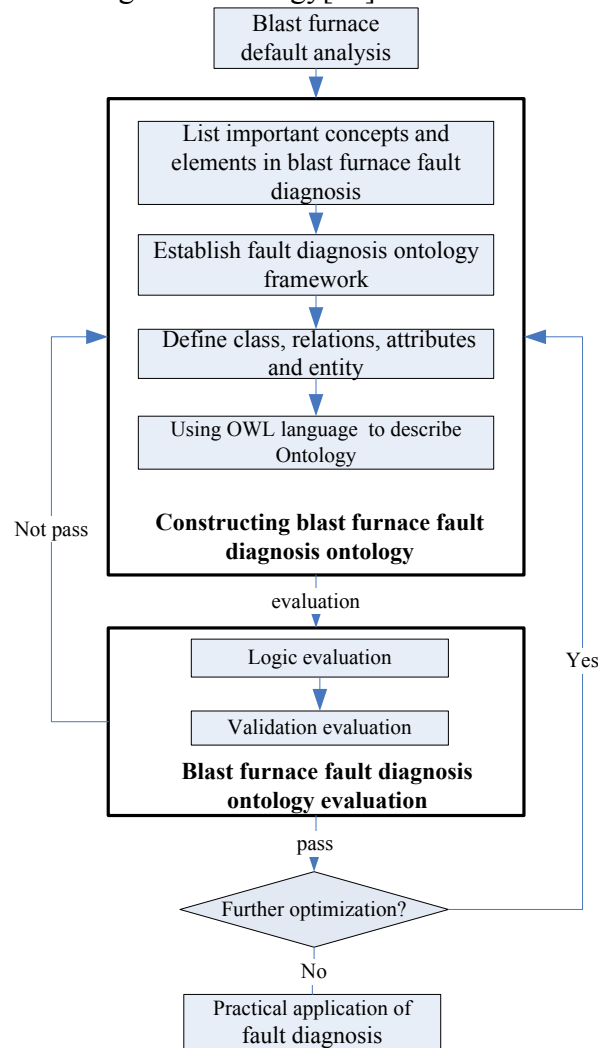


Fig. 1 The flow of knowledge modeling method based on ontology

**Ontology analysis of blast furnace fault diagnosis.** The essence of blast furnace fault diagnosis contains three parts. They are:

- 1) Identifying fault reason according to the fault phenomenon.
- 2) Confirming the fault location according to the fault phenomenon and the fault reason.
- 3) Developing solutions for repairing the fault.

The essence of blast furnace fault repair procedure is that to use the solution handle specific fault location and to eliminating the fault phenomenon. If we ignore the other auxiliary link involved in fault diagnosis process, the process of fault diagnosis and fault solution has explicit definition domain, value range and relation matching. Blast furnace fault diagnosis process usually involves the following 4 factors showing as figure 2.

1) Fault phenomenon: Appearance that can be got by visual sense, auditory sense and so on. Fault phenomenon can be described by user reports or operation records.

2) Fault reason: the crux of the fault. It's easy to find simple fault, but to confirm complex fault, the professional person of fault diagnosis is absolutely necessary.

3) Fault location: the part that doesn't work in the equipment. It may be some certain spare parts. It can be a subsystem also.

4) Fault solution: a design or a method to solve the problem which usually can be acquired after deep study of fault reason and fault location

The above four factors and their relationship is shown as figure 2.

