OntoWind: An Improved and Extended Wind Energy Ontology

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Abstract Ontologies are critical sources of semantic information for many application domains. Hence, there are ontologies proposed and utilized for domains such as medicine, chemical engineering, and electrical energy. In this paper, we present an improved and extended version of a wind energy ontology previously proposed. First, the ontology is restructured to increase its understandability and coverage. Secondly, it is enriched with new concepts, crisp/fuzzy attributes, and instances to increase its usability in semantic applications regarding wind energy. The ultimate ontology is utilized within a Web-based semantic portal application for wind energy, in order to showcase its contribution in a genuine application. Hence, the current study is a significant to wind and thereby renewable energy informatics, with the presented publicly-available wind energy ontology and the implemented proof-of-concept system.

Keywords wind energy · renewable energy · ontology · semantic modeling

1 Introduction

It is commonly acknowledged that domain ontologies are significant sources of semantic information [7]. Hence, new ontologies are being constructed for many different domains and they are effectively utilized within relevant applications in these domains. To name a few, in [3], a domain ontology for molecular biology is proposed. In order to perform public health surveillance, an ontology for this domain is created and described in [10]. A domain ontology is presented in [4] for the processes in infrastructure and construction. In [1], an ontology for the domain of materials science and engineering is described. A domain ontology for chemical process engineering is proposed in [15]. Regarding software systems, a Web service modeling ontology to describe all aspects of Web services is presented in [13], an ontology for scientific software metadata is proposed in [6], and an ontology to model the variability in software product modeling is presented in [2].

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The domain of energy is similarly a fruitful domain for semantic applications. For different applications in the energy domain, the conceptual modeling of the relevant energy subdomain is required and this phase will extensively benefit from domain ontologies. Similarly, ontologies will also alleviate the interoperability problems between different applications. Yet, there are few examples of domain ontologies regarding this domain and its subdomains. For instance, in [13], a domain ontology to model the electrical power quality parameters and events is described. In [12], a domain ontology for wind energy which was constructed through a semi-automated procedure is presented. A high-level covering ontology for the domain of electrical energy is presented in [11] where this ontology was also aligned with the aforementioned electrical power quality and wind energy ontologies. An ontology for energy efficiency in smart grid neighborhoods is presented in [14], and finally an ontology matching system for the smart grid domain is described in [20] which aims to reduce the related interoperability issues.

In this paper, we present an improved and extended version of the wind energy ontology proposed in [12], in order to increase its understandability, coverage, and usability. We first reorganize the existing ontology hierarchy, add new concepts, attributes, and instances, in order to arrive at a more useful and extended wind energy ontology. We make the ontology publicly-available and utilize it within a Web-based semantic portal application for wind energy. The rest of the paper is organized as follows: In Section 2 the extended and improved wind energy ontology is described. Section 3 presents the semantic portal application in which the ultimate ontology is used and finally, Section 4 concludes the paper with a summary and pointers to future work.

2 Extended and Improved Wind Energy Ontology

2.1 Initial Version of the Wind Energy Ontology

The initial wind energy ontology has been created through a semi-automatic procedure over Wikipedia articles related to wind energy [12]. In the first phase of this procedure, related Wikipedia articles are automatically processed to determine the high-frequency ngrams from the articles, and in the second phase, the resulting ngrams are manually organized into a wind energy ontology. The schematic representation of the concepts of this ultimate ontology with their interrelationships is given in Figure 1 as excerpted from [12]. The ontology has also been publicly shared for research purposes at http://www.ceng.metu.edu.tr/~e120329/wont.owl as a Web Ontology Language (OWL) file.

In order to include it within the larger electrical energy ontology with weighted attributes [11], the ontology has been extended to include weighted attributes and this extended version is again publicly shared at http://www.ceng.metu.edu.tr/~e120329/FWONT.owl. This form of the ontology is henceforth referred to as WONT due to the name of its initial OWL file and the electrical energy ontology [11] is henceforth referred to as FEEONT, based on the name of its publicly-available OWL file at http://www.ceng.metu.edu.tr/~e120329/FEEONT.owl.

2.2 Improved and Extended Wind Energy Ontology

In the current study, we have improved and extended WONT in order to make it more useful for applications related to wind energy. The final improved and extended wind energy ontology is henceforth referred to as OntoWind (ONTology for WIND energy).

All of the extensions and improvement efforts are carried out using the Protégé ontology editor [17] and the commonly-employed ontology development methodology described in [16] is roughly followed.
Fig. 1. The Initial Version of the Domain Ontology for Wind Energy [1, 2], i.e., WONT.
In the following subsections, the main procedures employed to construct OntoWind based on WONT are described.

