ONTOLOGY-ENABLED AIRPORT ENERGY MANAGEMENT

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Abstract – *For providing advanced, intelligent facility management systems, a comprehensive facility data model is needed which classifies and describes information within the domain of interest. This paper presents one way of providing this metadata layer based on the ontology modelling concept which was defined specifically to underpin the intelligent energy management systems (EMS) of complex infrastructures such as airports. The main ontology entities are presented, which define the general concepts behind the airport facility modelling from the energy management perspective. The aim was to model the semantics of the significant energy consumption systems installed at the airport. Furthermore, presented ontology-based approach offers common semantics needed in order to increase the interoperability and to provide seamless data transfer between diverse devices and systems involved into the EMS of the airports.*

1. INTRODUCTION

The application of emerging advanced Semantic Web technologies [1] considers increased usage of open-source and/or standardized concepts for data classification and interpretation. For providing advanced, intelligent facility management systems, definition of comprehensive facility data model which classifies and describes information/data within the domain of interest is needed. One way of providing this metadata layer is based on the concept of ontology modelling [2],[3]. Additionally, by allowing reasoning upon them, ontologies, as one of the techniques used to cope with the "big data" paradigm [4], facilitate rapid exploitation of information. Since "big data" represents a collection of data sets so large and complex that it becomes difficult to process using on-hand database management tools, it requires advanced technologies to efficiently represent and process large quantities of data. By attaching meaning to data and by providing logical relationship between entities, ontologies provide a way to transform information into knowledge, so the data become easier to retrieve, correlate and integrate.

Ontology, as one of the advanced Semantic Web technologies, can be defined as a formal way of knowledge representation. Apart from classification of related entities within domain of interest, ontology is utilized also to reason upon the modelled entities. It defines entities, properties, interactions, actors and basic concepts that compose the common vocabulary for all members of the domain in which it is defined. Therefore, ontology as a concept for knowledge representation found a broad perspective of application, such as: to share common understanding of the structure of information among people and/or software agents, to enable reuse of domain knowledge, to make domain assumptions explicit, to separate domain knowledge from the operational knowledge, to analyze domain knowledge, etc. There is a number of ontology-enabled facility management frameworks proposed in the literature. For instance, the enhanced control capabilities have been provided by usage of the ontologies in [5],[6]. On the other hand, the ontologies have been used to enable the integration of multivendor, multiplatform devices/sensors with existing applications of the building automation systems [7]-[9]. Also, in order to increase energy efficiency and to provide adequate energy saving strategies of so-called smart homes the ontologies were used to empower the building energy management in [10]-[12].

This paper introduces the ontology-based metadata layer defined specifically to underpin the intelligent energy management systems (EMS) of complex infrastructures such as airports. It describes the Airport ontology and provides the explanation for the modelling approach. As two major European air-traffic hubs with rather complex infrastructure, Malpensa airport located in Milan and Fiumicino airport located in Rome, were taken as both an ontology modelling test bed and a "proof of concept". Therefore, the Airport ontology was defined in order to model all static knowledge regarding the infrastructure of Malpensa and Fiumicino airports from the point of view of all energy related systems and belonging sensor/actuator devices installed at the site. Additionally, this paper presents the main entities of the Airport ontology class hierarchy which describe the airport facility model from the perspective of energy management. This paper is not justifying each decision made, but rather presents the general concepts behind the modelling. Moreover, the Airport ontology was modelled in such a way so as to facilitate the interpretation of signals, relevant to the energy management of the airport, going to/from DESIGO system [13] which currently serves as a Building Management System (BMS) at both chosen airports, as well as to describe the corresponding relationships among them. As a modelling environment of the Airport ontology, Protégé v3.4.1 [14] was utilized.