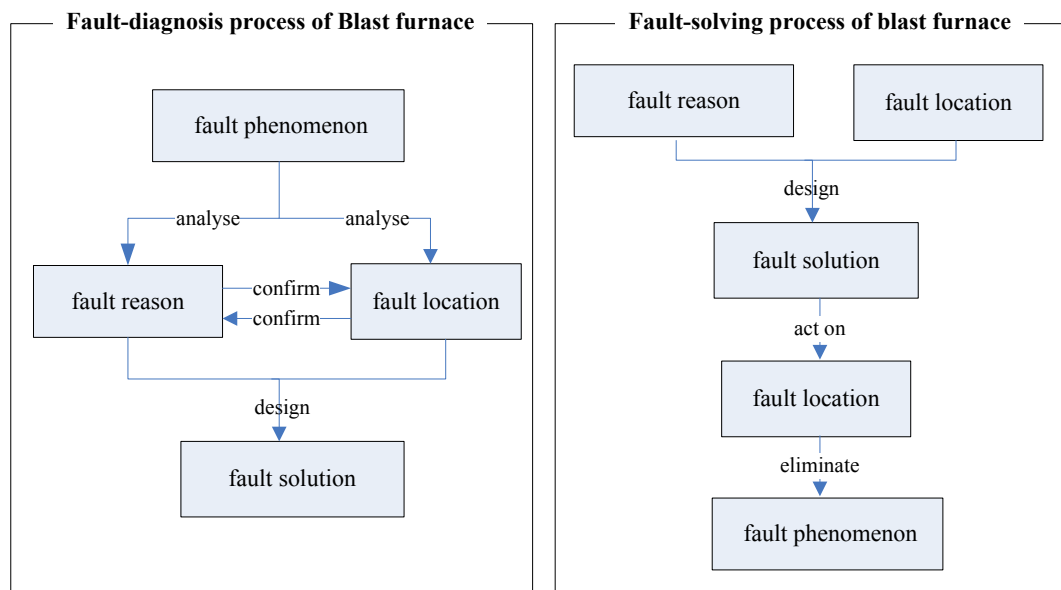


Fig. 2 The four factors involved in blast furnace fault diagnosis and their relationship

When we carry out blast furnace fault diagnosis, the four factors must be defined and be formulated to construct fault diagnosis ontology which should be processed by computer. The ontology must have the following three characteristics:

- 1) Concept and conceptual constraints are clearly defined.
- 2) Abstract model has high generality.
- 3) Abstract model is highly independent of environmental statement.

Such ontology can highly realize knowledge sharing and reuse.

### Significant definitions and ontology modeling of blast furnace fault diagnosis

Significant definitions. Based on the four factors of blast furnace fault diagnosis and the common rules of ontology construction, the following definitions can be acquired[11]:

Definition 1: Blast furnace fault diagnosis ontology, which can be described as the following formula:

$$BFFonto ::= (A, C, R, A^c, A^R, Id, l) \quad (1)$$

1)  $A, R, C$ : The basic sets for blast furnace fault diagnosis.  $A$  is property set,  $R$  is relationship set and  $C$  is concept set.

2)  $A^c$  and  $A^R$ : the set container of blast furnace fault diagnosis ontology.  $A^c$  is concept-property set container and  $A^R$  is relationship-property set container. Any element in the container represents a concept-property set or a relationship-property set.

3)  $Id$ : the identification of blast furnace fault diagnosis.

4)  $l$ : the logic language which is used to describe the blast furnace fault diagnosis ontology. In order to describe the blast furnace fault diagnosis, the basic logic relationship between the ontology and the description is a two-tuple function:  $Y := (A_x, \lambda)$ . In the function,  $A_x$  is Axioms identification,  $\lambda: A_x \rightarrow l$  represent relationship mapping. In formula  $Y := \lambda(A_x)$ ,  $Y$  is Axioms element.

Definition 2: The blast furnace fault ontology class ( $BFFClass$ ). The blast furnace fault ontology class is a highly abstract description about relationship, property and concept which is independent of specific contents. For example, we can define  $BfDeviceClass$  as blast furnace device class. According to the specific fault reason, fault phenomenon, fault location and fault solution, we also can create subclass of  $BfDeviceClass$  to represent parts of the device. And so on, an integrated structure can be described by hierarchical definition.

Definition 3: Relationship: Relationship refers to the interactions of blast furnace fault diagnosis

ontology. Some relationships are frequently used, such as whole and part (*part-of*), parent and child (*parent-of* or *child-of*). In order to describe the interactions of blast furnace fault diagnosis ontology, the relationship is integrated to construct ontology.

Definition 4: Object: Object is the instance of class.

Definition 5: Function: function(s) is a specific relation. Its domain and value range can be clearly defined by mathematical method.

### Blast furnace fault ontology modeling

Based on the above definitions, we can describe blast furnace fault ontology by four aspects. The four aspects are class, property, relationship and instance. The next section expounds the four aspects.

1) Blast furnace fault ontology (*onto\_of\_BFFD*) can be defined by the following five-tuple formula:

$$\text{onto\_of\_BFFD} = (\text{BFFDClass}, \text{BFFDProperty}, \text{BFFDInstance}, \text{BFFDRelationship}, \text{BFFDCodomain}) \quad (2)$$

In the above formula, *BFFDClass* is fault diagnosis ontology class; *BFFDProperty* is property class; *BFFDInstance* is instance class; *BFFDRelationship* is relationship class; *BFFDCodomain* is Codomain class.

