Ontology for Home Energy Management Domain

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Abstract. This paper focuses on an approach to build ontology for home energy management domain which is compatible with Suggested Upper Merged Ontology (SUMO). Our starting point in doing so was to study general classifications of home electrical appliances provided by various home appliances vendors and manufacturers. Various vendors and manufacturers use their own arbitrary classification instead of using a single standard classification system for home appliances and there exists no uniformity of appliances specifications among these vendors. Although appliances vendors provide energy efficiency rating of home appliances but they do not provide the detailed specification of the attributes that contributes towards their overall energy consumption. In the absence of these attributes and non existence of a standard ontology it is difficult for reasoning tools to provide a comprehensive comparison of home appliances based on their energy consumption performance and also to provide a comparative analysis of energy consumption of these appliances.

Keywords: Home Energy Management System, Ontology, Energy Efficiency, Sustainability, CO_2 Footprint

1 Introduction

Traditionally ontology engineering research has paid much attention to knowledge representation tools and formalisms such as KIF [1] and Ontolingua [2] but recent years have seen the shift of focus from knowledge representations to methodologies for constructing ontologies[3]. Knowledge acquisition methodologies such as KAD CommonKAD [4] and Protégé [5] are based on knowledge-level modeling frameworks and allow building of models to be used by problem solvers. Developing reusable/shareable ontologies to be used by various problem solvers is a challenging task even in presence of myriad of knowledge representation and knowledge acquisition frameworks. These challenges may include syntactical and semantic mismatch among concepts and their relationships.

This paper focuses on development of home electrical appliances domain ontology in particular inheriting from concepts and relationship described in SUMO ontology [6]. SUMO is an upper foundation ontology that could be used by variety of problem solving programs and it is available freely and owned by the IEEE.

The proposed ontology is a part of Digital Environment Home Energy Management System (DEHEMS) project [7]. DEHEMS is EU funded initiative to influence energy consumption behavior of household by providing the advice on efficient energy consumption and visibility to their energy consumption data.

The main objective of building electrical appliance ontology is to provide ontology that encompasses knowledge of home appliances and various energy consumption activities carried out by these appliances, their context, causality and relationships. We are less concerned with mechanical and physical properties of these appliances those do not have explicit information on energy consumption behavior of appliances.

Ontological modelers in different domains may represent same concepts and entities in real world using different terminologies which are not supposed to occur, but this kind of modeling flexibility results in limited or no interoperability of vocabularies. In order to address the challenges of interoperability a domain independent ontology that acts an abstract layer on top of domains ontologies is needed which ties together individual domain ontologies. SUMO is domain independent ontology that addresses the challenge of knowledge sharing between various information or knowledge based systems.

Current available classifications form manufacturers and vendors of electrical appliances, and electrical appliances ontologies [8, 9, 10] being used in smart home environments do not comply with a single standard. Moreover these ontologies use their own terms to describe conceptions and relationships in the domain. Such ad-hoc approach to ontology development leads to interoperability issues and restricted knowledge sharing. The motivation of this effort is to address the challenge of interoperability in home energy management domain by complying our proposed ontology with well accepted ontology interoperability standard [6].

The aim of complying our proposed ontology with SUMO is to allow knowledge sharing and information retrieval by making use of generic structure and concepts provided by SUMO. SUMO is upper level, domain-independent ontology which provides a framework by which disparate systems can utilize a common knowledge base and from which more domain-specific ontologies can be derived. SUMO supports metadata interoperability that allows the knowledge sharing of the proposed ontology with other SUMO compliant ontologies.

The proposed ontology provides a knowledge structure for reasoning sub-system in DEHEMS system. The ontology encodes knowledge of home appliances, their energy efficiency, and knowledge of energy saving strategies/tips.

The ontology allows the comparison between various brands of electrical appliance based on their energy consumption characteristics. Such comparison proves a valuable advice tool for household in buying new appliances and in comparing the energy consumption of DEHEMS users with other similar households in their locality.