The main objectives for the development of ontology-based metadata layer, tailored to suit the needs of the intelligent EMS of the airport are the following: 1) modelling the domain of interest (the infrastructure of the concrete airport building), 2) technical characterization and semantic interpretation of signals (going to/from the installed system/equipment), and 3) providing the topological profile of the airport facility (information about geographical location of every installed device/signal). By utilizing the concept of ontology modelling the aim was to structure/classify the technical characteristics of the airport facilities, i.e. to model the semantics of significant energy consumption systems installed at the airport. Furthermore, the ontology based approach has been selected as the core technology to build the transversal middleware which would provide a homogeneous and common platform for all diverse devices, sensors and systems involved into the EMS of the airport. This approach provides consistent, yet flexible means for classification and description of each device/signal that EMS framework might have to deal with.The Airport ontology can provide semantic enrichment of various signals coming either from the applied Fault Detection Diagnosis (FDD) algorithms or directly from sensors installed at the airport, thus enabling the high level information for the end-user (such as the airport energy manager). In other words, the Airport ontology offers common semantics needed in order to increase the interoperability and to provide seamless data transfer between the different existing systems. Finally, in order to integrate the ontology-based metadata layer into the overall EMS framework the corresponding interfaces towards other system components were defined.

The remainder of this paper is organized as follows. Section 2 describes the main components and the fundamental paradigms underpinning the ontology-enabled EMS architecture. The following Section 3 defines the ontology as a modelling concept. The main aspects of the Airport ontology are introduced in Section 4. Two aspects were addressed in this section: 1) the modelling approach undertaken in order to define the Airport ontology, and 2) a brief description of the main entities of the ontology class hierarchy. Section 5 describes the ontology-based approach to increase the interoperability and to provide common understanding among EMS components. Final conclusions are presented within Section 6.

2. AIRPORT ENERGY MANAGEMENT SYSTEM

This section describes the architecture and the fundamental paradigms behind the intelligent EMS framework [15]. The proposed ontology-enabled EMS framework is strengthened by the adoption of a number of principles such as Service Oriented Architecture (SOA) and loose coupling. Approach based on SOA provides the most flexible solution to tackle the intrinsic root problems of system integration, inherent complexity, unforeseeable requirements, and perpetual change [16]. SOA defines the interface in terms of protocols and functionality reflecting business and data transformation rules, i.e. a set of rules regarding how to integrate widely disparate applications for a Web-based environment. On the other hand, loose coupling refers to a system's interconnection that reduces the common dependence of knowledge of different parts of architecture. The usage of the flexible file formatting such as XML or JSON dramatically enhances loosely coupling between applications. This, in addition to the use of standardized data communication protocols such as SOAP or REST, will promote reusability and adaptability. The EMS framework [15] is based on a distributed network architecture following a typical three-tier architecture as shown in Fig. 1. These layers are Physical Layer, Business Logic Layer and Service Level or Application Layer.

The Physical Layer includes the hardware and physical network used for gathering data related to physical airport facilities, energy systems and environmental variables. Data are gathered and concentrated in a local server at the airport facility and forwarded further via internet for processing. Weather data is integrated as a crucial part to develop further analysis, energy consumption forecast and optimize energy system operation. Weather data can be retrieved from airport owned weather stations or national/commercial meteo-services. On the other hand, BMS is used to facilitate system control and building energy management. It is a computer-based control system installed in buildings that controls and monitors the mechanical and electrical systems. Though specific components may differ, these systems normally include heating, ventilation and air conditioning (HVAC), lighting, power and fire protection systems. The most of the system data are gathered form the BMS, however some of the data needed for feeding the FDD algorithms are obtained directly from the additional metering hardware (sensors and smart meters). Various enterprise management systems of the airport provide additional data such as Flight Information Display System (FIDS) which distributes and displays the critical information to the travelling public and airport tenants or Airport Information Management System (AIMS) which handles all aspects of gate use, passenger information displays, link with other information systems and management services, etc.