2) Fault diagnosis ontology class (*BFFDClass*) can be defined by the following four-tuples formula:

$$\text{BFFDClass} = (\text{BF\_Bf}, \text{BF\_P}, \text{BF\_R}, \text{BF\_S}) \quad (3)$$

In the formula, *BF\_Bf* is blast furnace ontology class, *BF\_P* is fault phenomenon class; *BF\_R* is fault reason class; *BF\_S* is solution class. Subclass can be defined through inheritance. In the end, we can get an integrated domain ontology class.

3) Fault diagnosis ontology property class (*BFFDProperty*) can be described by the following three-tuple formula:

$$\text{BFFDProperty} = (\text{ObjectP}, \text{DataP}, \text{AnnotationP}) \quad (4)$$

In the formula, *ObjectP* is object property class; *DataP* is data property class; *AnnotationP* is annotation property.

Further more, we can describe *ObjectP* by the following formula:

$$\text{ObjectP} = (\text{R\_caused}, \text{R\_sought}, \text{R\_made}, \text{R\_dispelled}) \quad (5)$$

In the formula, *bf\_caused*, *bf\_happened*, *bf\_repaired*, *R\_made* are relationship representations which are demonstrated in figure 2. These relationships show interaction between objects.

4) Blast furnace fault instance (*BFFDInstance*) is a blast furnace fault instance object which is represented by the formula:

$$\text{BFFDInstance} = (\text{bf\_Instances}) \quad (6)$$

*bf\_Instances* is instance set.

5) Fault diagnosis ontology relationship class (*BFFDRelationship*) is abstract about interaction between ontology.

6) Fault diagnosis ontology Codomain set (*BFFDCodomain*) can be defined as an Two-tuple set, that is:

$$\text{BFFDCodomain} = (\text{De\_Domain}, \text{Va\_Range}) \quad (7)$$

*De\_Domain* is definition domain set; *Va\_Range* is value range set.

### Case analysis

In order to verify the function of the application of blast furnace ontology, the author constructs blast furnace ontology by using Protégé. Blast furnace pulverized coal injection system is introduced as the case.

**Define class and subclass.** The structure of Blast furnace pulverized coal injection system is shown as figure 3. Blast furnace ontology class (*BF\_Bf*) includes the whole structure of the blast furnace. However, pulverized coal injection system is just a subclass of *BF\_Bf*. The components

of pulverized coal injection system are all in the pulverized-coal-injection-system class (*PulverizedCoal\_System\_Class*).

**Define relationships between classes.** The relationships between *BF\_Bf*, *BF\_P*, *BF\_R*, *BF\_S* should be defined. The relationship may be parent-son, inheritance, Mutual exclusion, and so on.

**Define the properties of the classes.** Three properties which are contained in the classes should be defined. They are object property (*ObjectP*), data property (*ObjectP*) and Annotation Property (*AnnotationP*). In order to represent the relationship between objects, such as *BF\_Bf*, *BF\_P*, *BF\_R*, *BF\_S*, some relationship must be defined. The relations are *R\_caused*, *R\_soked*, *R\_made*, *R\_dispelled*. The logic mapping between objects through relationships is shown as below:

```
BF_Bf (R_caused) BF_P;
BF_P (R_soked) BF_R;
BF_R (R_made) BF_S;
BF_S (R_dispelled) BF_P.
```

**Instance of class.** According to the fault diagnosis records in the history, we can design the instance of *BF\_Bf*, *BF\_P*, *BF\_R*, *BF\_S*. we can also build the relationships between *BF\_Bf*, *BF\_P*, *BF\_R*, *BF\_S*. The core XML code is shown as figure 4.

```
<?xml version="1.0"?>
  <owl:Class rdf:ID="BF_Bf">
    <owl:disjointWith rdf:resource="#BF_R"/>
    <owl:disjointWith rdf:resource="#BF_P"/>
    <owl:disjointWith rdf:resource="#BF_S"/>
  </owl:Class>
  <owl:Class rdf:ID="Blast_Furnace_Body">
    <rdfs:subClassOf rdf:resource="#BF_Bf"/>
  </owl:Class>
  <owl:DataP rdf:ID="bf_r0">
    <rdfs:domain rdf:resource="#BF_R"/>
    <rdfs:range rdf:resource="&xsd:string"/>
  </owl:DataP >
  <owl:Class rdf:ID="Gas_distributor">
    <rdfs:subClassOf rdf:resource="#PulverizedCoal_System_Class"/>
  </owl:Class>
  < Gas_distributor rdf:ID="Gas_distributor1"/>
  <BF_R rdf:ID="tempreture_of_heat exchanger">
    <bf_r xml:lang="en"
      > temperature_of_heat exchanger_is_lower_than_normal </bf_cause>
    <r_caused rdf:resource="#the_CO_density_from_the_distributor_is_too_low"/>
    <r_soked rdf:resource="#Gas_distributor1"/>
    <r_made rdf:resource="#solutions"/>
    <r_dispelled rdf:resource="#dispelled_it"/>
  </BF_R>
</rdf:RDF>
```

