Construction of Intelligent Maintenance Ontology Model for Shield Machine

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Abstract—In order to transform the shield machine maintenance engineers’ experience and related non-structural data into digital, structured and standardized maintenance knowledge, it is necessary to construct a shield machine intelligent maintenance ontology model. This paper has proposed a systematic method for the construction of this ontology model, which mainly includes seven steps. A professional ontology modeling tool protégé is used to complete the construction of the ontology model, and its own reasoning mechanism is applied to maintain the consistency of the ontology logical relationship. Moreover, a graph database by Neo4j is created to store the constructed shield machine intelligent maintenance ontology and related data for the shield machine its intelligent maintenance, ontology model construction technology can also migrate to the field of material synthesis.

1. Introduction

The shield machine is a high-end tunnel boring equipment designed based on multiple disciplines such as mechanical engineering and electrical engineering. Its structure is very complex, and contains a large number of systems and parts. At the same time, its working environment is mostly in the underground, mountain, silt, etc. Therefore, the maintenance of the shield machine is very difficult if a failure happens during the operation [1-2]. When the shield machine fails, the shield machine needs to be maintained for a long time. At present, the main maintenance method of the shield machine is to conduct an on-site inspection of the machine, and create issue related inspection reports based on the existing experience of engineers, and maintenance programs, etc. However, the relevant maintenance experience only exists in the engineers’ brain and related non-structural maintenance materials, which leads to a low degree of digitization, structure and standardization of shield machine maintenance knowledge. At the same time, China has issued relevant regulations, requiring that the maintenance of shield machines with specific qualifications and certifications. Based on the above background, companies undertaking shield machine maintenance urgently need to transform their engineers' own maintenance experience and related non-structured maintenance materials into more digital, structured and standardized maintenance knowledge.

With the development of artificial intelligence technology in recent years, knowledge graph technology has received more and more attention in the field of knowledge capture and representation. Knowledge graph is a technical method that uses graphic models to describe the piece of knowledge and its relationship, as well as modeling the world in terms of knowledge [3]. By applying the
knowledge graph technology, the engineers' own maintenance experience and related non-structured maintenance materials can be transformed into more digital, structured and standardized maintenance knowledge, which can be further use in the intelligent maintenance of shield machines. To build a high-quality and standardized knowledge graph for shield machine intelligent maintenance, it is necessary to construct a high-quality top-level ontology model as a basis. The focus of this paper is to propose a systematic method of building an ontology model for the construction of the knowledge graph for shield machine intelligent maintenance.

2. Method
The methods for constructing ontology are different, the most common ones are the seven steps method [4], the METHONTOLOGY method [5], the TOVE method [6] and so on. Among them, the seven steps method and the METHONTOLOGY method have a relatively complete life cycle. At the same time, the seven steps method and the METHONTOLOGY method have their related supporting technologies, but the METHONTOLOGY method is relatively incomplete. In addition, each method has a different ontology construction method. Except for the seven steps method which uses semi-automatic construction, most of the others are constructed manually. Therefore, the seven steps method and the METHONTOLOGY method are more mature than other methods.

Among them, the seven steps method mainly uses the following seven steps to construct the ontology model. The domain and scope of the ontology must be clearly constructed, and the domain and scope of the ontology model to be constructed must be clarified. Analyze and reuse existing ontology models. The process is mainly to determine whether there is a built ontology model that can be used for reference by searching related documents and materials. To acquire domain knowledge, knowledge engineers obtain relevant professional knowledge in the domain to be constructed through expert exchanges and data collection. The core concepts of the field are initially determined, and the knowledge engineer conducts a preliminary screening of the acquired knowledge and summarizes the core professional concepts in the field. Establish the core concept level of the domain, the knowledge engineer further derives and verifies the core concept summarized, and finally determines the level of the core concept. Define the attributes and constraints between concepts. Knowledge engineers use data to summarize the connections and attributes between core concepts, making the built ontology more logical. The ontology is instantiated, and after the ontology model is constructed, the rationality of the ontology model construction is further verified by filling in examples. The ontology construction process is shown in Figure 1.
3. Ontology modelling of shield machine intelligent maintenance

This article intends to use the seven steps ontology construction method to build the ontology model of the shield machine maintenance field.

3.1. Define the Domain and Scope of Ontology Construction

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3.2. Analyze and reuse existing ontology models

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3.3. Acquire Domain Knowledge

Knowledge acquisition in the field of shield machine maintenance is mainly accomplished by communicating with experts in related fields and obtaining a large number of relevant electronic materials in the field of shield machine maintenance from related companies. Relevant materials include "φ6260 Slurry Shield Machine Maintenance Information", "φ6340 Earth Pressure Balance Shield Machine Maintenance Information", "Herrenknecht AG Earth Pressure Balance Shield Machine Maintenance Information", "Robbins Earth Pressure Balance Shield Machine Maintenance Information" and relevant materials for the structural decomposition of the shield machine.
3.4. Identify the core concept of the domain

The acquired knowledge is classified, sorted out, and relevant important concepts are extracted, as shown in Table 1.