This Business Logic Layer coordinates the different parts of the proposed EMS framework. Command processing, decision-making and evaluation is performed remotely on a variety of application servers. This layer will comprise all IT artefacts, applications, rules and algorithms that deal with the transformation of data from the physical layer to the end-user interface. It will deliver a multi-provider "IT as a service" platform serving the final Application Layer. Internet is used as a network for information exchange. Measurement data received from the airport local data server are supplied: 1) to FDD tool for further processing; 2) to the energy management tool for action management; and 3) to the end-user through the advanced visualisation of the handled data of the EMS Web-interface. The FDD algorithms run with measured data collected from the airport local data server and provide output to the energy management tool. The energy management tool receives FDD alarms from the FDD providers, and transforms them into the content rich information by querying the Airport ontology which will be described later in more detail. Additionally, the energy management tool receives input from the users through the EMS Web-interface and supports the energy action management.

The Application Layer provides access and services to the

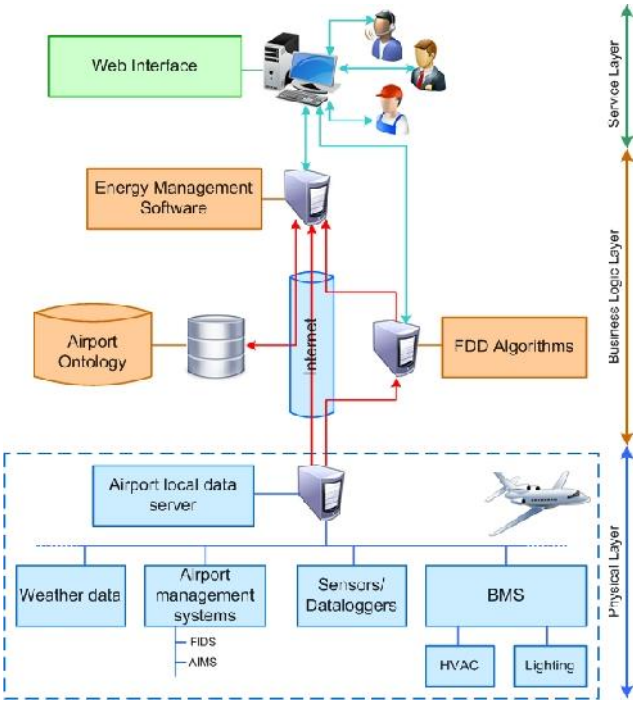

Fig. 1. EMS framework architecture.

end-user application. The main function of the EMS Graphical User Interface (GUI) is to translate tasks and results into information that users can understand and interact with. Energy management tool will provide the GUI with the support for effective energy action management. Additionally, the advanced visualisation of measured data and specific views of performance data related to detected faults will be provided at this level. Final EMS Web-interface will provide effective energy action management for all stakeholders involved in the energy operation and management process (such as energy management office, operation and maintenance unit, etc).

3. ONTOLOGY AS MODELLING CONCEPT

Ontology is a formal description of the concepts and relationships that can exist for an agent or a community of agents, usually inside a specific domain [2]. It defines entities, properties, interactions, actors and basic concepts that compose the common vocabulary for all members of the domain in which it is defined. Ontologies are defined by classes, properties that describe various features and attributes of classes and restrictions on these properties. Classes describe concepts whereas subclasses represent concepts that are more specific. The development of ontology usually includes: 1) definition of the ontology classes, 2) hierarchical arrangement of the classes, and 3) definition of the properties and their possible values.

Properties can be referred to a single class/subclass or can be used to relate different classes. Since ontology represents one of the advanced Semantic Web technologies and can be defined as a formal, explicit specification of a shared conceptualization, it has a broad perspective of applicability for representing the knowledge as a set of concepts within a domain of interest. The ontology concept found its applicability for describing various domains by classifying and defining the domain related entities, but also for reasoning upon the defined entities. Some frequent uses of any ontology are:

- to share common understanding of the structure of information among people or software agents,
- to enable reuse of domain knowledge,
- to make domain assumptions explicit,
- to separate domain structural knowledge from the operational knowledge,
- to analyze domain knowledge.

One of the benefits that ontology as a modelling concept provides is the definition of a framework where most of the disciplines, technologies, which will be involved in the domain of interest, can adopt the common vocabulary defined within the ontology.

