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RESEARCH ARTICLE

Semantic Information Modeling and Implementation Method for Water Conservancy Equipment

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ABSTRACT Water conservancy equipment (WCE) has a large amount of information, structural heterogeneity and complex relationship leads to the difficulty of semantic interoperability in smart water conservancy. To overcome this issue, we propose the WCE information interaction dimension theory, modeling process and instancing method. First, we analyze the smart water conservancy ontology and information factor, and propose semantic information interaction dimension structure of water conservancy Ontology. Second, we construct the network information model structure of water conservancy, through the relationship degree, a tree model which can realize semantic expression and interoperability is formed through the dimensionality reduction of the model. Third, the component attribute set hierarchical relationship architecture water conservancy information model is established, which use XML language to describe this model. Moreover, the three types of instancing methods are proposed. Through OPC unified architecture (OPC UA) technology, water conservancy information model can implement semantic interoperability. The experimental show that the proposed method of semantic information modeling and semantic interoperability of WCE is feasible, and obvious advantages of complete semantic interoperability than in the model architecture, semantic structure and technical implementation.

INDEX TERMS Information model, semantics, smart water conservancy, water conservancy equipment, OPC UA.

I. INTRODUCTION

Water conservancy equipment (WCE) include sluice, pump and sensors, etc. In the WCE, interconnection is between the underlying equipment to achieve collaborative management and sensing information for reducing labor [1]. Water conservancy neglect construction of interconnection interfaces and communication protocols before the smart water conservancy era, so that the interfaces between WCEs are heterogeneous, uneven, and interoperable information models are different widely due to their heterogeneity. The trend of WCE's management is data sharing to improve management efficiency, real-time control, data decision-making, and personalized customization. This requires rapid adaptive interconnection, interoperability and interoperability in smart WCE [2], [3]. With the continuous development of smart information technology [4], people have also demanded information management and big data decision-making for water conservancy and equipment [5], for driving the water conservancy to become networked and smart [6].

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As an information entity, a precise description of WCE is required. Smart WCE domain ontology is the semantic foundation of interoperability [7], artificial intelligence reasoning, information retrieval [8], database design and other technologies. As far as we know, information attributes [9] of things based on ontology [10], and expressed the abstract nature of objective reality. Jussi Kiljander [11] believe that the ontology of semantic technology, such as Resource Description Framework (RDF), and Web Ontology Language (OWL) [12] can be used to describe Internet ontology attribute types [13], attributes values, and resources, etc., which expounded the specific definition and standardization of data element attributes, researched and developed data element attribute description rules based on ISO/IEC 11179 from the aspects of language, expression, region, data and application. Pasandideh [14] proposed a strategy based on Petri nets, which is an effective tool for system modeling. M2M (Machine to Machine) service model and device description model, and proposed a general M2M service architecture, device abstraction access, and semantic annotation [15]. Rohjans [16] modeled the public domain of transmission and distribution networks according to the IEC standard [17]. An integrated management system modeling design method can meet the understandability and reusability of modeling, coupling, and data consistency checks.

Water conservancy equipment not only manage water, but also continuously generate large amounts of data. About smart WCE data mining [18], data is the foundation, and the main elements of smart WCE are equipment, which is also the source of production data. TFOF (term frequency and ontology frequency) calculation formula to measure the strength of the semantic relationship of the information model [19]. Thongnuch [20] proposed a semi-automatic modeling method to convert the 3D geometric model of the WCE unit into a virtual representation which supported simulation. The information model and modeling method mainly include OPC unified architecture (OPC UA), Unified Modeling Language (UML), etc.

There are many types of complex data structures in the smart water conservancy management. The data has shown large, diverse, and real-time big data characteristics, there is no direct relationship between the various devices. Most studies have integrated a single type of sensor information. WCE face multiple types of information interaction in the cloud management system [21], it is urgent to break through efficient and reliable interoperability methods [22], [23]. WCE own static identification data, also has a large amount of process data which changes with time. There is a certain dependency relationship between the data, which contains the running characteristics and changing laws. In order to better management, the general research is to solve the problem from the collection method of the Internet of Things (IoT) information. There is no modeling from the WCE itself. Most of the running information comes from the automation equipment, and no classification of the data of WCE, equipment Special studies such as modeling and modeling just obey the needs of management systems. As WCE becomes more and more automated, data becomes more abundant, and big data analysis capabilities increase, WCE manufacturers need to conduct running monitoring and data analysis from the perspective of complete information model for WCE [24].

This paper study the theory of ontology meta-modeling in the field of WCE, establishes the theory and dynamic process of semantic information modeling, implementable methods, establishes a domain information model, and integrates OPC UA technology to realize the information model of WCE.

II. SMART WATER CONSERVANCY ONTOLOGY

In field of smart water conservancy, a specific term set of conceptual models for information systems is established to form a set of explicit assumptions about the meaning of management system. First, the classification hierarchy of concepts are described for complex water conservancy systems and based on the concept classification hierarchy. The smart water conservancy domain ontology is established, a set of appropriate relationships, axioms, and rules are added to represent other relationships between the concepts and constraints. Then, define a complete smart water conservancy ontology consisting of four basic elements: concept, conceptual attributes, relationships, and axioms. Equipment Ontology Model (*EOM*) is defined as:

$$EOM = \{C, A^{C}, R, X, E\} \tag{1}$$

C is the concept set in smart water conservancy field, A^{C} is the concept set attribute, R is the relationship between concepts, and X is the axiom set. Smart water conservancy ontology is the semantic foundation of interoperability, artificial intelligence reasoning, information retrieval, database design and other technologies. Smart water conservancy field concept set C expresses the concept definitions of equipment component classes and information nodes in the ontology of water conservancy. Each information node contains attribute variables, files, and so on. Through the representation of ontology, it is used for the representation, interaction and inference of information in the field of smart water conservancy. The smart water conservancy domain concept set appears in the form of information nodes, and the definition rule set is:

$$\begin{aligned} C =< \text{Information Node}, \{&Concept\ Name, Concept\ Identifier, \\ &Class, Abstract\ Identifier, Attribute, Operation, etc.\} \end{aligned} \tag{2}$$

The definition of the A^{C} attribute set of the attributes in the field of smart water conservancy is:

$$\begin{aligned} A^{C} =< \text{Attribute}, \{&Name, ID, Type, Initial\ Value, Range, \\ &Tag, Necessary, Explanation, etc. > \end{aligned} \tag{3}$$

Then, define the basic relation R set as:

$$\begin{aligned} R = \{&is-, part\ of, member\ of, kind\ of, instance\ of, \\ &attribute\ of\} \end{aligned} \tag{4}$$

TABLE 1. Expression of basic relations in the field of smart water conservancy.