2.2.1 Restructuring

The main concepts in WONT are restructured to better separate the different concept groups. In WONT, the concept hierarchy tree was a rather short one, as the concept-subconcept (or, class-subclass) relations were not exhaustively specified. By taking a top-down approach, we first determine the top general concepts of the wind energy domain and the resulting four general concepts in OntoWind are illustrated in Figure 2. Next, the existing concepts in WONT are re-modeled by putting them under their relevant general concepts. Along the way, we exclude some concepts like the PowerQuality which was included in WONT to model the power quality characteristics of wind energy, as OntoWind can be integrated with external power quality domain ontologies like PQONT to model these characteristics.

The ultimate concept hierarchies grouped under the four general concepts of OntoWind are provided schematically in Figure 3.

The top general concepts of OntoWind are described below:

- **WindRelatedData**: This concept and its subconcepts given as a tree structure in Figure 3 are used to model the measurement and forecast data related to wind energy. For instance, meteorological forecasts obtained by running the numerical weather prediction (NWP) models as well as meteorological measurement outputs through the related sensors are all represented by the corresponding meteorological data concepts included in the ontology. Namely, these concepts include WindSpeed, WindDirection, Temperature, Humidity, in addition to others. The main attributes of these concepts are value corresponding to the actual measurement/forecast data and date corresponding to the actual time that the data value belongs to.

- **WindRelatedModel**: This concept represents the wind-related NWP and wind power forecast models. Hence, it has the corresponding concepts of NumericalWeatherPrediction and WindPowerForecastModel for these models. These subconcepts, in turn, have the related commonly-used NWP models.
Fig. 3 The Concept Hierarchies under the General Concepts in OntoWind.
such as ALADIN, IFS, and WRF, and wind power forecast models such as ANFIS, ANN, and SVM as their subconcepts.  

– WindRelatedStructuralComponent: This concept represents the physical components within a wind power plant (WPP). Hence, it has subconcepts such as WindPowerPlant, WindTurbine, and Sensor as its subconcepts. The concepts in this category have the necessary object attributes to represent the details of the corresponding structural components. For instance, WindPowerPlant has the related attributes to model the characteristics of WPPs such as its geo-referenced location information, installed capacity, number of turbines, etc.

– WindRelatedOrganization: This concept represents the international and national organizations, and commercial companies related to wind energy. Therefore, it has subconcepts such as InternationalOrganization and NationalOrganization to model those organizations with finer granularity. Common organizations such as research centers, national weather services, and electricity transmission system operators are all modeled with the concepts under this category.

2.2.2 Extensions

Apart from the general restructuring efforts to arrive at OntoWind, it also includes several extensions over WONT.

First of all, new relevant domain concepts are added to the ontology to increase its coverage. For instance, in order to model the national and international organizations related to wind energy, several concepts are added under the generic concept of WindRelatedOrganization, as previously described. Similarly, several common models for numerical weather prediction and wind power forecasting are included as subconcepts under the generic concept of WindRelatedModel.

Secondly, several annotation attributes are added to the ontology to make it applicable in different semantic applications. For instance, we have added the textual attributes of webAddress and twitterAccount especially for the prospective instances of the subconcepts of WindRelatedOrganization. The former attribute will be used to model the Web site of the wind-related energy organization, while the latter is used to hold the address of its official Twitter account, if any. Similarly, another attribute named country is added to hold the country codes of the national wind-related organizations.

Finally, plausible instances (also called objects or individuals) are included in OntoWind to again make it a useful resource for Semantic Web applications. A total of 25 instances, belonging to the subconcepts modeled under WindRelatedOrganization, are added to OntoWind. The numbers of instances per their immediate concept types are given in Figure 4.

The names of the instances and the attributes of one of them, namely, MGM denoting Turkish State Meteorological Service, are illustrated in Figure 3. MGM is an instance of the NationalWeatherService concept which is a subconcept of GovernmentalEnergyOrganization and it, in turn, is a subconcept of NationalOrganization subconcept of WindRelatedOrganization. The readers are referred to the concept hierarchies provided in Figure 3 for a schematic view.

Figure 5 also demonstrates the use of the aforementioned new attributes of OntoWind, namely, country, webAddress, and twitterAccount. The remaining ones are the already existing attributes from WONT and FEEONT, and they are explained below again, for the purposes of completeness:

1 The following are the open forms of the abbreviations used in the concept names:

ALADIN: Aire Limitée Adaptation dynamique Développement InterNational
IFS: Integrated Forecast System
WRF: Weather Research and Forecasting
ANFIS: Adaptive Neuro-Fuzzy Inference System
ANN: Artificial Neural Network
SVM: Support Vector Machine
Fig. 4 Number of Instances per Concept Names in OntoWind.

