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Associating Semantic Sensor Web with Domain Ontology: The Way to Obtain Meaningful Sensor Data

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Abstract

To realize the sharing and reuse of sensor data and improve interoperability, semantic sensor web(SSW)is proposed to add semantics information to existing sensor networksby utilizing domain, spatial and temporal anthologies and other related semantic technology.However these is seldom research on how to fully utilize the sensor data through a semantic way such as domain ontology based inference. This paperpresents stateofthe art of SSWin various aspects,and proposesthe method to associate data from semantic sensor web with domain ontology to realize the communication between different domain ontologies and SSW. In addition, this paperalso proposes a new calculation method of semantic similarity amongdifferent entities in different ontology. Experiments show that this method can effectively find the similar entitiesandrealize the knowledge sharing and ontologies reuse.

Keywords: *semantic sensor web, ontology, semantic annotation, semantic similarity*

1. Introduction

Due to the characteristics of low cost and simple installment, there are many sensorscollecting various kinds of data, from simple phenomena to complex events. However, lack of unified operations and display standards, these data are isolated ininformation islands. It's difficult to discover useful information from large amountsof data, lots of sensor data left behind but little knowledge discovery.To solve this problem, the Open Geospatial Consortium (OGC) [1] proposed SWE (Sensor Web Enablement [1][6]) and relevant standards, depicting the sensor web. By developing a series of specifications related to sensors, sensor data models, and sensor web services, SWE is not only an interoperability framework, but also a set of web-based services, which allows discovering, exchanging, and processing of sensor data; but its standards are purely syntactic standards [3], it's insufficient to fully realize the knowledge-based reasoning and discovery. Moreover,it doesn't state the essence relations among data and the meaning of sensor observations clearly, still increasing the difficulty of the interoperability and the detection of situation awareness [9].

In order to obtainfurther information and knowledge, researchers propose SSW by adding semanticsthrough domain ontology andspatial and temporal ontology to the existing sensor network language standards. Withthe semantic web technologies, SSWhas the capability of enhancing semantics to sensor data, realizing sharing and reuse of sensor data, and improving the sensor interoperability as well.Sheth et al leveraged current standardization and semantic web and proposedSSW which is a framework for providing enhanced descriptions and meaning to sensor observations by adding semantic annotations to SWE[5]. Zhang holds the opinion that SSW is a kind of technology using time, space and theme metadata

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annotatingsensor data, which is designed to extendSWE functionsby use of semantic web technology and enhance descriptions and ability of sharing and reuse of sensor data [4].Durbha et al mentioned SSW annotates sensor data with semantic metadata, which increases interoperability and provides contextual information.The semantic data for sensor nodes usestemporal, spatial, thematic metadata[8].Pileggi thought SSW is a progressive concept that would improve current sensor web model with a semantic layer in which the semantic or meaning of information is formally defined [20].We believe SSW, combining SWE with semantic web and ontology, is considered as a framework that enhances the expressiveness of sensor data, providesabundant and meaningful semantic descriptionsfor sensor data, and realizes sensor knowledge reasoning. Itenablesinteroperability between heterogeneous multi-mode sensor data, and improves analysiscapabilities of situational awareness as well.

The remaining of this paper is organized as follows. In section 2, we give a comprehensive review on theresearch and application of SSW; section 3 gives a new mechanism of associating sensor with domain ontology and section 4 gives the concrete implementation method. Finally, section 5 draws a conclusion of this study.

2. SSWResearch and Applications

To deal with the issues like sensor data sharing and sensor network interconnection, researchers have done lots of related researches and made research achievements. We review the core technologies related with SSW in this section.

2.1. Semantic Web

Tim Berners-Lee who first proposed the semantic web believed it is a very promising technology, helping users to find the information, the answer and the product accurately. It’s an evolving extension of the World Wide Web. The semantic web is regarded as a platform of information and knowledge exchange for both man and machine [15]. Kong [11] described the semantic web as a massive distributed database, the content of the data, namely the semantics of the data as its core, with the computer-understandable and computer-processable way to link up. Its goal is to define and interconnect the web andit tries to make the computer understand the meaning of information to some extent; so it makes contributions to information sharing and reuse, allowing the web to provide dynamic, personalized, and initiative services [17]. It adds metadata in structured format to the existing web information. With the use of RDF, schemas and inference engine, data can be effectively queried [16].