Relationship type	Relationship description
is -	Describe the equivalence between concepts in smart water conservancy
part of	Describe the relationship between the whole and the parts of the concepts in the smart water conservancy field
member of	Describe the inclusion relationship between smart water conservancy domain concepts
kind of	Describe the inheritance relationship between concepts in the smart water conservancy field; for any x that belongs to C and x belongs to F, then F is called the parent concept of C and C is a child concept of F
instance of	Instantiation relationship between concepts and examples describing concepts in the smart water conservancy domain
attribute of	Describe the attribute relationships between concepts in smart water conservancy

The types of relationships between smart water conservancy information nodes are described in Table 1.

X is the axiom set in the field of smart water conservancy, reflecting the use of smart water conservancy information, constraint rules, and the basic principles of activities. Information theory and information interaction in the field of water conservancy, including the semantic constraint relationship of information nodes in the field of water conservancy, such as equivalence, exchangeability, symmetry, reciprocity, transitivity, orderliness, etc.

E is an example in the field of smart water conservancy, which is the result of instantiation of the ontology metamodel in the field of smart water conservancy.

Process of establishing the ontology metamodel in the smart water conservancy field is divided into the informal and formal stages. In the informal phase, the ontology model is described by natural language, diagrams, etc., and the domain of the language diagram is used to represent the prototype of the ontology for the ontology in the field of water conservancy, it is necessary to use natural language to describe the accurate objective and complete meaning; the inferences derived from the concept of the ontology in the field of water conservancy are compatible with the meaning of the ontology and will not cause contradictions.

A formal description ontology is formed through the network node structure, description language of the information nodes and connections. Generally, the ontology is constructed by a cumulative method. First, build a basic ontology, and then further develop a complete methodology for building ontology to form domain information. Third, construct a gradual learning type semantic information model, and construct a formal and structured water conservancy ontology. Different from general equipment, there are many types of WCE, which constitute a natural information interaction barrier. However, the semantic information model based on unified theory has an interoperable mapping foundation.

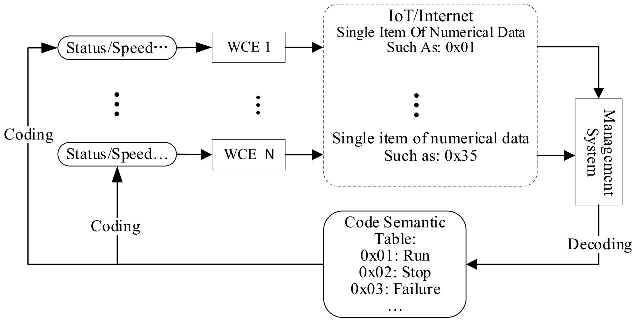


FIGURE 1. Information interaction structure of common equipment.

III. WCE SEMANTIC MODELING THEORY

A. INFORMATION INTERACTION DIMENSION MODELING THEORY OF WCE

We improved the ontology meta-modeling theory in the smart water conservancy field with the requirements for interconnection and interoperability of WCE, for common interconnection and interoperability technologies, the basic technologies such as data communication, network architecture, and protocols involved in data transmission are very mature, common interconnection and interoperability technologies mainly provide pure data transmission, such as the sensors of IoT. In the information node, information generated is only a single data body such as status and speed, information interaction structure shown in Figure 1. As a complete, WCE is relatively independent domain ontology system, which has complete automated parts. Different WCE has a large number of heterogeneous component structures, and each component structure produces different information, or different combinations of components. Therefore, the information structure of WCE is diverse, and a certain point or part of the information node cannot represent the information entity of the entire WCE.

Figure 2 shows WCE information interaction structure. WCE has a large amount of data and types. For understand the semantics of the interactive data, it is necessary to require both parties to communicate in advance to have the same standardized data transmission format and codec semantic system. For data receivers without a decoding system, they cannot understand the content of the data. Furthermore, if WCE system want to understand about the internal connections and dynamic operation functions of the data provided by the data provider, it will raise a higher level on the information supply side. It is required to organize the information on the information supply side organically, and clarify the network relationship between the data to build a standardized information model on the information supply side, so that the information receiver can understand the meaning of the data and the relationship between the data.

According to ontology metamodel of the smart water conservancy field, it consists of concept sets, conceptual attributes and relationships, and combines the real-time data characteristics of water conservancy to divide the WCE

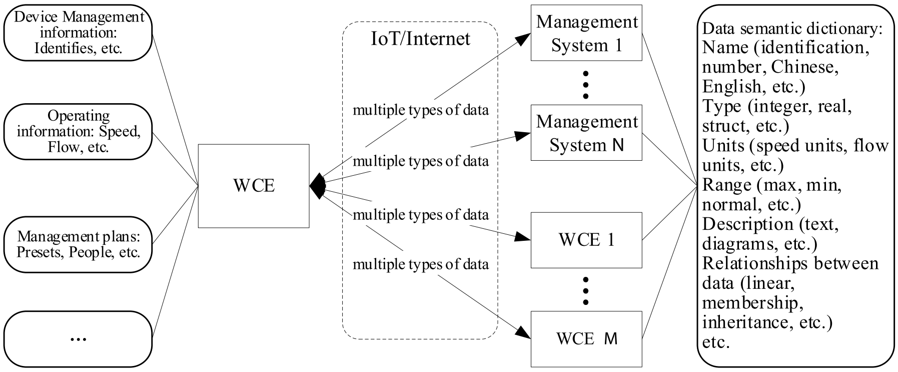


FIGURE 2. Water conservancy information interaction structure.