4. AIRPORT ONTOLOGY MODELLING ASPECTS

This section describes the main aspects of the Airport ontology which provides a model of the airport facility. The aim of the undertaken ontology approach was to classify the technical characteristics of the airport facility, i.e. to model the semantics of the energy management related systems installed at the airport. Furthermore, the ontology approach has been selected in order to build the comprehensive metadata layer which would provide a common understanding between diverse devices and systems involved into the proposed EMS solution.

The Airport ontology (shown in Fig. 2) has been defined, offering common semantics needed to increase the interoperability and to provide seamless data transfer between different existing systems. This includes the definition of the main ontology entities with the corresponding properties and their relations, as well as the harmonization of the ontology model with energy management related regulations and standards. Therefore, in order to align the Airport ontology model with the contemporary ontology architectures, leading ontology modelling standards, such as SUMO (Suggested Upper Merged Ontology) [17] and CIM (Common Information Model) as part of IEC 61970 series of standards, were considered as a starting point. Furthermore, in order to provide transparent communication within the EMS framework, the Airport ontology model was also aligned with the unified data-point naming convention used in the proposed EMS solution [15]. Owing to their rather complex infrastructure, two specific European airports, Malpensa airport located in Milan and Fiumicino airport located in Rome, were taken as an ontology modelling test bed and a "proof of concept". Based on the data gathered for the technical characterization of the ICT systems and the analysis of the different aspects of the involved devices and modules, the Airport ontology model should be instantiated further into two separate instances representing the facility model of Malpensa and Fiumicino airports. Additionally, since it will be used as a

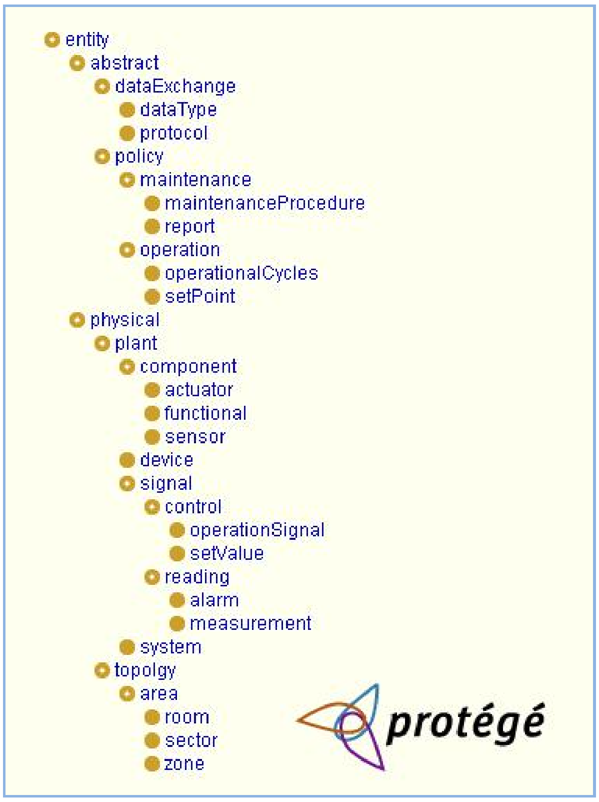

Fig. 2. Airport ontology class hierarchy.

central data repository of the proposed EMS, the Airport ontology has been modelled in order to store all the static data regarding the targeted systems (information related to the Significant Energy Users (SEU), e.g. air handling units (AHU), such as nominal mass flow, fan drive power, etc) which will be later used to calculate the energy waste due to faults and corresponding saving potential.

The main aspects of the Airport ontology are given as following:

- modelling the domain of interest, i.e. defining the infrastructure of the concrete airport building by classifying installed systems relevant to the energy consumption aspect with belonging devices (sensors/actuators),
- providing means for technical characterization and semantic interpretation of signals going to/from the installed system/equipment (which incoming/outgoing signal belongs to which device/system, what its characteristics are, relationships with other devices/signals),
- providing the topological profile of the airport facility and information about geographical location of every installed device/signal (useful for analyzing spatial correlation of data).

In addition, this approach provides consistent, yet flexible means for classification and description of each signal that EMS framework might have to deal with.