2.2. Sensor Web Enablement

Mike Botts et al [2] introduce SWE being built is a unique and revolutionary framework for open standards. The models, encodings, and services of the SWE architecture allow implementation of interoperable and scalable service-oriented networks of heterogeneous sensor systems and client applications; it focused on developing standards to allow the discovery, exchange and processing of sensor observations, as well as the tasking of sensor systems. Figure 1 shows the framework of SWE.Sheth et al [5] introduced a series of core language and service interface specifications of SWE framework; the goal of SWE is to allow all types of web and/or Internet-accessible sensors, instruments, and imaging devices to be accessible and, where applicable, controllable via the web. However, A. Sheth and M. Perry [3] pointed out that the standards provided by SWE are purely syntactic standards specifications which are insufficient for realizing the discovery, exchange and

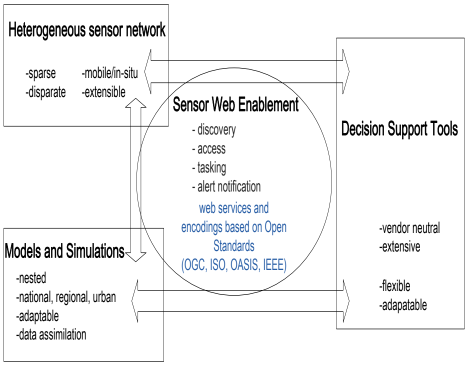


Figure 1.The Framework of SWE

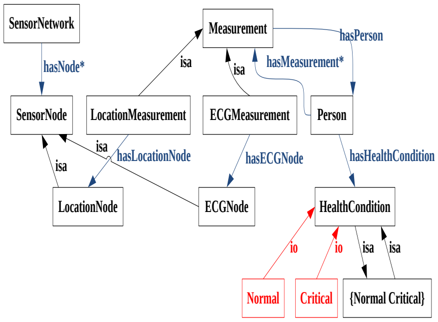


Figure 2. Example of Sensor Ontology

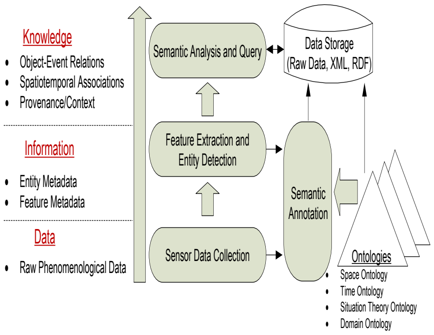
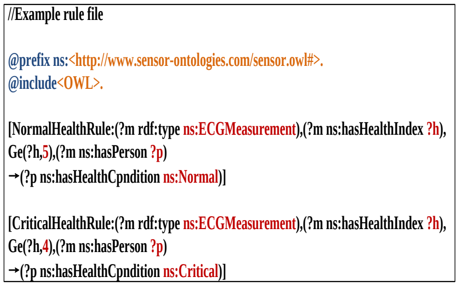


Figure 3. Semantic Sensor Data-to-Knowledge Architecture



```
//Example rule file

@prefix ns:<http://www.sensor-ontologies.com/sensor.owl#>.
@include<OWL>.

[NormalHealthRule:(?m rdf:type ns:ECGMeasurement),(?m ns:hasHealthIndex ?h),
Ge(?h,5),(?m ns:hasPerson ?p)
→(?p ns:hasHealthCpndition ns:Normal)]

[CriticalHealthRule:(?m rdf:type ns:ECGMeasurement),(?m ns:hasHealthIndex ?h),
Ge(?h,4),(?m ns:hasPerson ?p)
→(?p ns:hasHealthCpndition ns:Critical)]
```

Figure 4.Examples of Rules

processing of sensor data. Durbha et al [8] also proved such deficiency. During the last decade, a number of syntactic standardization and metadata standards have been proposed and developed. Though these standards alleviate the syntactic heterogeneity of the data to a large extent, the problem is still not completely solved.

2.3. Semantic Annotation

The semantic annotation is to derive relevant semantic metadata from the ontology for making the semantic streams understood. There are many languages that can be used to annotate sensor data. RDFa, a markup language and a W3C proposed standard, allows the layering of RDF information appearing in any XHTML or XML documents. A set of attributes provided by RDFarepresent semantic metadata within the XML language, RDF triples canbe extracted from these attributes using a simple mapping [5]. Examples of the location attributes encoded in RDF can be found in [13].