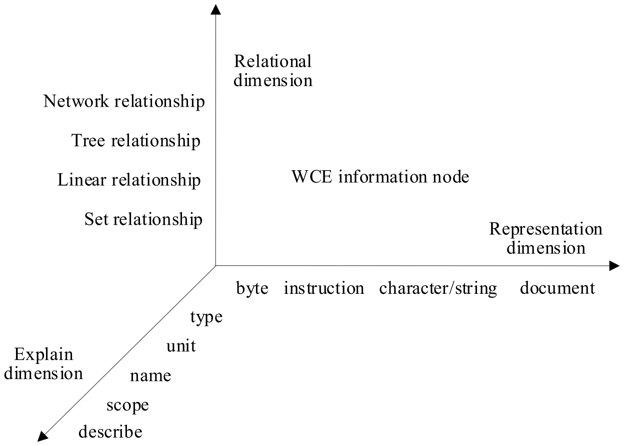


FIGURE 3. Semantic information interaction dimension structure of water conservancy Ontology.

information into three dimensions. The first is the information representation dimensions, which is the specific value, such as byte, instructions, characters, strings and files, etc. Second, the semantic interpretation dimension is the meaning of the components represented by each information, such as units, descriptions, ranges and data types, etc. Third, the relationship dimension is the structural relationship between information points, such as set relationships, linear relationships, tree-like (hierarchical) relationships and network relationships, etc., as shown in Figure 3. These three information dimensions are indispensable aspects of the WCE information factor. The information indicates that one dimension cannot be decoded, and no more relationship information can be obtained. The richer information expressed in each dimension, the clearer the semantics of WCE.

The data representing the dimension is the most basic part. The value of information nodes is used to measure the status of information nodes. It is the main form of interconnection information for interconnection networks. Data can be one-dimensional simple variable values, which can express real-time or historical values of an information node. The receiver of the information determines the meaning of the data through the codec format by the two parties to the information exchange, such as to determine whether the data represents speed or flow, and to determine other aspects of the validity of the data.

Information interaction between the two parties only in the data representation dimension requires the two parties to have a consistent semantic system. However, most WCE requires adaptive connection, but not have a pre-prepared semantic system lead to cannot identify data for unknown WCE. This makes it difficult to achieve interoperability between WCE. In fact, adding the semantic interpretation dimension can solve the encoding and decoding problems of both parties to the information interaction, that is, before the information interaction parties interoperate, the semantic system can be exchanged at first, then achieve semantic interoperability of numerical data based on the common semantic system.

The computer software field use Extensible Markup Language (XML), JavaScript Object Notation (JSON), semantic gateway and other technologies to realize the transmission of basic semantics. XML uses the string nested format to inform the data receiver of the meaning of the data value, such as "<speed> 67 </ speed>" characters. The value is "67", which means "speed". Basic patterns such as XML are suitable for situations with few industrial information elements and simple semantics, and are based on short-link communication. Industrial Internet with pre-decoding system is easy to ignore semantic interaction. The XML semantic expression method is added to the WCE interconnection protocol system. Each communication instruction contains a semantic expression, but the general data numerical dimension is changed, and the semantic dimension is basically unchanged. Frequent semantic interactions increase the communication burden, and reduced communication efficiency. In addition, the basic semantics of XML and other basic models are limited, and it is impossible to build a complete semantic system for WCE. The universality of XML in the Internet also results in a low level of data interaction security. The ideal solution for industrial communication is that the two sides of the information exchange first perform semantic system interaction, and only the data value is required to represent the dimensional interaction in the later stage, which can achieve efficient interoperation between WCE, and management system.

The relationship dimension is reflected in the fact that there are many information nodes in WCE, and there is often an information factor between nodes. In the software industry, UML is often used to express information elements such as classes, objects, attributes, and methods. Hierarchical relationships between information nodes are expressed through inheritance and instantiation, but it cannot further represent the relationship between arbitrary information nodes. WCE is generally a complete mechanical component organic structure, and the relationship dimension between data is a key element for accurately understanding equipment information. The OPC UA technology, which is widely used for large-scale industrial equipment interoperability, has a mesh node relationship address space model. It uses the reference node type to express the connection between any nodes in the model. The relationship dimension is necessary for the information receiver to fully understand the discrete WCE information and production situation. As with the semantic interpretation dimension, before the two parties of the WCE information interaction perform data numerical representation dimension interaction, the relationship dimension interaction between data variables is performed first.

In short, the WCE interoperability data is information that eliminates random uncertainty. The scalar information can only be understood when the communication parties have a semantic decoding system. This leads to the lack of self-adaptation of information interaction, and requires semantic system interaction. For the complete information body of WCE, the data relationship dimension is also required, which support to accurately express its information, eliminate the random uncertainty of interoperable information, and achieve interoperable functions, such as adaptive connection between plug and play and WCE. In addition, a feature of interconnection and interoperability is self-adaptation, that is, when the two parties to the connection are not clear about the semantics represented by the data to be transmitted, to be able to adaptively interoperate semantics, it is necessary to prepare a rich semantic interpretation library or semantic interpretation system, and also transmitted together, the problem can be solved by transmitting the semantic system and the relationship dimension. Numerical representation, data semantic metadata, and the relationship between data are necessary conditions for implementing the WCE information model.

B. COMPLETENESS OF SEMANTIC INFORMATION MODEL FOR WCE

There are many types of WCE, through the information model field description meta-modeling, non-formal modeling, and the integration of WCE semantic information interaction dimension theory to build a heterogeneous WCE information model cluster. Constructing WCE ontology group ($WCEOG$) based on model domain metamodel Formula (1):

$$WCEOG = \{EOM | N, N^{C}, R_{w}, X_{w}, G\} \tag{5}$$

N is the WCE information node set, N^{C} is the information node attribute set, R is the information node relationship set, and G is the WCE information model group instance set. Through the unified information element model EOM, a heterogeneous WCE information model cluster is constructed. The WCE information node is constructed from the concept set C. The semantic information model should have a clear semantic interpretation and data relationship dimension model axiom set X. According to the theory of EOM information interaction dimensions, the WCE semantic information model dimensions of DIR include representation (D_{w}), interpretation (I_{w}), and relationship (R_{w}). Each set is:

$D_{w} = \{$*Bit, Byte, Instruction, Character string, File, etc.*$\}$. The finite set D_{i} data represents a subset of dimension D, which is a representable and understandable data type that reflects the real-time values of the information nodes.

