Earthquake Emergencies Management by Means of Semantic-Based Internet of Things

Gilberto Taccari[1](✉), Gabriele Bernardini[1], Luca Spalazzi[1], Marco D'Orazio[1], and Waleed Smari[2]

[1] Università Politecnica Delle Marche, Ancona, Italy
{g.taccari,g.bernardini,l.spalazzi,m.dorazio}@univpm.it
[2] Ball Aerospace and Technologies Corporation, Ohio, USA
smari@arys.org

Abstract. Semantic technologies can play a key role in representing, storing, interconnecting, searching, and organizing information generated/consumed by things. In order to evaluate its feasibility, this paper presents a set of reasoning mechanisms based on an IoT ontology to be applied in an emergency management scenario. The scenario presented in this paper consists in the earthquake emergency management.

Keywords: Semantic Web · Semantic reasoning · Internet of Things · Earthquake Emergency Management

1 Introduction

In the recent years, Internet of Things (IoT) attracted more and more researchers for its pervasiveness, the variety of involved technologies, and the several areas where it can be applied. On the other hand, the research on IoT must face several challenges, among them are *scalability*, w.r.t devices, data, and users interaction; *interoperability*, due to the heterogeneity of devices and platforms; *efficiency*, w.r.t. device energy consumption and bandwidth; *ubiquity*. This complexity produced at least three different visions of IoT: the *internet-oriented* vision, the *thing-oriented* vision, and the *semantic-oriented* vision [2]. Whereas the first two visions are quite obvious, the third one is one of the consequences of scalability and interoperability that pose issues related to how to represent, store, interconnect, search, and organize information generated/consumed by a plethora of physical and virtual (immaterial) things. According to several authors [2,4,8,19], such issues can benefit from semantic technologies.

Therefore, this work focuses on the semantic-oriented vision of IoT and applies semantic technologies to a specific scenario, in order to evaluate their potentialities: the *earthquake emergency management*. This work is part of the Italian project SHELL[1] — Research Objective OR4 "Safety & Security Manager".

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Regarding the semantic-oriented vision, it should be considered that in spite of the great number of works in literature, the formal modeling of things by means of semantics is still an emerging area and there does not exist a de facto standard to do that. This obstructs the collaboration among Things themselves and between things and IT systems [4]. The only exception is represented by the Semantic Sensor Network (SSN) ontology, an outcome of the W3C Semantic Sensor Network Incubator Group [4]. Unfortunately, this ontology deals only with sensors, their sensing capabilities, the observations that they may produce, and their physical characteristics. No standard exists for actuators and a more general notion of things. On the other hand, other works deal only with specific application domains [19].

Regarding the emergency domain, previous works and recent disasters underline the importance of tools for earthquake disaster management [9] in order to assist people and rescuers during the event and so increasing the level of community resilience [5,18], especially in historic preservation areas and at urban scale. Up-to-now, a similar approach has been adopted for indoor fire management [11,14]: data involving the spread of fire and the position of people are acquired by sensors and processed by a central server; actions in response to the fire and to facilitate evacuating people are consequently performed through a series of actuators. In other words, this means that an IoT approach could be useful also for earthquake emergency management. Indeed, following the "smart city" network vision [1], IoT tools must involve real-time monitoring and include the information communication to both evacuating pedestrians and rescuers. This aspect is widely stressed in the aforementioned project SHELL-OR4.

This work provides the first step for an emergency management system based on the semantic-oriented vision of IoT. This is accomplished by means of a set of basic semantic reasoning techniques that can be combined to form the so-called Perception/Action Cycle. In order to do that, it exploits a general IoT ontology that extends the SSN ontology [15].

The paper is structured as follows: Sect. 2 briefly introduces the earthquake scenario and the related ontology is described in Sect. 3. Section 4 deals with the Perception/Action cycle, whereas some concluding remarks are reported in Sect. 5.