2.4. Ontology

Ontology means a specification of a conceptualization. To solve the problem that the same concept may have many lexical representations or the same word may have many meanings, it is necessary to introduce ontology and apply it into the domain of Internet research to help human communicate with machines, to support exchanges on the semantic level not just only on the syntactic level, and to provide more professional supports for the concepts and their relationships in certain domain. [14]. By obtaining knowledge in related domain, mutual recognition of vocabularies on behalf of the domain and multi-layer structure of these vocabularies will be gained, which would achieve a common understanding of domain knowledge. Ontology provides shared concept model for sense datasupporting sharing and reuse of sensor resources; it achieves sensor knowledge reasoning, offering favorable decision support to the human perception to the objective world [4]. A sample of sensor ontology is shown in Figure 2.

2.5. Rule-based Reasoning

In order to get more additional knowledge from semantically annotated sensor data, it is necessary to define and use rules. Many rule languages and rule-processing systems are also being developed. The W3C proposed SWRL as a standard rule language in the semantic web, which is based on OWL (Web Ontology Language) and uses the *antecedent → consequent* structure to define rules[5].The architecture of the semantic sensor Data-to-Knowledge is shown in Figure 3 and the rules which are used for deriving the health condition of a person based on the health index measurement is shown in Figure 4. [10]

2.6. SSW for Internet of Things

M. Alexandra proposed a system for publishing sensor data with the use of a relational database to store the data following the linked data principles and providing integration with the semantic web [12]. The main components of the system are the semantic enrichment component and data publishing component. To achieve maximum impact that the sensor web can have on the development of Internet of Things, challenges have appearednot only for the physical infrastructures, but also for data management and processing. But now, a semantic layer is added in the proposed system, which can enrich the sensor data and metadata. The system follows the principles of linked open data and uses standardized vocabulary for describing the data; the outputs of the system are data sets of semantic sensor description and real-time measurements.

2.7. Ontology Mapping

Ontology mapping refers to establish associations between concepts or relationships in different ontologies. Many methods about ontology mapping have been proposed in previous studies, including manual, semi-automatic, and automatic methods; some are using the machine learning [19]and some are using heuristic rules [2] to find the specific mapping model; others solve the ontology mapping by analyzing the semantic information of the elements in ontologies [22, 23].Among the methods of analyzing the semantic information, Maedche A et al. [21] adopted “edit distance” to compare concepts similarity and Doan AH et al. [19] used joint distribution probability of instancesexisting in concepts to calculate the concepts similarity. These methods depend on name match, resulting the calculations are not precise. Comprehensive methods of semantic similarity calculation can be found in [7, 18]. However, none solution is given to solve the problems such as how to aggregate multiple similarities and how to assign weights. In this paper, we present a new semantic similarity calculation method, considering the semantic similarity from three aspects: properties set, name of entities and structure characteristics of ontology. Based on the idea of “similarproperties, similar concepts”, the entity name and ontology structure act as the gain of property similarity, enablingthe semantic similarity calculation resultmore comprehensive.To evaluate our method, we adopt another method of semantic similarity in references [24]. Comparison results prove the effectiveness and operability of our proposed approach.

3. The Mechanism for Sensor and Domain OntologyAssociation

Sensor ontology, with sensor as its core, provides explicitshared conceptual model for the sensor and sensor observations, realizes semantic descriptionsfor characteristics of sensor itself, and achieves time, space, theme semantics for sensor data. By establishing the relations between sensor and domain ontology, sensor data in sharing and reuse can be achieved.Domain ontology, which is the ontology about certain specific domain, provides descriptions about relationships between concepts in certain professional discipline domain. The relevanceof sensor ontology to domain ontology could be found through the semantic relations, thus the integration of domain ontology with sensor ontology can be realized.

Table 1. Relevancy Algorithm

Relevancy Algorithm

O_1,O_2: two different ontologies;e_1,e_2:elementsin ontology;Sim: the value of semantic similarity; ss: the value of structure similarity; *preprocess()*//prepare synonym set

```
for each entity in ontologies
    $Sim = propertySim(O_1,O_2)$// calculate property similarity
    if $nameSim(O_1, O_2) == 2$ // $e_1$,$e_2$ has same name or belongs to synonym set
        $Sim += 0.5 – (Sim^2)/2$
    else if $nameSim(O_1, O_2) == 1$ //names of $e_1$,$e_2$ has inclusion relation
        $Sim += 0.25-(Sim^2)/4$
allSimSet// all entity pairs
qualifiedSimSet// the value of similarity is larger than threshold
for $(O_1, O_2, Sim)$ in allSimSet
    $ss = structSim(O_1,O_2)$// calculate structure similarity
    $Sim += (1-Sim)×ss×(Sim + ss)/2$// the semantic similarity
return qualifiedSimSet
```