$I_{w} = \{$*name, serial number, unit, type, range, description, etc.*$\}$, the richness of the semantic interpretation dimension set determines the accuracy of the information semantics.

$R_{w} = \{$*set, inheritance, extension, linear, tree, layered, network*$\}$, which represents the relationship dimension between WCE information nodes, and the relationship expressed by the complex relationship dimension is more specific.

Each WCE semantic information node element $DIR_{\mathrm{i}} = \{D_{w\mathrm{i}}, I_{w\mathrm{i},} R_{w\mathrm{i}}\}$ must be semantically clear and unique in the DER space. Define a WCE information completeness information model $DSI = \{D, E, R\}$, spatial system, if a subset of any limited information service set $S = \{S_{1}, S_{2}, \ldots, S_{\mathrm{n}}\}$ is covered, where $n \geq 1$, The WCE semantic information model DIR has the completeness based on the service set S, namely:

$$S \propto DSI = \{D, I, R\} \tag{6}$$

In view of the continuous change of WCE with equipment upgrades, the information model of WCE is constantly changing for any information service subset, it is described by an evolutionary WCE information model. with the development of WCE groups and informatization requirements, the model structure will be continuously improved, which is a dynamic update process. As a model language, it finally serves the semantic information model in the form of data dictionary, semantic database and ontology library, etc.

IV. WCE SEMANTIC MODELING PROCESS

In order to ensure the consistency of the WCE information model and the equipment ontology, according to the information model, the process is constructed from an informal, formal, and strength process through a continuous evolution method, continuous improvement according to the requirements of the management system and the specification of the ontology meta-model. The theoretical model construction process is shown in Figure 4. while ensuring the completeness of the semantic information model of WCE, the feasibility

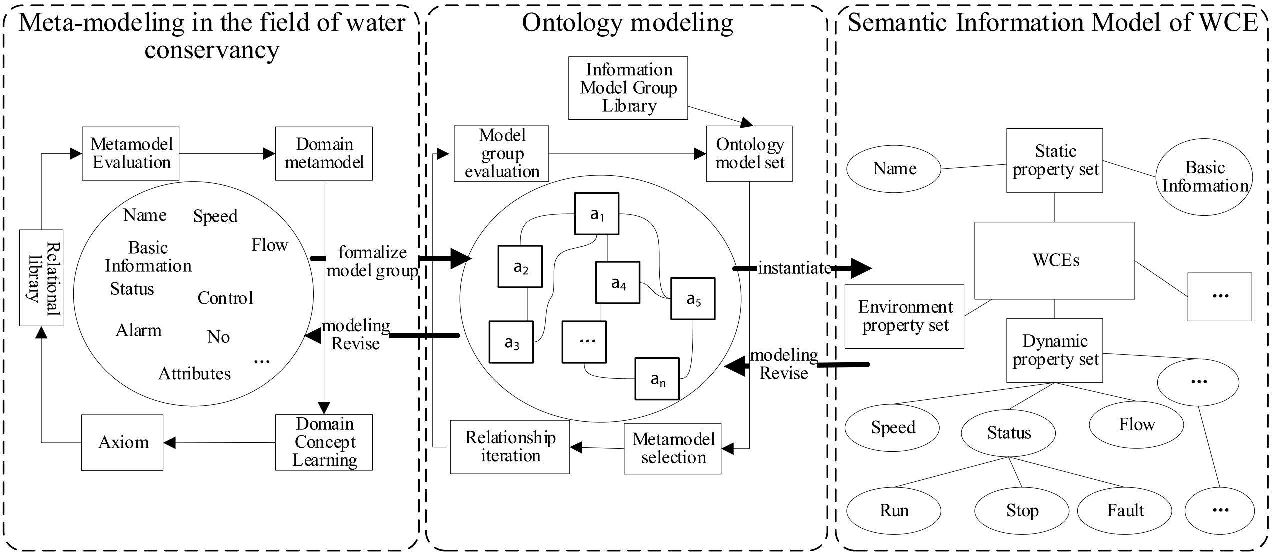


FIGURE 4. The evolution of WCE semantic information model construction.

of implementation is also taken into account. The dimension can be reduced from the network relationship to a tree relationship.

A. THEORETICAL MODELING

First collect information in the field of smart WCE to achieve informal modeling, then build a formal WCE model group through processes, such as modeling revision, meta-model selection, iteration of relationships, and finally generate a WCE information model instance. Construct a network diagram structure of the information model to comprehensively represent the relationships between information nodes, but the complexity of the model relationship also restricts the representation and implementation of the model. Most important, the tree structure information is generated by the WCE information model relationship generation tree method Models for interoperability of information. The steps of building WCE information model are as follows:

1) The information of smart WCE is be Initialized. Informal information descriptions can enumerate all concepts in the field and a detailed explanation of the concept, in addition, for each concept, all possible attributes are listed, and each attribute has a corresponding attribute value. Through domain concept learning and axiomatic analysis, the domain concept relation library is realized, and through the iterative mechanism of evaluation and relearning, the informal set of metamodel concept set C in the smart WCE domain is realized. The commonality of each concept set is extracted, and the concept attribute set A^C of the basic model in the smart WCE field is established according to the rule set of formula (3). Each iteration increases the concept information nodes of the smart WCE field, the relationship between the existing information nodes is determined according to Table 1, and a relation database based on the relation set R_w is formed.

2) A formal WCE information model group is be constructed based on the smart WCE domain metamodel. It construct the WCE information node set $N = \{a_1, a_2, a_3, \ldots, a_m\}$ to form the WCE ontology information model group, establish the N^C according to the rule set formula (3), form the network relationship space R_s of the WCE information node, and establish the relationship between the information node i and the information node $j's$ $con(i, j)$:

$$Con(i, j) = \sum con\,(i, j) * w \tag{7}$$

The relationship degree is composed of the change activity of the data, various relationship structures, and the weight w.