2 The Earthquake Scenario

Previous works [6] define the actors involved in the earthquake scenario (*Environment* and *Pedestrians*) and the related features that have to be monitored by different sensors in order to eventually activate a set of actuators, both at a single building or at urban scale. About the Environment, an immaterial sensor composed by a CAD or GIS database should describe the characteristics of the pre-event scenario, including urban plan, usable paths and safe areas [6]; moreover, each building should be related to its own seismic vulnerability [7], by using GIS techniques [17]. Physical sensors monitor the event and the scenario changes. A seismometers network could define fundamental earthquake data, such as duration, Richter magnitude and epicentre position [10]. Accelerometers would define the presence of site amplification [16] or the building response to the earthquake. Devices for crack or story drift (displacement) monitoring could assess the structural building health or the presence of local damage mechanisms or collapses [12]. Data from these building sensors could be merged with the ones from seismometers and losses estimation models, for the evaluation of scenario modifications (e.g.: ruins influence on evacuation routes [13]). The Pedestrians characteristics and positions [6], including people with disability and rescuers, should be monitored during the whole process. The IoT system would collect data from these sensors, and address particular actions to the actuators [14]. Pedestrians would be assisted during their evacuation by means of information regarding the correct behavior, the evacuation path to select, and how to gain the safe areas in the safest and fastest way. Notification messages (e.g.: SMSs) would be sent to them in order to interact with them. Moreover, fixed building elements (e.g.: escape lights in both outdoor and indoor conditions), or personal device (e.g.: smartphones) applications would be activated in order to indicate the evacuation path. Finally, rescuers have to be informed about crisis areas, damages on buildings, infrastructural fails, and Pedestrians in emergency conditions (e.g.: in ruined buildings or in not accessible areas).

3 The Earthquake Emergency Management Ontology

In order to formally describe entities and features that characterize the earthquake scenario, we take advantage of the IoT and Earthquake Emergency Management (EEM) ontologies proposed by Spalazzi *et al.* [15][2]. The IoT ontology extends the Semantic Sensor Network (SSN) ontology [4] and, beside the *Stimulus-Sensor-Observation pattern* [4] used to model sensors and observations, proposes the *Actuator-Stimulus-Operation pattern* that models actuators and operations. The above patterns allow the ontology to deal with sensor and actuator properties (denoted by the two equivalent concepts ssn:MeasurementCapability and san:ChangeCapability depicted in Fig. 1) in terms of accuracy (ssn:Accuracy), resolution (ssn:Resolution), precision (ssn:Precision), and other similar characteristics. These are related to particular conditions (denoted by the concept ssn:Condition), consequently several capabilities (one for each condition) can be associated to a given sensor or actuator. Furthermore, even each observation or operation (denoted by concepts ssn:Observation and san:Operation depicted in Fig. 1) can be associated with its properties (e.g. an observation with its accuracy). The EEM ontology is built upon the IoT ontology and deals with the modeling of specific sensors and actuators to be used in the earthquake scenario. We have concepts to describe sensing devices such as seismometers (eem:Seismometer), accelerometers (eem:Accelerometer), lasers to measure story drift displacements (eem:Laser), and the GPSes (eem:GPS), as well as to describe actuating devices such as signaling escape lights (eem:Signaling-EscapeLight), and alarm message notifiers (eem:AlarmMessageNotifier). Beside the

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[2] Available at https://code.google.com/p/federated-cot-owl/source/browse/.

descriptions of things, the EEM ontology models also the features of interest and their related properties that may be sensed and/or modified by the devices. In this work we extend such ontology in order to provide all the knowledge to implement the Perception/Action Cycle described in the next section. A fragment of this ontology is depicted in Fig. 1. Four subclasses of ssn:Observation (eem:MagnitudoGreaterThan4, eem:AccelerationGreaterThan0.2g, eem:DiplacementGreaterThan0.003h, eem:VulnerabilityGreaterThan0.17) are created in order to represents specific cases of observations that sensors may produce. These new classes of observations are linked to three instances of eem:Intensity (eem:LowIntensity, eem:MediumIntensity, and eem:HighIntensity) in order to specify which kind of intensity (i.e. damages) we have depending on the observed earthquake parameters. Such instances are linked to operations too; in this manner we specify which operations have to be accomplished in relation with the intensity of the earthquake. Finally, we add to the EEM ontology the concept that represents a person to evacuate eem:PersonToEvacuate. We add to this concept the property dul:asLocation that links a person to her/his geographical position represented by an istance of the concept geo:Point taken by the GeoSPARQL ontology[3] that models spatial concepts and their relations.