Fig. 4 The core XML code fragment of ontology construction

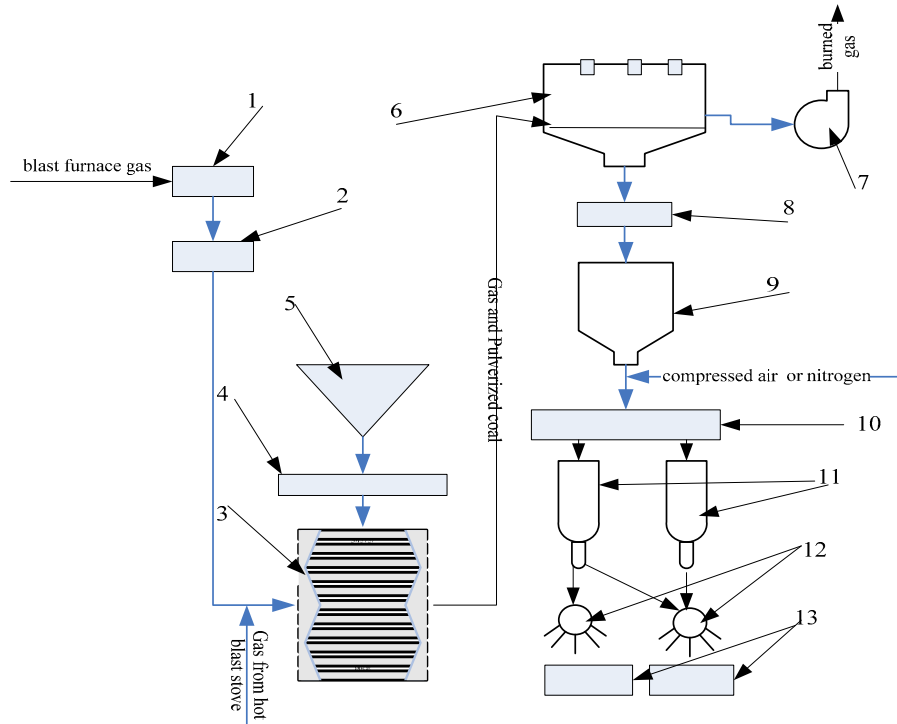


Fig. 3 The structure of pulverized coal injection system

There: 1: burner; 2: flue-gas converter; 3: mill; 4: pulverized coal feeder; 5: raw coal bunker; 6: pulverized-coal dust collector; 7: air-suction machine; 8: Impeller feeder; 9: pulverized-coal bunker; 10: heat exchanger; 11: injection tank; 12: distributor; 13: blast furnace

**The realization of ontology-based fault knowledge reasoning.** Figure 4 show how the blast furnace ontology is represented. The representation has obvious advantages in knowledge transmission, knowledge storage and knowledge reasoning. Figure 5 show us the procedure of fault knowledge reasoning.