- **label**: This attribute holds the exact concept name.
- **labelEN**: This attribute holds the most common English phrase referring to the concept.
- **membershipValueLabel**: This attribute holds the degree of membership of the value in labelEN to the domain of wind energy. The degree of membership is a real number between [0,1]. This attribute and similar attributes have previously been utilized to denote the weights of the corresponding attributes (like labelEN) within FEEONT [11]. In [11], Wikipedia’s disambiguation pages have been used to determine the weights. In this study, we manually determine these weights based on expert judgement instead of the order in the Wikipedia’s disambiguation pages. In [11], if the sense related to wind energy is in the $n^{th}$ place among the entries in the disambiguation page corresponding to the value of labelEN, then the value of membershipValueLabel is set to $1/n$. This is the reciprocal rank metric used in information retrieval and question answering literature [21]. As previously mentioned, we have used expert judgement to manually determine the value of membershipValueLabel as a real number between [0,1]. The values of all attributes beginning with membershipValue are similarly determined. Also, the existing values in WONT for such attributes are revised in case a change of value is needed.
- **labelTR**: This attribute holds the most common Turkish phrase referring to the concept. As it has been pointed out in related work like [13] and [11], attributes like labelTR facilitate the use of the ontology in multilingual settings. For instance, to extend the ontology to other languages like Spanish or French, attributes like labelES and labelFR can be added to the ontology with the corresponding values in these languages.
- **membershipValueLabelTR**: This attribute holds the degree of membership of the value in labelTR to the domain of wind energy.
- **synonymSet**: This attribute holds the list of English synonym phrases corresponding to this concept, if any.
- **membershipValueSynonymSet**: This attribute holds the list of the degrees of membership of the list of elements in the value of synonymSet to the domain of wind energy.
- **synonymSetTR**: This attribute holds the list of English synonym phrases corresponding to this concept, if any.
- **membershipValueSynonymSetTR**: This attribute holds the list of the degrees of membership of the list of elements in the value of synonymSetTR to the domain of wind energy.
As described above, the attributes beginning with membershipValue hold weighted values corresponding to fuzzy membership functions, as previously explained in [11].

All of the 25 instances of OntoWind, shown in Figure 5, correspond to national or international organizations related to wind energy. Apart from MGM which models Turkish State Meteorological Service, other instances include international organizations like ECMWF (denoting European Centre for
Medium-Range Weather Forecasts) and WMO for World Meteorological Organization, and national ones like CENER which is a Spanish institute for renewable energy research and NCAR which corresponds to National Center for Atmospheric Research of the USA.

The final form of the improved and extended wind energy ontology, OntoWind, is made publicly-available at [http://www.ceng.metu.edu.tr/~e120329/OntoWind.owl](http://www.ceng.metu.edu.tr/~e120329/OntoWind.owl) as an OWL file. To summarize its characteristics again, OntoWind is an extended and reorganized wind energy ontology which:

- supports multilinguality with its relevant attributes such as labelEN, labelTR, synonymSet, and synonymSetTR, and the ontology can be extended with similar attributes for other languages as previously pointed out,
- supports attributes conveying crisp as well as weighted information (such as membershipValueLabel and membershipValueLabelTR) for the other attributes,
- can also be considered as a larger knowledge base including the ontology concepts and their hierarchies as well as concept instances (as illustrated in Figure 5).

3 Semantic System for the Surveillance of Wind Energy Information

In this section, we present a semantic portal for wind energy surveillance on the Web, based on OntoWind as the underlying source of semantic information. The portal enables its users (i) to examine the concepts in OntoWind ontology, (ii) to view the wind-related research organizations with links to their official Web sites and Twitter accounts, which correspond to the instances of OntoWind ontology, and (iii) to observe the automatically-extracted wind-related scholarly articles. A snapshot of this Web-based semantic portal application is provided in Figure 6. The application is implemented using Java programming language, JavaServer Faces (JSF) technology and PrimeFaces JSF library as the underlying technologies, and Java OWL API to programmatically access OntoWind as an OWL file.

On the left panel of the portal, the taxonomy of the OntoWind concepts are provided in the form of a tree. The tree is automatically generated by processing OntoWind using Java OWL API. The users can freely examine all of the ontology concepts through this panel.

On the right panel of the portal, OntoWind’s concept instances described in the previous section are listed. All of these instances are significant organizations related to wind energy, that are automatically extracted from OntoWind. Based on the values of the webAddress and twitterAccount attributes of these instances, related buttons to access the Web sites and official Twitter account pages of these organizations automatically appear.