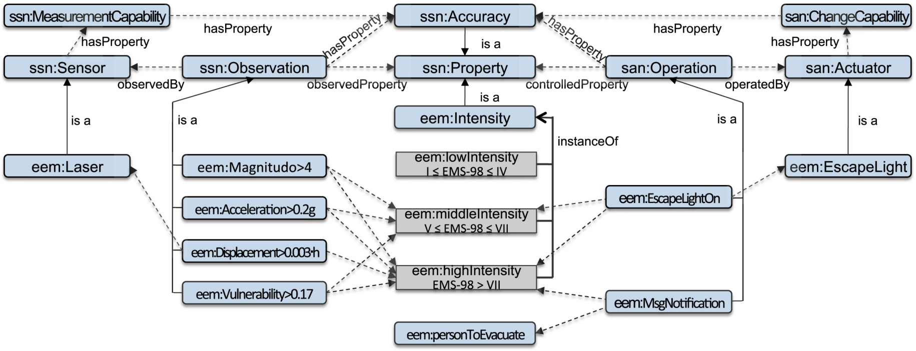

Fig. 1. An fragment of the EEM ontology.

4 EEM: Perception/Action Cycle

The Perception/Action Cycle extends the Perception Cycle proposed by Henson *et al.* [8] taking into account the intention of acting as a consequence of what has been perceived. In this respect, this model is rooted in the Belief-Desire-Intention model proposed by Bratman [3] that has been widely used for developing intelligent agents. The Perception/Action Cycle consists of four basic activities: *explanation*, *discrimination*, *decision*, and *justification*.

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[3] http://schemas.opengis.net/geosparql/1.0/geosparql_vocab_all.rdf (Accessed: 2014-06-26).

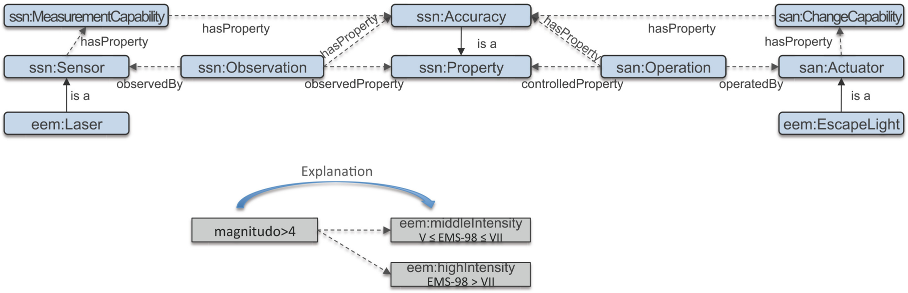

Fig. 2. An example of the Perception/Action Cycle: explanation.

Explanation. It deals with deriving a set of elements (that Henson *et al.* called *explanations*) that can explain what has been perceived. In the approach proposed in this work, one or more sensors produce a set of observations, such observations are semantically represented as RDF triples that are instances of ontology concepts as ssn:Observation and ssn:ObservationValue. As each instance of eem:MagnitudoGreaterThan4 is linked to a set of instances of eem:Intesity (Fig. 1), such instances form the set of explanations (Fig. 2). In the example of Fig. 2, we supposed it has been measured by a seismographer an earthquake whose magnitude is greater than 4. According to the *European Macroseismic Scale* [7] adopted in the EEM ontology (see Fig. 1), the earthquake intensity may correspond to a middle or high value.

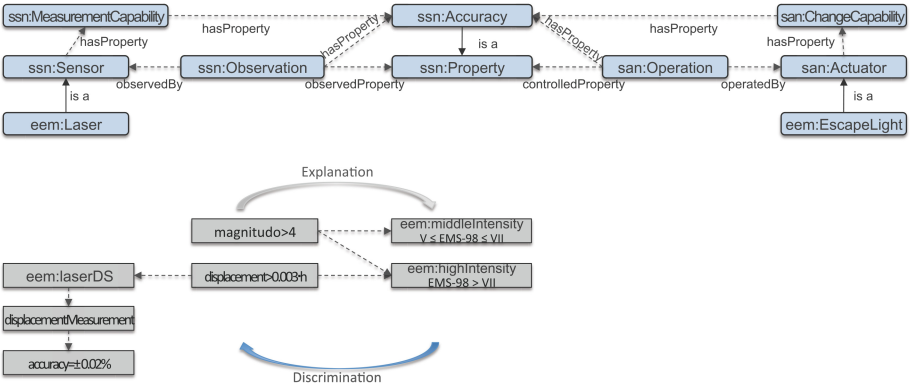

Fig. 3. An example of the Perception/Action Cycle: discrimination.