The ontology has potential to be adopted by vendors and manufacturers of home appliances to create a uniform classification of home appliances that allows automated reasoning over energy efficiency related characteristics of the appliances. In DEHEMS the ontology enables the reasoning system to make energy consumption visible based on various categories and generate advice on appliances efficient energy usage.

2 Home Appliance Ontology Knowledge Acquisition

Domain ontologies have large number of domain specific concepts and rich relationships between these concepts. Various approaches of ontology design have been proposed by researchers. We follow the methodology proposed by Uschold et.al [11] to define ontology. Their methodology is consists of following three phases.

a) Brainstorming: Have brainstorming session to identify all potential concepts and phrases in the domain of interest.
b) Grouping: Structure the terms into provisional categories.
c) Refine the grouping and identify the semantic cross-reference between areas.

To capture appliances and thier energy efficiency knowledge we have complied related terms and relationships by obtaining home appliances specification from various venders and manufacturer websites. The knowledge of the various energy consumption activities associated with these appliances is encoded as pieces of efficient energy usage advice and it relation to abnormal energy usage. The ontology includes definitions of concepts and properties adopted in part from SUMO and extend these generic concepts to include home appliances concepts in SUMO.

Ontologies in several domains have been implemented by extending SUMO but to our knowledge there is no effort exists in literature that extends SUMO to implement domestic electrical appliances ontology.

The SUMO ontology was created by merging publicly available ontological contents into a single, comprehensive structure [6]. In SUMO concrete entities are represented by Physicals, while abstract entities are represented as Abstracts. SUMO promotes the interpretability among various ontologies by providing more general concepts and allowing the implementation of domain ontologies by using these concepts. The SUMO ontology comprises low-level details ontologies for various domains such as computing military finance, geography, time, economy, and transportations, etc, our proposed ontology will be the one of domain ontology in SUMO.

We also incorporate household information in ontology in order to associate appliances with households (all family and family members individually) and of residency unit. Various domestic appliances are associated with family members individually and collectively. For example fridge, microwave and TV are mostly used collectively by family members while some other appliances such as HI-FI and hair straighter may be used by family members individually. This association allows reasoning system to alert family members of their combined and individual energy usage, in order to help them avoiding their weekly/monthly set targets for energy consumption.

The ontological representation allows classifying energy consumption appliances in various groups such as kitchen energy consumption, bedroom energy consumption and entertainment devices energy consumption, heating energy consumption and washing energy consumption etc.

Such knowledge representation also allows us to make energy consumption comparison at social level thereby allowing household to share knowledge of efficient energy consumption among members of DEHEMS community. Figure 1 below depicts the association between family unit residency and home appliances using SUMO concepts.

One of the goals of DEHEMS is to enable various kind of comparison of energy consumption among similar member and family unit within DEHEMS community in order to allow the people to have comparative view of their energy consumption within their local community.