Table 1. TheSimilarity Value of Each Entity Pair Given by Sim

S1 Sim S2	GS	master	doctor	CRS	SS	CNS
student	0.551	0.315	0.281	0.442	0.363	0.370
US	0.340	0.218	0.218	0.341	0.341	0.341
GM	0.516	0.685	0.218	0.510	0.233	0.256
GD	0.473	0.218	0.585	0.207	0.207	0.207
FM	0.500	0.510	0.216	0.605	0.225	0.225
EM	0.226	0.417	0.216	0.216	0.241	0.284
MBA	0.232	0.250	0.200	0.233	0.239	0.282

In Table 2 and table 3, "GS","CRS","SS", "CNS", "US","GM","GD","FM" and "EM" stand for "graduate_student","commoner_student","scholar_student","commission_student","undergraduate_student","graduate_master","graduate_doctor","fullday_master" and "engineering_master", respectively.

Table 3. TheSimilarity Value of Each Entity Pair Given by Sim

Sim S2 S1	GS	master	doctor	CRS	SS	CNS
student	0.61	0.3945	0.3333	0.5596	0.6288	0.5596
US	0.5556	0.5739	0.5282	0.4166	0.4929	0.4613
GM	0.5596	0.8792	0.3695	0.6893	0.7394	0.6893
GD	0.5012	0.4720	0.8126	0.6525	0.7246	0.6525
FM	0.6556	0.4606	0.3807	0.6091	0.6606	0.6091
EM	0.3762	0.6790	0.3172	0.6280	0.6790	0.6594
MBA	0.4001	0.4606	0.3774	0.6092	0.6606	0.6091

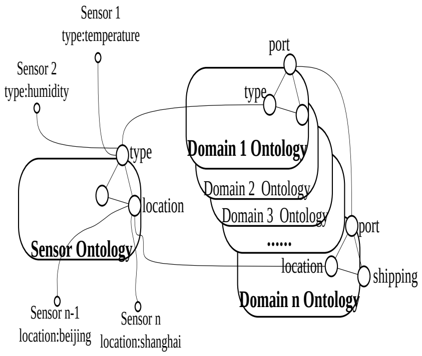


Figure 5.The New Mechanism Associates Sensor with Domain Ontology

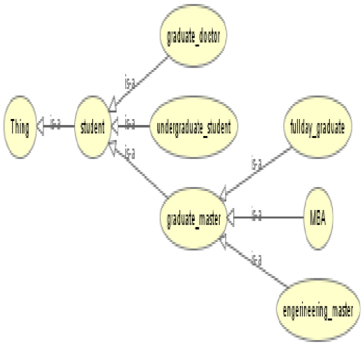


Figure 7. The Structural Drawing about Student1 Ontology

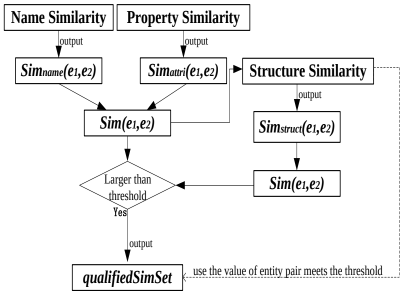


Figure 6.The Calculation Method about Semantic Similarity

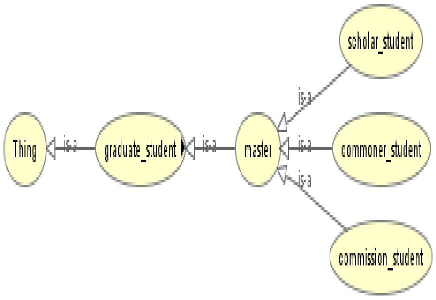


Figure 8. The Structural Drawing about Student2 Ontology

Previous studies have mentioned the relevance of sensor to sensor ontology, but none of them did researches aboutthe relevance of sensor to domain ontology. Now we associate sensor ontology with domain ontology to achieve the relevance of sensors to domain ontology, and put forward the operation mechanism of new intelligent applications for the upper layer based on the relevance between multiple sensorsand multiple domain ontology.