The final and the most significant feature of the semantic portal for wind energy is the panel appearing at the center of the portal page. This panel presents automatically-extracted content from the Web, using OntoWind as the underlying semantic resource. In its current form, it basically presents automatically-extracted scholarly articles related to wind energy. We have implemented this proof-of-concept extractor system, we have followed the categorization strategy previously proposed in [11]. That is, we have built a text categorization system based on OntoWind, which categorizes a given text as related to the wind energy domain, if it includes at least one concept from OntoWind and the sum of the values of the membershipValueLabel attributes corresponding to the included concepts is at least 1.0. Otherwise, the text is categorized as irrelevant to the wind energy domain.

In order to test our categorizer, we have used 91 articles related to the energy domain which have been published in the 134th volume of Elsevier’s Energy journal. For each journal article, we

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2 We should note that the first two characteristics are not specific to OntoWind, as the first one is a characteristic of both PQONT [13] and FEEONT [11], and the second one is a characteristic of FEEONT.

3 134th volume is the most recent volume of the journal, at the time of writing this paper.
have executed our categorizer on a piece of text including the title, abstract, and keywords of this article. We have built a similar categorizer for comparison purposes, which employs WONT instead of OntoWind, and this categorizer is also executed on the same article texts. In order to create the answer key using which the performance rates of the categorizers will be calculated, we have manually annotated each article in the set of 91 articles as relevant or irrelevant to the wind energy domain. At the end of this process, it is found that 12 articles are related to wind energy while 79 articles are not. Based on this answer set, the performance evaluation results of the OntoWind-based and WONT-based categorizers are presented in Table 1.

When the results in Table 1 are examined in details, we see that both the OntoWind-based and WONT-based categorizers are good at finding the relevant articles. Yet, WONT-based categorizer spuriously outputs irrelevant articles as relevant as revealed with the high number of false positives. In general, it can be concluded that the performance of the categorizer based on OntoWind is highly favorable and better when compared with the results obtained by the WONT-based categorizer. This finding provides evidence for the coverage and utility of OntoWind in semantic applications.
We have previously stated that a similar categorization experiment has been reported in [11]. In the experiment given in [11], the data set contains articles from many different domains while in the current study, the articles are already from the energy domain in general which makes it harder to extract those ones relevant to the specific domain of wind energy. This difference in the data sets also explains the performance difference of the OntoWind-based categorizer of the current study and the categorizer presented in [11] which achieves an accuracy of 99.09%.

Our main objectives in this categorization experiment are (i) to showcase the practical contribution of the improved and extended OntoWind ontology over its predecessor, WONT, which is revealed with the findings given in Table 1 and (ii) to use the automatically-extracted articles by the OntoWind-based categorizer in our semantic wind energy portal as shown in the middle panel of the portal shown in Figure 6. The middle panel titled “Scholarly Articles Related to Wind Energy” also facilitates access to the actual publisher pages of these articles through the accompanied links.

The semantic wind energy portal application is a proof-of-concept system and an initial prototype. The following extensions to this application are envisaged as part of future work:

- The portal will be extended to list recent automatically-extracted news articles related to wind energy, so that it will be a plausible information hub for semantic information related to wind energy.
- Similarly, recent social media content related to wind energy like relevant tweets will also be automatically extracted and presented through the portal.
- Currently, the semantic portal for wind energy is not publicly accessible. After the above mentioned extensions, we will make the portal accessible through the Internet.

As wind energy and renewable energy resources in general are important research topics with considerable public impact, we believe that both our extended and improved ontology, OntoWind, and the semantic portal application for wind energy are important contributions to the related literature.

4 Conclusion

Wind energy is a ubiquitous renewable energy type and several research topics regarding wind energy still need extensive efforts to fulfill the research needs. One of these topics is the representation and application of semantic information regarding wind energy. In this study, we present an extended and improved wind energy ontology, called OntoWind, in order to conveniently represent the semantic information in the wind energy domain. We restructure, improve, and extend an existing semi-automatically created ontology for this domain by adding new concepts, attributes, and instances to arrive at OntoWind. After making it publicly-available, we have developed a semantic portal for wind energy utilizing the final form of the ontology, hence showed its contribution to a genuine semantic application. The portal currently presents automatically extracted scholarly articles in addition to the concept taxonomy and instances of OntoWind. As part of future work, we plan to extend the portal to publish other semantic content related to wind energy, like recent news articles and social media content. Other directions of future work include similarly building ontologies for other renewable energy resources and then consolidating them to make them applicable to significant semantic applications regarding renewable energy and energy in general.

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