**TABLE I. IMPORTANT CONCEPTS IN THE FIELD OF SHIELD MACHINE INTELLIGENT MAINTENANCE (PART)**

| Category               | Terminology                                                                 |
|------------------------|-----------------------------------------------------------------------------|
| Shield machine structure | Front shield, Middle shield, Tail shield                                     |
| Operating tools        | online monitoring tools, monitoring tools, maintenance tools                |
| Operation              | regular maintenance operations, predictive maintenance operations          |
| Operator               | inspector, dismantler, repairman                                            |

The above-mentioned related concepts are not particularly standardized and unified. If you want to build a more standardized and logical concept, you need to further integrate it through the ontology development software protégé.

3.5. Establish the domain core concept hierarchy

It mainly classifies, merges, summarizes, and abstracts the core concepts in the field of shield machine intelligent maintenance, and turns the repetitive and irregular core concepts into abstract and representative core concepts. This paper mainly uses the ontology development software protégé to abstract and summarize the core concepts in the field of shield machine maintenance. The top level of the ontology of the shield machine intelligent maintenance is the Thing class, and its sub-categories include operators, shield machines, and computers. There are specific related categories in the sub-categories, such as the shield machine class. See Figure 2 for details.

![Figure 2 Shield machine class in the field of intelligent maintenance of shield machine](image)

3.6. Define inter-concept attributes and constraints

When the class and level definition of the shield machine intelligent maintenance field is completed, the ontology model cannot fully express the knowledge of the shield machine intelligent maintenance field. It is necessary to define the attributes and constraints of the class in the shield machine intelligent maintenance field. Describe the structure and characteristics of the class in detail. Defining the attributes of a class means defining the properties of the object, and the description of the relationship between the classes is achieved by defining the object properties. Constraint is to define data attributes, through defining data attributes to realize the description of the characteristics of the class. As shown in Figure 3, the repair, disassembly, replacement, cleaning, and dredging operations in the fault maintenance operation are all object attributes that describe the relationship between the operator and the components of the shield machine.
Figure 3 Shield machine intelligently maintains the object attributes of the ontology

As shown in Figure 4, the online monitoring standard values, regular maintenance standards, and monitoring standards in the relevant standards all belong to the characteristic data attributes of the description category.

Figure 4 The shield machine intelligently maintains the data attributes of the ontology Ontology instantiation

3.7. Ontology instantiation

After constructing the top-level ontology model, protégé can be used to fill the ontology model maintained by the shield machine and add some instances of classes to further verify the actual application value of the constructed top-level ontology. Protégé has the function of visualizing ontology and instances. Through the visualization of ontology, we can clearly see all the classes and attributes defined by the ontology and the relationship between classes and classes. Figure 5 shows the filling of the shield machine intelligent maintenance example. Figure 6 is an effect diagram after visualizing the ontology and some examples.
Figure 5 Shows the filling of the shield machine intelligent maintenance example

Figure 6 Visualization of intelligent maintenance ontology and case of shield machine

4. Logical detection and knowledge storage
Logical reasoning means that existing classes and attributes form concepts according to the laws and rules of logical thinking to make judgments to achieve the purpose of reasoning. Protégé itself has a reasoning mechanism, which can check the consistency of ontology instances and eliminate semantic differences, that is, it can maintain the consistency of ontology logical relations, thus providing guarantee for subsequent ontology reasoning.

After the ontology model maintained by the shield machine is constructed and the corresponding examples are added, the ontology model maintained by the shield machine can be expressed in the ontology description language OWL and stored in the form of a document. If you want to store relatively large-scale data instances, you need to use a related database, such as Neo4j, which is a mature and high-performance graph database. If you want to store the OWL file in Neo4j, you need to convert the OWL file into an RDF file stored in an RDF structure, and then store the structured data of the RDF file in the graph database Neo4j, and finally you can retrieve the relevant instance through the graph database Neo4j And extended applications.
5. CONCLUSIONS
This article mainly proposes the construction of an ontology model for shield machine intelligent maintenance. As the top-level framework of the knowledge graph, the ontology model plays an important role in constructing a complete knowledge graph. The method of construction is mainly carried out by a seven steps method, with the help of ontology development software Protégé. After constructing the shield machine intelligent maintenance ontology model, fill in examples according to the framework of the ontology model, thereby constructing a knowledge graph of shield machine intelligent maintenance with a large number of examples, so as to realize the maintenance experience of the engineer and related non-structural The maintenance information is transformed into more digital, structured and standardized maintenance knowledge.

Ontology construction technology can also migrate to the field of materials. At present, there are many kinds of materials in the field, which are divided into metal materials, inorganic non-metal materials, organic polymer materials and composite materials according to their physical and chemical properties. The synthesis of materials has affected all aspects of human life and promoted the development of various fields [9]. In the synthesis of materials, it is necessary to understand the characteristics of each material before starting relevant synthesis work. Due to the wide variety of materials in the material field, each material has its own characteristics [10], and this knowledge exists in an unstructured or semi-structured form, and it is difficult to make it without understanding the characteristics of each material. Relatively excellent material synthesis combination. If the ontology construction technology is applied to the field of material synthesis and the knowledge map of the material field is constructed, unstructured or semi-structured knowledge is transformed into structured knowledge, and then the structured knowledge map is used as an auxiliary decision-making, then you can greatly improve work efficiency in the field of material synthesis.

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