Discrimination. It should be noticed that the previous step can produce multiple explanations from the same set of observations. This set can be reduced by further observations. As the set of observations grows, the set of explanations shrinks. Once again, semantic reasoning can help us in establishing what are such further observations. Indeed, the ssn:observedProperty relation can be used to discriminate which kind of observations allow us to shrink the explanations (Fig. 3). As each subconcept of ssn:Observation is linked to a specific ssn:Sensor that has a set of capabilities (as accuracy, precision, and so on), thanks to *discrimination* we are able to obtain a list of sensors that can be used in order to produce the further observations we need and are able to guarantee the required capabilities. In the example of Fig. 3, we have to discriminate what is the earthquake intensity, therefore we need further observations. According to Fig. 1, we need to measure the horizontal displacement of a given building using a sensor with a given accuracy.

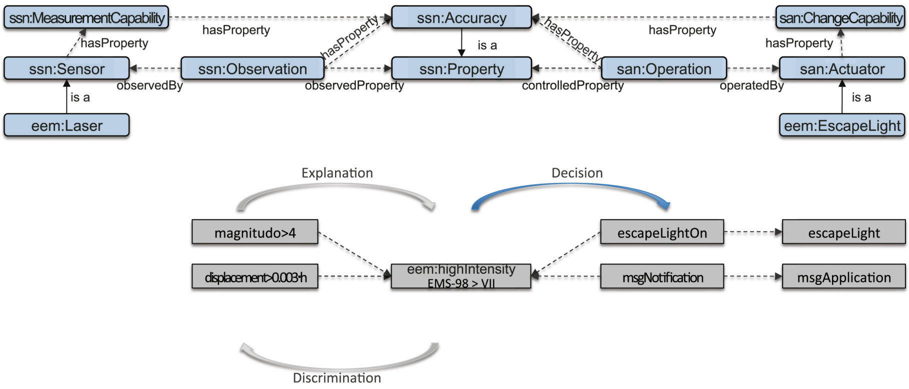

Fig. 4. An example of the Perception/Action Cycle: decision.

Decision. It is similar to *discrimination*. Indeed, it aims at looking for subconcepts of san:Operation that are linked to the explanations, i.e. they are linked to instances of ssn:Property (Fig. 4). As each subconcept of san:Operation is linked to a specific san:Actuator that has a set of capabilities, thanks to *decision* we are able to obtain a list of actuators that can be used in order to react to what has been perceived and, again, are able to guarantee the required capabilities. In the example of Fig. 4, we have to select the actuators to use. According to EEM ontology (Fig. 1), we need to turn on the escape lights and to send a message to rescuers. In this specific example, capabilities as accuracy and precision can not be applied to such a kind of sensors.

Justification. It is similar to *explanation*. Indeed, it aims at looking for all the instances of ssn:Property that justify the selected operation (Fig. 5). In the example of Fig. 5, we need to send to rescuers a message with the position of possible victims.

The activities above represent the building blocks to be used in order to define any kind of emergency management policy based on using (physical and virtual) things. It should be noticed how such basic reasoning services can be composed in any order.

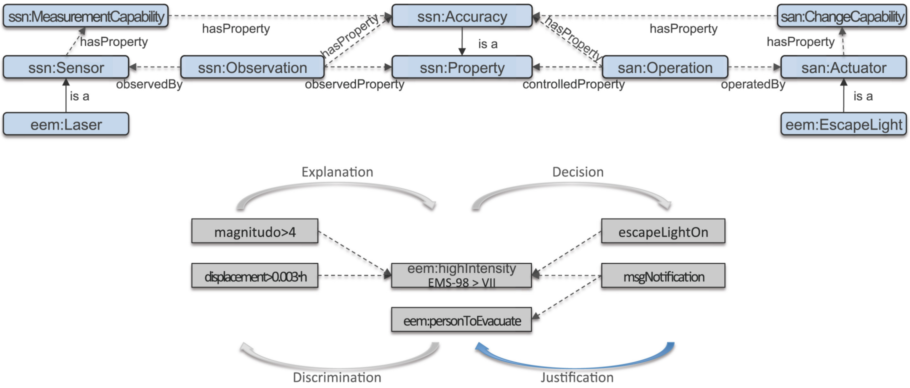

Fig. 5. An example of the Perception/Action Cycle: justification.