3) It set up a set of WCE model information nodes $\{a_1, a_2, a_3, \ldots, a_n\}$, build a network structure of WCE's basic model, and generate a weighted directed graph $GD = (V, con\,(G), V_1$ is root node), where:

$$con(G) = \begin{bmatrix} con\,(1,1) & con\,(1,2) & \cdots & con\,(1,j) \\ con\,(2,1) & con\,(2,2) & \cdots & con\,(2,j) \\ \cdots & \cdots & \cdots & \cdots \\ con\,(j,1) & con\,(j,2) & \cdots & con\,(i,j) \end{bmatrix} \tag{8}$$

4) Repeating steps (2)-(3) until the basic model group of WCE is complete in the current service set cognitive domain, and it meets the requirements of formula (6).

5) It constructs a WCE information model spanning tree T.

The uncertainty of the path between the directed model's information nodes also leads to the amount of information in the information space, and indicates a serious burden for processing. Thus, the directed graph of the mesh space information node is transformed into a tree graph. The weighted directed graph is used to build a spanning tree, and a spanning tree based on root nodes and breadth-first are established, as shown in Figure 5, generate a standardized modeling language based on the tree structure.

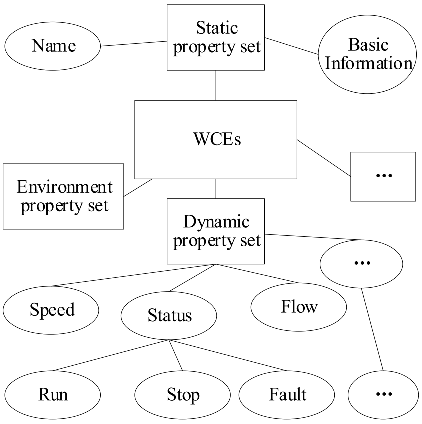


FIGURE 5. WCE information model's tree structure.

TABLE 2. Comparison of information model description languages.

Modeling language	Basic structure	Representation level	Main application objects
RDF	Subject-predicate object triples	Syntax	Web, information system
OWL	Ontology language expressions	Semantic	Web
XML	Markup language for transmitting and storing data	Data hierarchy, extensible	Common in information and industrial fields

The main process of the information model spanning tree algorithm centered on the root node of WCE in Algorithm 1.

Algorithm 1 Information Model Spanning Tree

```
Input: Connected graph $GD$ with $n$ nodes
$S = \{v_0 \mid v_0$ is root node$\}$
$S' = \{v_1, v_2, \ldots, v_n\}$
Output: a spanning tree $T$
$T = \{v_1\}$
while true do
    for starts from $i = 0$, finds the trailing nodes $v_j$ of all edges
     connected to $v_i$,
        if con $(i, j) >$ con $(j, i)$, then
            $v_j$ is a child node of $v_i$, $T = \{v_1, v_j\}$, $S' := \{S' \mid v_i$
        $S'\}$, $S = \{v_0, v_j\}$
                if $S' = \emptyset$, then
                    return $(T)$
    end
end
```

Finally, the WCE information model spanning tree T and the new relationship matrix $con(T)$ are generated.

B. WCE INFORMATION MODEL DESCRIPTION

The XML language description method is different from RDF and OWL, which focuses on grammatical and semantic accuracy. As shown in Table 2, the biggest feature of XML is that it is based on formatting extensions. The use of XML universal schema description to realize the information of WCE is universal, extensible and suitable for interoperation between WCE and information systems.

XML's own hierarchical semantic system and information node relationship reference tags are also adapted to construct the information relationship dimension and data attribute semantic dimension. WCE model attribute type description can be used as follows:

```
<DMEAttribute >
<DMEID> </DMEID>
< DMEAttributeName> </DMEAttributeName>
<DME AttributeDes > </DMEAttributeDes>
< DMEAttributeAccess > </DMEAttributeAccess>
< DMEAttributeDataType > </DMEAttributeDataType>
<DMEAttributeValue> </DMEAttributeValue>
<DMEAttributeEngineeringUnits>
</DMEAttributeEngineeringUnits>
<DMEAttributeLowlimitValue>
</DMEAttributeLowlimitValue>
<DMEAttributeHighLimitValue>
</DMEAttributeHighLimitValue>
</DMEAttribute >
```

The attribute elements described by the attribute type include attribute name, attribute description, access rights, attribute value type, attribute value size, engineering unit, low and high value, and so on. DMEID is used to represent the attribute ID. The attribute of AttributeValue is represented according to its data type. Ordinary data types can be directly filled in. The attribute elements of WCE can be further enriched with management needs.

The description of the component set and attribute set information type (SetinfoType) is as follows:

```
<DMESetInfoType>
< SetInfoName > </SetInfoName >
< SetInfoID > </SetInfoID >
< SetInfoDes > </SetInfoDes>
</DMESetInfoType >
```

Reference information (DMERefencedListInfo) includes reference name, reference ID and reference file path, etc. The reference type description table and its XML file description method are as follows:

```
<DMERefencedListInfo>
<DMESetInfoType> </DMESetInfoType >
<DMERefencedInfo>
<ReferencedName> </ReferencedName>
<ReferencedID></ReferencedID>
<XmlFilePath> </XmlFilePath>
</DMEFRefencedInfo >
<DMETRefencedInfo>
<ReferencedName> </ReferencedName>
<ReferencedID ></ReferencedID >
<XmlFilePath> </XmlFilePath>
</DMERefencedInfo>
</DMERefencedListInfo>
```

The WCE information model XML description method is different from the XML information interaction method. It mainly reflects the description of WCE type node attributes, and based on the information node reference type description

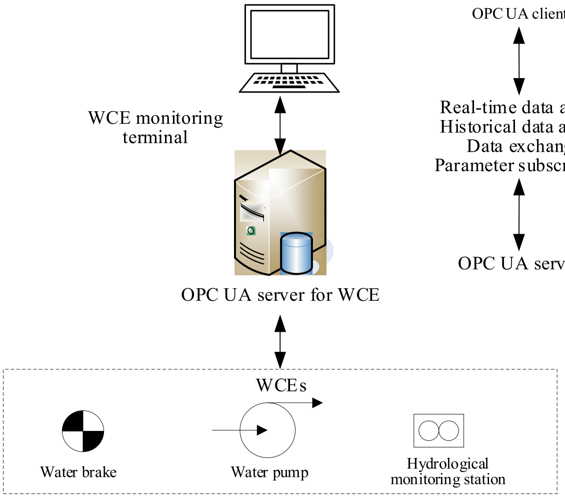


FIGURE 6. OPC UA independent system for WCE.

relationship, in order to facilitate the rapid introduction of WCE information model.