The Airport ontology provides a generic model of the airport facility as a set of concepts and corresponding relationships among them. The purpose of the Airport ontology is to describe technical characteristics/relations of related systems installed at the site, their topological profile, as well as to facilitate the interpretation of signals. It was necessary to define the approach which will be undertaken for modelling tasks and the general concepts behind the modelling. This issue highly influences the decisions regarding granularity, abstraction and classification of different real world objects/devices at different levels of the Airport ontology model. On the other hand, definition and population of the Airport ontology is the task for the experts and not for the end-users. After the Airport ontology is modelled the end user will not have to understand and deal with the ontology as a modelling concept. Finally, all the static knowledge stored within the Airport ontology will be presented to the end user in an easy understandable manner through the EMS Web-interface (shown in Fig. 1).

The following is a short description of the main entities of the Airport ontology class hierarchy. Two highest entities of the ontology class hierarchy are:

- **"abstract"** - for modelling of abstract entities such as data types, protocols used for communication, a maintenance procedures and corresponding operation cycles, etc; inherited from SUMO;
- **"physical"** – for modelling of real world objects; entire energy related systems with belonging devices and signals; inherited from SUMO.

Subclasses of "abstract" entity are the following:

- **"dataExchange"** - it represents the data types and protocols used for data exchange within the integrated system (HVAC, lighting system);
- **"policy"** - this entity models management related procedures (from the perspective of system operation and maintenance).

Subclasses of "physical" entity are the following:

- **"plant"** - for modelling of concrete energy consumption related subsystem installed at the airport (HVAC, lighting system, baggage handling system (BHS), visual landing aid system (VLA), etc) from signals, through components/devices (water pumps, AHUs, electrical switchboards, lighting devices, etc) to subsystems;
- **"topology"** - for representing the topological profile of the airport facility; this is the base class for topological modelling; it represents the topological model in the real world using "area", "zone" and "sector" entities.

"Plant" class should be populated according to the detailed system/device technical characterization and 2D plans of installed systems. In order to provide the information about physical placement of devices/signals, premises located at the airport should be mapped and instantiated so they reflect the actual state at the airport. Additionally, all airport premises should be instantiated with corresponding attributes describing the interconnection and geographical location in correspondence to other airport premises.

5. ONTOLOGY-ENABLED INTEROPERABILITY

Based on the Airport ontology, a support was provided to the integration and interoperability of the overall EMS framework and its components, such as the FDD algorithms and the energy action methodology for the “improvement opportunities” recognition (according to the ISO 50001). This also included a specification of the communication means between the EMS components, such as energy management software and ontology layer, which enables extraction of the needed data, in order to build “content rich” actions for assignees (communicated in reports, dashboards and visualisation tools). In other words, this considered the definition of the missing information that could be stored and the specification of how that information could be extracted from the ontology layer. With respect to the mentioned, the corresponding ontology layer Application Program Interfaces (API) have been implemented, providing the transparent means for extraction and delivery of the needed information (such as technical characteristics of devices/systems, their topological information, energy management regulation and procedures related data, etc).

The application of the Airport ontology within the EMS framework can be beneficial in many aspects, from assisting the manual user input of the ISO 50001 energy management SEU template (only ID of device/sub-system/system is needed and the rest of information such as technical specification or location is then extracted automatically) to creating high level fault, warning, notification messages which contain precise information about critical device measurements and even inferring upon them. In other words, it can provide semantic enrichment of various signals (illustrated in Fig. 3), coming either from the applied FDD algorithms or directly from sensors installed within airport facilities, thus enabling the high level information delivery for the EMS Web-interface end-user.

The benefits of the Airport ontology can be easily reflected within a potential list of relevant variables which can be easily extracted from the ontology in order to create an energy saving action:

- actual SEU,
- location of the SEU,
- category (HVAC, lighting, etc),
- sub-category (AHU 1, lighting zone, etc),
- energy performance indicators (cost, energy, emissions per m^2/person/flight, etc).