5 Concluding Remarks

In order to develop the ontology described in the previous section we use the open source ontology editor Protege[4]. Then we import the ontology elements in the Parliament triple store[5], a high-performance triple store designed for the processing of GeoSPARQL[6] queries that deal with geospatial information about the triples. After that, we populate the triple store with instances describing the earthquake emergency scenario proposed in Sect. 2. The queries related to the reasoning activities depicted in Figs. 2, 3, 4, and 5 (see Sect. 2) are reported in Figs. 6, 7, 8, and 9, respectively. It should be noticed as query 7 allows us to select sensors having a given accuracy. Furthermore, it should be noticed as query 9 allows us to select the localization of victims from all the data gathered by sensors. As a consequence, victim localizations can be sent to rescuers.

```
# Explanation query
SELECT DISTINCT ?intensity
WHERE {
   eem:MagnitudoGreaterThan4 ssn:observedProperty ?intensity.
}
```

Fig. 6. GeoSPARQL query implementing explanation.

The examples reported above show how very simple semantic reasoning techniques can provide a support to an emergency manager in refining its knowledge according to a first set of observations and, thus, finding which actuators should

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[4] http://protege.stanford.edu/ (Accessed: 2014-06-26).

[5] http://parliament.semwebcentral.org/ (Accessed: 2014-06-26).

[6] http://www.opengeospatial.org/standards/geosparql (Accessed: 2014-06-26).

```
# Discrimination query
SELECT DISTINCT ?sensor
WHERE {
%   ?sensor a ssn:Sensor .
   ?sensor a ?sensorType .
   ?sensorType a owl:Class .
   ?sensorType rdfs:subClassOf ssn:Sensor .
   ?observation a eem:DisplacementGreaterThan0.003h .
   ?observation ssn:observedBy ?sensorType .
   ?sensor ssn:hasProperty ?capability? .
   ?capability a ssn:MeasurementCapability .
   ?capability ssn:hasProperty ?accuracy .
   ?accuracy a ssn:Accuracy .
   ?accuracy eem:hasValue ?a
   FILTER(?a <= 0.05)
}
```

Fig. 7. GeoSPARQL query implementing discrimination.

```
# Decision query
SELECT DISTINCT ?actuator
WHERE {
%   ?actuator a san:Actuator .
   ?actuator a ?actuatorType .
   ?actuatorType a owl:Class .
   ?actuatorType rdfs:subClassOf san:Actuator .
   ?operation a ?operationType .
   ?operationType a owl:Class .
   ?operationType rdfs:subClassOf san:Operation .
   ?operationType san:controlledProperty eem:highIntensity .
   ?operation san:operatedBy ?actuator .
}
```

Fig. 8. GeoSPARQL query implementing decision.

```
# Justification query
SELECT ?victim
WHERE {
   ?victim a eem:PersonToEvacuate:
           geo:hasLocation ?localization .
   ?localization geo:asWKT ?lWkt .
   FILTER(geof:sfWithin(?lWkt,
   "POLYGON((<coordinates>))"^^sf:wktLiteral))
}
```

Fig. 9. GeoSPARQL query implementing justification.

be activated adapting pre-defined emergency management policies to the current scenario. These preliminary experiments seem to confirm the feasibility of the proposed approach. Its application in a real scale scenario is the next step in our work. In order to do that, we are setting up an Emergency Management System (EMS) based on a knowledge base defined according to the above ontology. This application uses the basic reasoning activities presented in this paper. The knowledge base is populated in real-time with earthquake data coming from the Twitter service offered by the Italian Geophysical and Volcanology Institute (INGV)[7]. The story drift displacement is computed by means of a laser displacement sensor (produced by our own laboratories) connected to a Cubieboard2 (based on a ARM Cortex A7 dual core processor). An Android application plays both the role of sensor, sending geolocalization data, and the role of actuator, receiving notifications from the EMS. The experiments are still on going and the related results will be reported in a follow-up paper.

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[7] Available at https://twitter.com/INGVterremoti.

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