V. INSTANCING METHOD FOR WCE SEMANTIC MODELING

The WCE network communication protocol is the interconnected data part. Based on the reliable TCP transmission based on the Internet, in view of the difference in data processing capabilities of WCE, it is convenient to design an application layer adapted to the WCE networking business functions protocol. Three kinds of instancing methods are provided for semantic modeling.

A. FULL INTEGRATION OF OPC UA AND THE ELECTRONIC CONTROL SYSTEM

The WCE information model service is directly embedded in the control system function of the equipment itself, and is completely integrated with the information model of OPC UA, without the need for other gateways for conversion. There are many types of WCE, and each control system platform is also different. It is necessary to further develop the data, information model, address space, and references of OPC UA based on the WCE information model. It can be mainly used for expensive large-scale WCE.

B. STANDALONE SERVER

The WCE OPC UA server is used as a part of an independent executable program based on ordinary computers. The Software Development Kit (SDK) is developed based on Windows. The visual secondary development is based on the WCE information model data dictionary. Management system can be interconnected. In addition, an OPC UA server platform can be connected to multiple WCE terminals to achieve interconnection and interoperability between large-scale WCE. The overall structure is shown in Figure 6. The development of an independent server method is relatively easy to implement and has a wide range of applications. It is the main way to implement the WCE information mode.

C. OPC UA DATA GATEWAY

During the transformation and upgrade of active manufacturing WCE, because there is no unified interconnection and interoperability interface between WCE, an embedded OPC UA-based data gateway can be developed. Figure 7 shows a unified communication interface is used for the upper management system, and more is used for the downward management. A compatible interface to access active service equipment to achieve interconnection and interoperability between WCE, and between WCE and management systems.

VI. EXPERIMENT

A. EXPERIMENT SETUP

The method of developing independent servers is adopted, the UaExpert SDK based on Windows system, build a typical WCE information space, set up an address space server based on water pumps and sluices, which is based on Windows system, and test the WCE Interoperation at last. A Xeon E5-2660 dual-core 64G memory computer is configured as a UaExper server, which can read about 1,000 attribute data per second, and has the data collection capability for about 100 WCE on a scale. In this WCE information model, water pump is set with 103 items of static data, and the frequency of change of 20 items of dynamic data is changed every 3 minutes, and only 8 items of data are changed in real time. To this end, different sampling frequencies are used, and real-time data tables and data shadow historical data tables are separately established for each table, which improves the performance of data library addition, modification, query, and deletion (CURD). The experiment setup connects a warp WCE to the OPC UA server, and use the OPC UA client to access the information model data of the warp WCE on the OPC UA server, including attribute sets such as master control, operation, shift production, and other attributes, which include the element structure of name, type, and authority, etc. The experiment setup proves the feasibility of the WCE information model under the OPC UA framework.

The information model editor can be used to accelerate the generation of XML description files of WCE attribute sets. The XML files are imported into the OPC UA Server address space, and the OPC UA platform is submitted to a third-party authoritative organization for inspection. OPC UA test platform of information model is shown in Figure 8. The OPC UA information model editor and fast loader to improve verification efficiency. In the verification scenario, the OPC UA Client is used to perform information model editing tests, attribute writing tests, and attribute reading tests on water sluice, pump and hydrological monitoring station. Verification platform OPC UA Server software is Prepared by the IEC 62541 OPC UA standard and passed the OPC Foundation's standard software Unified Automation UA Expert

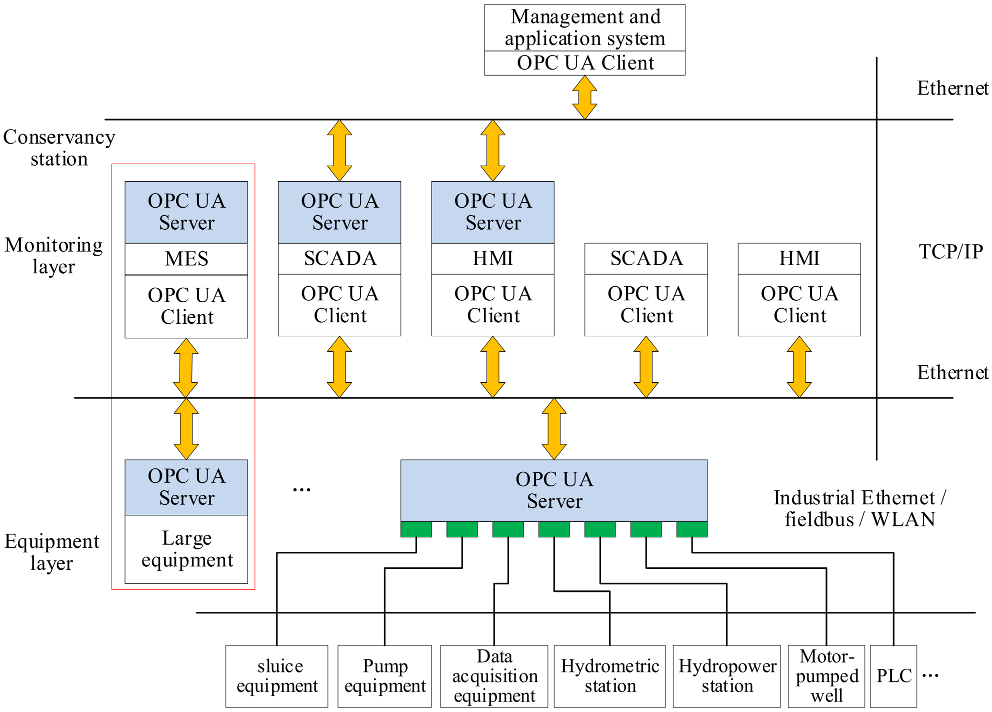


FIGURE 7. WCE OPC UA information model verification.