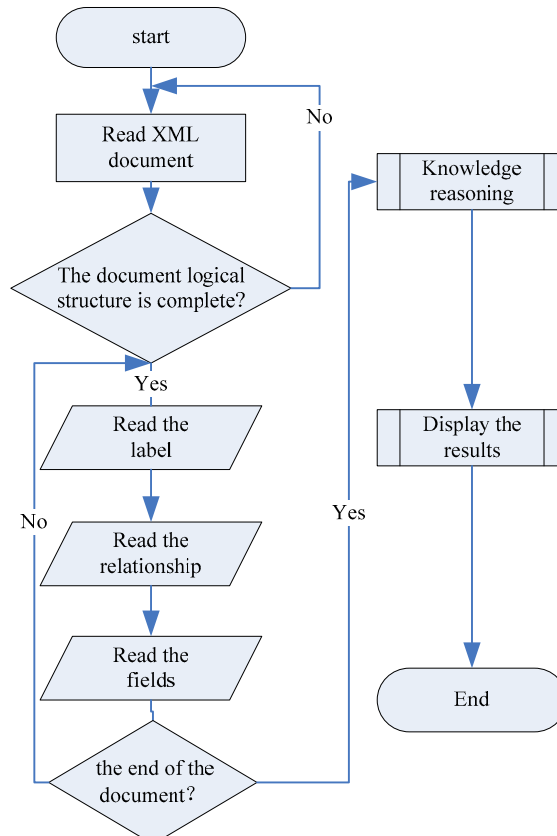


Fig. 5 The procedure of fault knowledge reasoning

For example, when we confront the “*the\_CO\_density\_from\_the\_distributor\_is\_too\_low*” phenomenon, we should first search the instance of *BF\_P* class after analyzing default phenomenon. By analyzing the labels and relationships, we can get the “*temperature\_of\_heat\_exchanger*” instance of *BF\_R* class. The “*temperature\_of\_heat\_exchanger*” instance is just a property of “*Gas\_distributor1*” instance, a subclass instance of *PulverizedCoal\_System\_class*. The corresponding “*r\_dispelled*” solution is just in the *BF\_S* class. When the “*r\_dispelled*” solution is adopted to solve the default, the “*temperature\_of\_heat\_exchanger\_is\_lower\_than\_normal*” phenomenon will be eliminated.

## Summary

It is very complicated to construct ontology in view of the blast furnace fault diagnosis process. Many aspects should be carefully to plan, such as knowledge representation, structural reasoning and so on. According to the four elements which are fault phenomenon, fault location, fault cause, fault solution, this paper put forward a kind of knowledge representation and reasoning method for blast furnace fault diagnosis based on ontology. The author quotes the pulverized coal injection system of blast furnace as a case and analyses the case by using Protégé tool. This case indicates that this method is intuitive and high efficiency.

## Acknowledgements

This research is supported by national natural sciences foundation of China (Project NO. 51275547)", national natural sciences fund of China (Project NO. 51275547), Chongqing Science and Technology Research Projects (No.cstc2011pt-gc70007, cstc2012gg-yyjs0118), the Achievements support Foundation of Chongqing Municipal Education Commission (No. kjzh11221, kj121413, 201028), and Research Foundation of Chongqing University of Science & Technology (No. CK2010Z10, CK2011B01).

## References

- [1]YU De-jie, ZHOU An-mei, GUO Jian-wen: *Research on Fault Diagnosis Knowledge Management*[J]. Journal of Hunan University(Natural sciences), V01.38, No.5, May.2011
- [2]Spielman S E, Thill J C: *Social area analysis, data mining, and GIS*[J]. Computers, Environment and Urban Systems, 2008, 32 , p. 110-122.
- [3] Demsar U. Investigating visual exploration of geospatial data: *An exploratory usability experiment for visual data mining*[J]. Computers, Environment and Urban Systems, 2007,31, 31, p. 551-571 .
- [4]CAO Wen-liang,WANG Bing-shu,MA Liang-yue: *Study of fault diagnosis approach based on rules of deep knowledge representation of signed directed graph*. International Conference on Industrial Technology.Hong Kong,2005, p. 778-782.
- [5]Jiang Lian-xiang,LI Hua-wang,YANG Gen-qing: *An improved fault Petri net for knowledge representation*[J].Computational Intelligence and Software Engineering.Wuhan,2009, p. 1-4
- [6]SHI Jiang-ping,Tong Wei-guang,WANG Da-liang: *Design of the transformer diagnosis expert system based on fuzzy reasoning*. Computer Science Technology and Applications. Chongqing, 2009, p. 110-114.
- [7]Zhang Mei, Hao Jia, Yan Yan, Li Bo. *Ontology-based knowledge modeling*[J]. Transaction of Beijing Institute of Technology.2010.12:1405-1408
- [8]M. Sintek, S. Decker. *TRIPLE—a query, inference and transformation lanage for the semantic Web*[J], Proceedings of the first semantic Web conference[C],LNCS 2342, Springer-Verlag, 2002:364-378.
- [9]Heymans Stijn, Korf Roman and etc. *F-Logic#: Loosely coupling F-Logic rules and ontologies*[C]. Proceedings - 2010 IEEE/WIC/ACM International Conference on Web Intelligence. 2010,1: 248-255.

[10] F. Baader, D. L. McGuinness, D. Nardi, et al. *the description logic handbook: theory, implementation and applications*[M], Cambridge: Cambridge University Press, 2003.

[11] ZHOU Yang, LI Qing. *modeling and semantic retrieval for aircraft fault knowledge*. Computer Engineering and Applications. 2011, 47(16):12-15