Here, we put forward a new mechanism which associates sensor with domain ontology and we show it in Figure 5.In order to maximize the support of the sensor data in sharing and reuse, associated entitiescan be found bythe semantic similaritycalculation and act as semantic annotations added for each sensor and sensor data and services based on SWE standard serve as the instances of domainontology, realizing the relevance of sensor todomain ontology. Finally, with the use of rule reasoning, better decision services can be achieved.

4. Semantic SimilarityCalculation

4.1. Property Similarity

The property is mainly composed of properties characteristics and range. Based on the idea of" same properties, same concepts; similarproperties, similar concepts", this paper considers the semantic similarity from the perspective of the property sets.

The property sets refer to a collection of properties about a certain entity. The properties in sets are mainly determined by properties characteristics and range.Property characteristics: composed of property's ID, name, label and its domain. Each property in ontology has the information above describing itself.

The range type of data properties is simple data type, but the range type of object properties is the concept defined in ontology.

Based on above theory, the similarity calculation formula about property set is defined as Eq. (4-1), where e_1, $e_2$refer to two elements in different ontology, their property sets are respectively expressed by set1 and set2;$|Set1 \cap Set2|$is the number of similar elementsin thesetwo property sets,$|Set1\text{-}Set2|$ is the number of different elementsin thesetwo property sets. $S_{i(e_{1attr},e_{2attr})}$stands for the similarity between $e_{1attr}$and e_{2attr}, which denote relevant properties in set1 and set2, depending on property characteristics and propertydatatype, $\sum S_{i(e_{1attr},e_{2attr})}$ represents the sum of properties similarity.

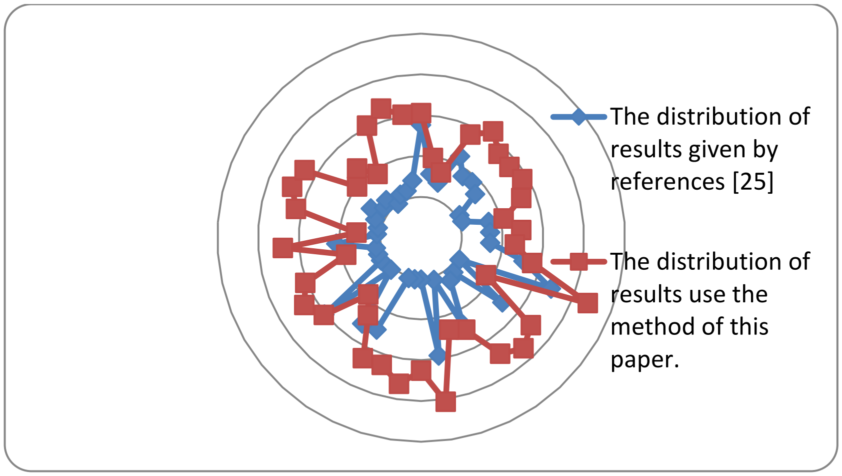


Figure 9. The Distribution of Results Given by Different Semantic Similarity Calculation Method

$$Sim_{attri}(e_1,e_2)=\frac{\sum_{i=1}^{i=n}S_{i(e_{1attr},e_{2attr})}}{|set1\cap set2|+|set1-set2|+|set2-set1|} \tag{4-1}$$

The calculation of property characteristics and the range of data propertyare based on the comparison on the similarity of the string. This paper adopts the edit distance algorithm to compare strings similarity. The strings similarity,$Sim_{string}(S_1,S_2)$,is defined as Eq. (4-2), where S_1, S_2 represents two different strings, their Levenshtein distance is given by $EditDist(S_1,S_2)$. The lengths of S_1 and S_2 are $|S_1|$ and $|S_2|$. The range about strings similarity from the Eq. (4-2) is between 0 and 1.And at this time the semantic similarity$Sim(e_1,e_2)$ equals the value of the property similarity.

$$Sim_{string}(S_1,S_2)=\frac{|EditDist(S_1,S_2)-\max(|S_1|,|S_2|)|}{\max(|S_1|,|S_2|)} \tag{4-2}$$

$W_{attridesc}$ and $W_{attritype}$ aredifferent weights assigned for standing forthe calculation results of property characteristics and propertydatatype, and$W_{attridesc}+W_{attritype}=1$.

Besides, iterative formula (4-1) calculates the range of object properties.