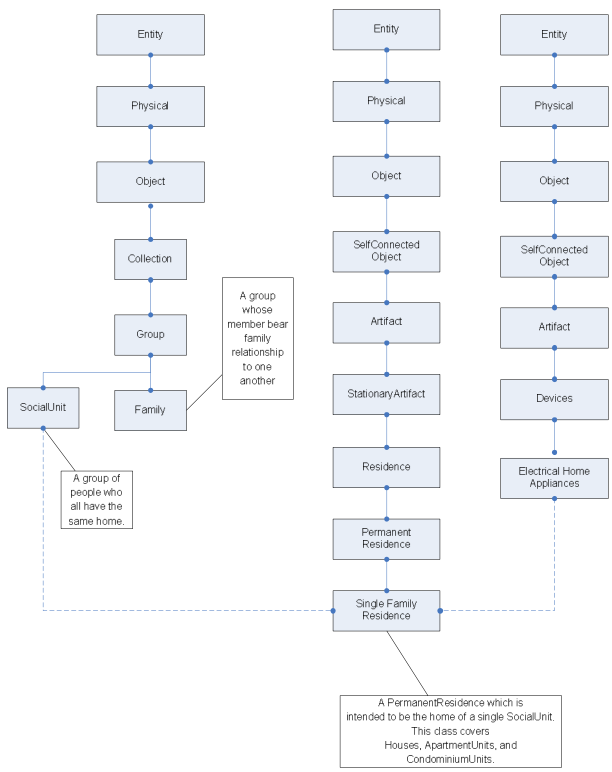

Fig.1. Relationship between Appliances and Household in SUMO

4. Ontology Implementation

Traditionally home appliances ontologies have been used in home automation system to control varieties of energy consumption appliances and devices. The focus of these ontologies is to provide semantic interoperability between heterogeneous components in smart home environments [8, 9] and the most automation actions supported by these ontologies are not energy aware. The fundamental issue with these efforts is that the ontologies implementations were driven by their specific needs, without any regard to knowledge sharing with other information systems. Although the home automation systems mange comfort of the home environment, but energy consumption management is not their primary goal [9]. There are also some efforts to implement ontologies for energy efficiency in smart homes. One of such effort is ThinkHome ontology [10] which is part of energy efficient smart home system. ThinkHome ontology is concerned with concepts related to thermal comfort, building information and external weather; and it does not encode energy consumption related concepts at appliance level. The ontology uses OWL [12] language for its implementation and it does not explicitly model home appliances individually and their association with family members. In term of operability ThinkHome ontology does not comply with SUMO and it is hard share its vocabulary with other SUMO compliant ontologies.

SESAME [13] *uses an ontology-based modeling approach to describe an energy-aware home and the relationships between the objects and actors within the control scenario*. SESAME is specified in OWL and N3 [14] representations and provides a hierarchy of concepts of automation domain and the energy domain. SESAME ontology includes a number of concepts such as resident, location, appliance, sensors and tariff etc, and relationships between them. SESAME ontology is not SUMO compliant and it does not provide appliances representation from perspective of energy consumption saving, rather it relies on overall energy consumption information and various tariff information provided by smart meter supplier.

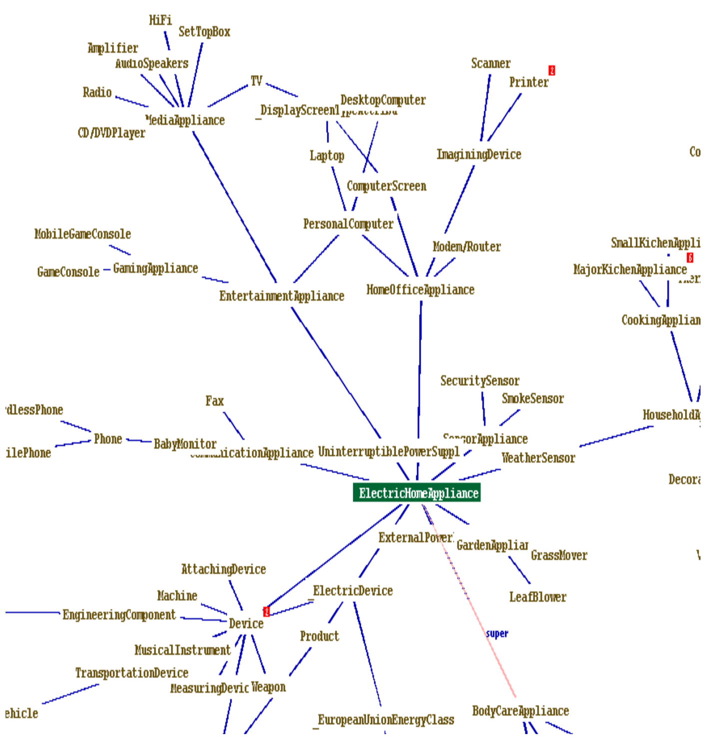

Fig 2. Partial View of Home Appliances Ontology

The proposed ontology is implemented using Protégé ontology development environment by extending and using meta concepts defined in SUMO. The concepts of home energy management domain are organized into various hierarchies based on their functionality their relationships with energy consumption activities in domestic environment. A partial graph of this hierarchy of our implemented ontology is shown in Figure 2.