Namely, the listed variables, i.e. the corresponding information about specific devices, are modelled within the Airport ontology. This information is available on demand and can assist the creation of high level messages for the end-user, such as energy saving action/opportunity messages.

The input for creating an ontology-based metadata layer was extracted from the various data sources such as survey, audits, technical sheets, equipment manuals,

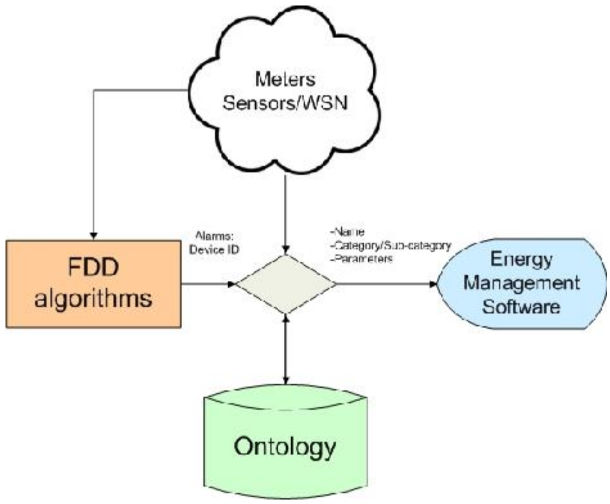

Fig. 3. Ontology knowledge extraction schemata.

interviews, questionnaire, etc. These sources contain information that enable classification of energy management related entities (such as HVAC, water supply system, etc) and definition of the corresponding relations between them. All the extracted information was transferred into the Airport ontology, affecting both the domain model (ontology hierarchy) and creation of new instances of the ontology entities. Semantic queries [18] are used for extracting the knowledge from the Airport ontology. Moreover, apart from structuring and describing the airport infrastructure related data, the ontology has been delivered with accompanying APIs, which enable the end-user to extract the needed information (by querying the ontology). Querying the ontology could be performed in two ways, whereas each of them requires a specific API. The first way would be to communicate with the ontology “locally” (ontology stored at the end-user side), simply by calling the corresponding function (provided by predefined API) to retrieve the needed information. The second one would be to access remotely the ontology in the web-service based manner, by sending the requests and receiving the response carrying the needed information. Two main processes related to the manipulation of the data stored within the ontology would be information extraction through the use of the Semantic Web query languages [18], and reasoning upon this information utilizing the Semantic Reasoner.

As mentioned previously, the ontology-based metadata layer consists of both the knowledge base repository, i.e. the ontology itself, and the corresponding interface (Airport ontology API) towards the components which have benefits from retrieving the information stored within (related to HVAC, water supply, lighting system, etc). The Airport ontology API has several important functionalities, necessary for providing a transparent interface for the seamless integration of the knowledge base repository and other software components within the EMS, such as: generation and execution of the SPARQL queries [19], updating the ontology entities, reasoning upon the ontology entities using the generic rule engine based on the set of the pre-defined rules, and finally, retrieving the information from the Airport ontology.

6. CONCLUSIONS

Definition of standardized and comprehensive facility data model which classifies the information/data within the domain of interest is needed for providing advanced, intelligent facility management systems. One way of providing this metadata layer is based on the concept of ontology modelling. This paper presents the ontology-based metadata layer defined specifically to underpin the intelligent EMS of complex infrastructures such as airports. More precisely, it describes the Airport ontology and provides the explanation for the undertaken modelling approach. The main components and the fundamental paradigms underpinning the ontology-enabled EMS architecture were addressed in particular. The aim was to structure/classify the technical characteristics of the airport facilities, i.e. to model the semantics of the energy management related systems (such as HVAC, lighting system, etc) installed at the chosen airports by utilizing the concept of ontology modelling. Additionally, the ontology based approach has been selected to build the transversal middleware which would provide a common platform for all diverse devices and systems involved into the EMS of the airport. Finally, it was described how the Airport ontology as a metadata layer can offer the common semantics needed in order to increase the interoperability and to provide seamless data transfer between the different EMS components.

ACKNOWLEDGEMENTS

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