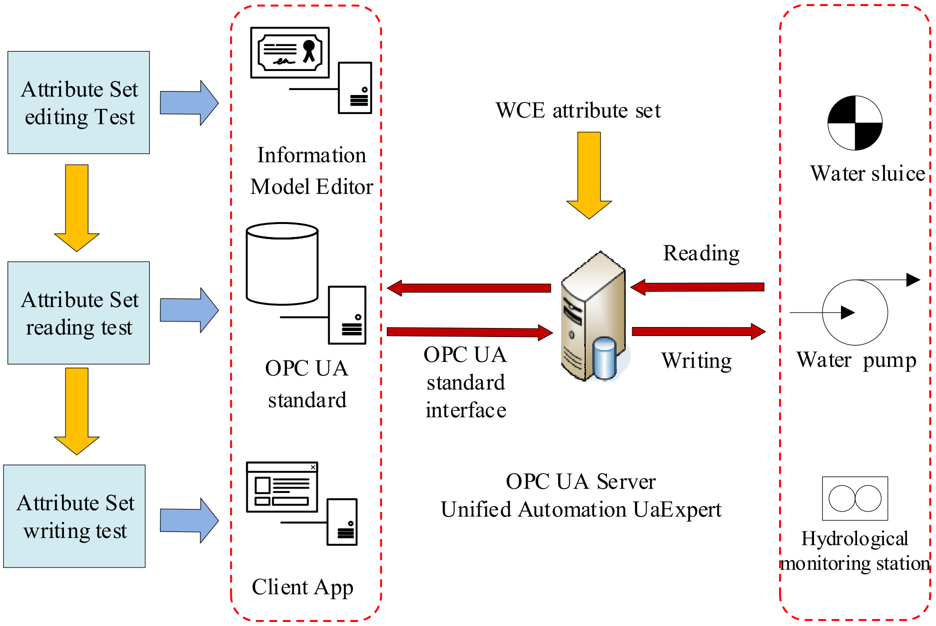
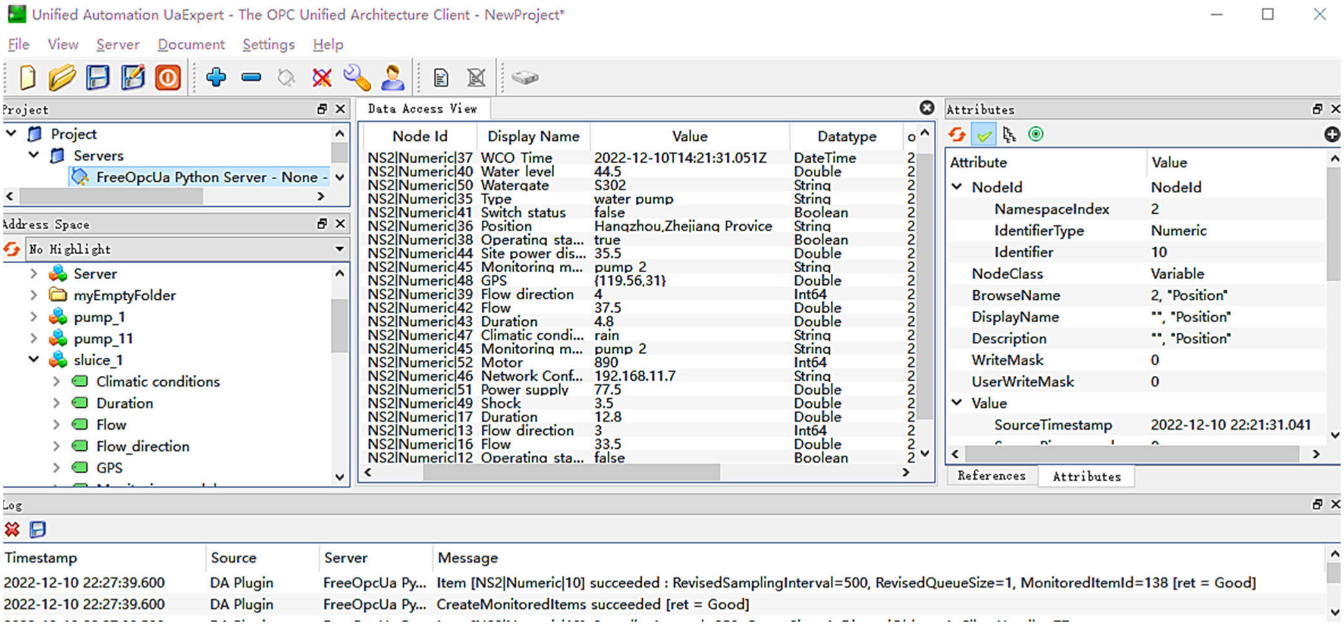


FIGURE 8. WCE OPC UA information model verification.

client test, which can ensure that the platform software is accessed by a variety of devices that comply with the OPC UA interface specification. The OPC UA Client connects the three types of WCE through the OPC UA server software. The OPC UA Client reads the attribute values and attribute elements of the three types of WCE in real time and executes the write command.

B. EXPERIMENTAL RESULT AND DISCUSSION

Figure 9 shows unified OPC UA client interface for data operating. The left side of the window displays the information model structure of WCE, with real-time data of model attributes displayed in the middle. The right side of the window displays the type, permissions, explanation, update time, and other characteristics of the specified attributes. The



Node Id	Display Name	Value	Datatype	o
NS2|Numeric|37	WCO Time	2022-12-10T14:21:31.051Z	DateTime	2
NS2|Numeric|40	Water level	44.5	Double	2
NS2|Numeric|50	Watergate	S302	String	2
NS2|Numeric|35	Type	water pump	String	2
NS2|Numeric|41	Switch status	false	Boolean	2
NS2|Numeric|36	Position	Hangzhou,Zhejiang Provice	String	2
NS2|Numeric|38	Operating sta...	true	Boolean	2
NS2|Numeric|44	Site power dis...	35.5	Double	2
NS2|Numeric|45	Monitoring m...	pump 2	String	2
NS2|Numeric|48	GPS	{119.56,31}	Double	2
NS2|Numeric|39	Flow direction	4	Int64	2
NS2|Numeric|42	Flow	37.5	Double	2
NS2|Numeric|43	Duration	4.8	Double	2
NS2|Numeric|47	Climatic condi...	rain	String	2
NS2|Numeric|45	Monitoring m...	pump 2	String	2
NS2|Numeric|52	Motor	890	Int64	2
NS2|Numeric|46	Network Conf...	192.168.11.7	String	2
NS2|Numeric|51	Power supply	77.5	Double	2
NS2|Numeric|49	Shock	3.5	Double	2
NS2|Numeric|17	Duration	12.8	Double	2
NS2|Numeric|13	Flow direction	3	Int64	2
NS2|Numeric|16	Flow	33.5	Double	2
NS2|Numeric|12	Operating sta...	false	Boolean	2