In development of home appliance ontology we focus on encoding energy efficiency characteristics of the appliances as much as possible to provide and rich knowledge representation for reasoning tools to not only reason about short term energy efficiency of an appliance but also provide a long term operational aspects of the appliance energy consumption. For example a washing machine that consumes less energy per cycle but consume more water may not be an energy efficient machine in the long term.

The ontology development takes into account energy efficiency rating/labeling provided by ENERGY STAR [15] and European Energy Efficiency Labels [16]. This is an important piece of knowledge for classification of energy efficient appliances.

EU labels classes are defined in the ontology and MoreEfficentThan relationship is defined among European energy efficient ratings. This relationship provides automated energy efficiency comparisons based on appliances efficiency rating. EU Energy rating label enables consumers to compare the appliances based on their energy efficiency labels, but these rating are encoded into machine readable format as yet.

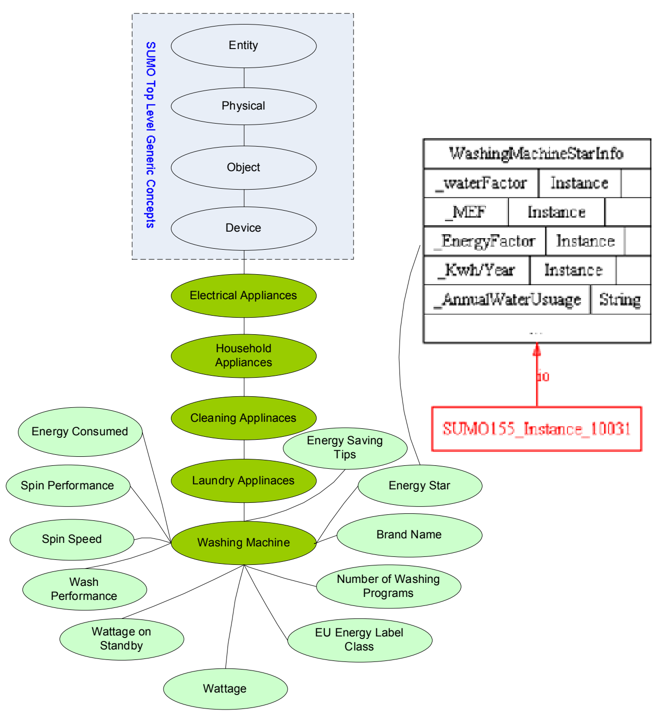

Fig. 3. Ontology Hierarchy

ENERGY STAR is a US Environmental Protection Agency and US Department of Energy backed program helping businesses and individuals to protect the environment by using more energy efficient appliances, machines and energy saving strategies. ENERGY STAR rating provides a more detailed view of energy efficiency of the appliances. As shown in Figure 3 ENERGY STAR rating of washing machine provides information on various factors that contribute to overall energy consumption of washing machine. Whereas EU label define energy efficiency of washing machine on a scale from A to G, with A most efficient and G least efficient.

The proposed ontology encodes ENERY STAR information in WashingMachineStarInfo class as shown in Figure 3 inherits from SUMO Abstract class; it contains all slots of abstract class and adds new slots related to ENERGY STAR. These slots provide more insight into energy efficiency of the washing machine. Slot _MEF is Modified Energy Factor which is a measure of energy efficiency that considers the energy used by the washer and the energy used to heat the water.