The range aboutproperty similarity$Sim_{attri}(e1,e2)$ is between 0 and 1 as well.

4.2. Name Gain

This article considers the name similarity from three aspects: similar, contained and unrelated. On the basis of above theory, synonym setshould be given. If two concepts exist in this synonym set at the same time, these two concepts are considered to be same. Eq. (4-3) gives thecalculation about name gain.

$$Sim(e_1,e_2)+=0.5-(Sim(e_1,e_2)\wedge 2)/2 \tag{4-3}$$

If two concepts don't existin synonym set, but inclusion relation exists in the name of these two concepts, Eq. (4-4) gives thecalculation about name gain.

$$Sim(e_1,e_2)+=0.25-(Sim(e_1,e_2)\wedge 2)/4 \tag{4-4}$$

In addition to above two cases, we think these two concepts have no relation and have no gain, so we don't give the calculation about name gain.

4.3. Structure Gain

The paper only considers the structure similarity from the perspective of class,obtaining corresponding information structure via the hierarchical information between super class and subclass. The structure similarity is defined as Eq. (4-5), where e1, e2refer to two elements in different ontology, and n is the number of entity pairs which the value of property similarity and name gain is greater than the threshold.The similarity of each entity pair is expressed by $Sim_i(e1,e2)$, and d_{i1},d_{i2} represent the D-value of depths of e1, e2elements relative to the i_{th}entity pair.

$$Sim_{struct}(e_1,e_2)=\frac{1}{\max(d_{e_1},d_{e_2})}\times\sum_{i=1}^{n}\frac{Sim_i(e_1,e_2)}{|d_{i1}-d_{i2}|+1} \tag{4-5}$$

The range aboutstructure similarity give by Eq. (4-5) is between 0 and 1. Eq. (4-6) defines the calculation about structuregain.

$$Sim(e_1,e_2)+=\frac{1}{2}(1-Sim(e_1,e_2))\times Sim_{struct}(e_1,e_2)\times(Sim(e_1,e_2)+Sim_{struct}(e_1,e_2)) \tag{4-6}$$

4.4. Semantic Similarity

Figure 6 shows the calculation method about semantic similarity given in this paper.Suppose we have two ontologies, O_1 and O_2; e_1,$e_2$refer to two elementsin these two ontologies, their semantic similarity are given by $Sim(e_1,e_2)$. Compared with predetermined threshold, the value of the entity pair larger than threshold is retained.

In actual operation process, changing the threshold in a set of training sample set can determine the threshold. By experimental results and analysis, the threshold with highest accuracy acts as final threshold.

4.5. Relevancy Algorithm

Based on above sections about the calculation of the semantic similarity, table 1 gives the key steps of algorithm.

4.6. Algorithm Comparison

To prove the validity of the proposedmethod and good distribution of results, same data source but different similarity calculation method has been used to make a comparison between the results of ontology mapping in this section. The data source and similarity calculation method are from references [24].

Figure7 and figure8 show the structural drawings about student1 ontology and student2 ontology from references [24].

Their properties are listed as follows: R1={ number,name,sex,birthdate,department,enrollmentdate,lengthofschooling,politicalcharacter,telephone,nativeplace,address}, R2={ number,name, age, sex,department, major, enrollmentdate,lengthofschooling,politicalcharacter,telephone,nativeplace,address}, and the similarity values of each entity pair given by *Sim* are listed in table 2.

The similarity values using semantic similarity calculation of each entity pair of this paper given by *Sim*are listed in table 3.

Figure 9 gives the distribution of resultsby these two kinds of similarity calculation method.From figure9, conclusionsare drawnas follows:relative to singleaspect to calculate semantic similarity, comprehensive calculation method of semantic similarity makes the results more fully and reasonable; besides, the calculation results have a better distribution, enabling threshold have a wider choice to some extent to find any association between entities as more as possible andwell complete the mapping between different ontologies.

5. Conclusion

By incorporating the standards of OGC and W3C, researchers have proposed semantic sensor web, which provides an environment for enhanced query and reasoning within the sensing domain. Great potential for semantic sensor web can be seen in various domains, including weather forecasting, oceanography, biometrics, videos on the web and Event Web. This paper gave a complete review on the current SSW research work and applications, a new calculation method of semantic similarity between different entities in different ontology is also presented to associate SSW with domain ontology. In the future work, we will keep working on the optimization methods and reasoning mechanism to utilize the ontology associated SSW.

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