Attribute	Value
NodeId	NodeId
NamespaceIndex	2
IdentifierType	Numeric
Identifier	10
NodeClass	Variable
BrowseName	2, "Position"
DisplayName	"", "Position"
Description	"", "Position"
WriteMask	0
UserWriteMask	0
Value	
SourceTimestamp	2022-12-10 22:21:31.041

```
Timestamp                Source     Server           Message
2022-12-10 22:27:39.600  DA Plugin  FreeOpcUa Py...  Item [NS2|Numeric|10] succeeded : RevisedSamplingInterval=500, RevisedQueueSize=1, MonitoredItemId=138 [ret = Good]
2022-12-10 22:27:39.600  DA Plugin  FreeOpcUa Py...  CreateMonitoredItems succeeded [ret = Good]
```

FIGURE 9. Unified OPC UA client for data operating.

TABLE 3. Features comparison of WCE information models.

Model factor	Mode evaluation factor	Fragmented information point	OPC UA model	Structure and method of information interaction dimension modeling in this paper
Model architecture	Method	-	-	Formal modeling
	Structure	-	Mesh	Tree, mesh (attribute element implementation)
	Model language	-	XML extension	XML extension
	Information node relationship degree	-	Qualitative	Quantitative
	Model carrier	-	OPC UA address space	Improved OPC UA
	Model flexibility	-	Manual development	Automatic evolution
Semantic structure	Supported data types	No fixed types	Boolean、byte、int16、uint16、int32、uint32、float、string、datetime、guid、xmlelement, etc.	File, and others types compatible with OPC UA
	Semantic dimension	1（data only）	3	3
	Information node semantic attribute elements	-	Generally fixed	Rich, editable and modifiable
	Have semantic dictionary	-	Yes, fixed mode	Yes, very rich semantics
	Model semantic completeness	Fragmented and incomplete	Fixed mode	Coves all semantic services of WCE
Technical implementation	Synchronous data access	One-to-one	Mainly one-to-many	Many-to-many
	Modeling efficiency	-	Labor, low	Automation, high

bottom side of the window displays real-time communication information between the client and the server. This standard client fully displays the sluice_1. The data of the device and the ability to control the WCE unit by modifying the state of the read/write attribute switch states. The experimental results prove the semantic interoperability of WCE information model.

However, the unified OPC UA client lacks file interoperability, and needs to rewrite semantic interoperability instructions for file level communication. We have designed this application scenario separately, which is feasible in the laboratory environment when WCE terminal uploads image and video information, and when upper server downloads instruction cluster files.

Table 3 shows the comparison of semantic interoperability features of WCE in model architecture, semantic structure and technical implementation. Structure and method of information interaction dimension modeling in this paper is different from fragmented information point and OPC UA model.

In the model architecture, method is formal modeling, the structure has completed semantic structure, such as tree and mesh, model language is XML extension, which is versatility and convenience.

In the semantic structure, it supports file, and others types compatible with OPC UA, semantic dimension include three Semantic information interaction dimensions, more than fragmented information point's only data, information node semantic attribute elements are rich, editable and modifiable, and very rich semantic dictionary, coves all semantic services of WCE compare with others.

In the technical implementation, synchronous data access type is many-to-many, theoretically support a large number of WEC synchronous semantic interoperability. Modeling efficiency is Automation and high, and adapt to the trend of intelligent development.

Based on the theory and technology of WCE semantic modeling theory in this paper, compared with the semantic interoperability of WCE under the general fragmented information point and OPC UA model, it has the characteristics of strong semantic interoperability core capabilities, flexible and comprehensive service functions, strong service capabilities, and wide range of use. It adapts to heterogeneous WCE with limited information processing capabilities, and improves the semantic interoperability. At the same time, it is also noted that the implementation of the semantic information model through the OPC UA standard architecture requires more hardware and software costs, while the independent development of an adaptive tailoring structure can reduce the cost of the server platform and achieve semantic interoperability at the file level, but its versatility is not as good as the OPC UA standard architecture. Combining the OPC UA data gateway proposed in this paper may be a compromise solution.

VII. CONCLUSION AND FUTURE WORK

For WCE to realize smart water conservancy, it is necessary to realize semantic interoperability. WCE has heterogeneous information, a large amount of information, and physical relationships between information nodes. Research on the theory of information modeling for WCE is proposed. The proposed dimension theory of WCE's information include three information dimensions: numerical representation, data semantics, and the relationship between data. The information space information node attributes and mesh structure can reflect the WCE information dimension, so that the information demander can whole understand the semantic system and organizational structure of the WCE by the information supplier. Based on the theory of the dimension of WCE information interaction, a general information model for the hierarchical structure of the WCE component attribute set is constructed, and the WCE information nodes and XML language description methods are defined, the data frequency, attribute data priority, and attributes are defined. The correlations were analyzed and improved to improve the service efficiency of the information model. In the integration of SDK, based on standardized methods and models, the development cycle is further shortened based on the SDK. The OPC UA server can be independent of WCE, can also be paired with it as a data gateway, or can be fully embedded in WCE. Structure and method of information interaction dimension modeling in this paper has some advantage in semantic interoperability.

In future work, we plan to combine semantic and structural information and optimize the factorization rules. The interaction rules are more concise, so as to separate from basic development modules such as OPC UA, improve the convenience of system development, realize convenient interoperability of information models and documents, and it can be popularized and applied to equipment in other industrial equipment.

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