For illustration purpose we will describe the hierarchical nature of our developed ontology and explain one electrical appliance within this hierarchy. As shown in Figure 3 “Washing Machine” is lowest level concepts which inherit from top level SUMO concepts and other defined concepts. Washing machine has a number of attributes such as brand name, standby wattage, number of programs and Energy Star rating etc. The Energy Star rating slot of the washing machine is of type WashingMachineStarInfo and holds reference to single instance of WashingMachineStarInfo. The hierarchy also shows that washing machine is type of laundry appliance and which in turn is type of cleaning appliance. This type of hierarchy allows the classification/grouping of appliances in a various way. A higher level (group based) view of energy consumption is enabled by such classification. All other appliances in ontology are encoded in similar way.

A part of ontology is concerned with knowledge about abnormal energy consumption of appliances and their causes. This knowledge is type of heuristic and experiential knowledge. It is represented as pieces of advice that will be generated as by reasoning system as recommendations in specific cases of abnormal energy consumption. The pieces of recommendations are encoded in ‘Energy Saving Tips’ slot of each appliance as shown in Figure 3. Energy Saving Tips is multi-slot which holds reference to multiple tips instances. For example tips related to washing machines are related to washing temperature, washing load, fabric type etc.

5. Evaluation and Testing

We have developed ontology to use it in energy management of domestic environment. The ontology is integrated in DEHEMS system to provide essential knowledge for reasoning subsystem. The overall architecture of the DEHEMS system is illustrated in Figure 4.

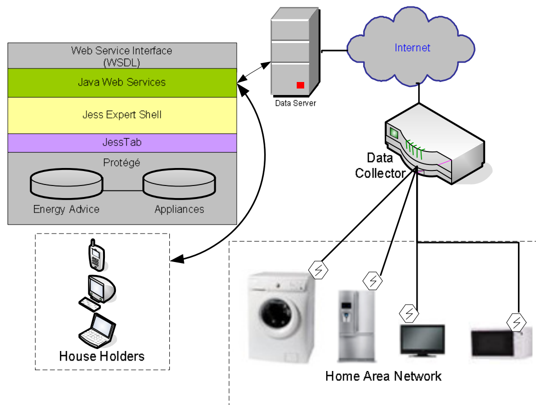

Fig. 4. DEHEMS Architecture

The appliances in home are connected to a data collector that acts as gateway between home area network and data server at remote location. The ontology and other knowledge based systems are deployed on a remote server. This system integrates home devices, sensors, appliances, or display devices, through wireless interfaces. Web service interfaces are provided so the DEMEHS services could be consumed by other systems such as social networks. DEHEMS reasoning sub-system uses JESS [17] expert shell for reasoning about abnormal and normal energy consumption by an appliance and tries to find underlying causes of abnormal energy consumption autonomously and in interactively by asking users various questions. JessTab [18] is used by JESS to load ontological object as Java fact objects in Jess memory.

We have evaluated the accuracy and effectiveness of the ontology in live system. Although the ontology support many core functions of DEHEMS but we report two evaluation scenarios in here.

	Evaluation Scenario	Response
1	Insert energy consumption of washing machine more than normal consumption to indicate abnormal energy consumption of washing machine	The system goes through reasoning process and poses various questions to household interactively, and 40C washing temperature was provided in response to washing temperature question. The system correctly retrieved advice related to energy

		efficient temperature of washing machine by obtaining information from ontology
2	System was asked to provide tips on standby energy consumptions of all appliances	A correct list of tips was retrieved by reasoning subsystem by interaction with ontology

6. Conclusion

This paper describes development of a SUMO compliant ontology of electrical home appliances. The ontology is part of DEHEMS project whose goal is to improve energy consumption efficiency by making appliance level energy consumption visible to households in order to influence their behavior towards efficient energy consumption. The ontology encodes knowledge of electrical appliances and their efficiency and association of appliances to households. Such a rich vocabulary allows reasoning subsystem to provide intelligent advice on efficient energy consumption to household and provide comparative analysis of energy consumption within DEHEMS community.

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