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Engineering IoT Healthcare Applications: Towards a Semantic Data Driven Sustainable Architecture

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Abstract. As the number of developed sensors is growing, new Internet of Things applications are being developed. Healthcare applications offer a perfect domain for Internet of Things since they respond to the challenge of the ageing population while offering safe and quality care in the home. We present in this paper a new Internet Of Things architecture for IoT healthcare applications. The architecture focuses mainly on the principles of weak coupling and of semantic data exchange. We present a software architecture based on a message oriented middleware driven by semantic OWL messages.

Key words: Home care, semantic representation, Message oriented middleware (MOM), Internet-of-things, health applications

1 Introduction

The world population is rapidly ageing; According to the WHO¹ statistics the number of people aged 65 and over will exceed 15% of the global population by 2050. As the global population ages, the demand for end-of-life care will continue increasing over the years. Elders desire staying in their own homes as long as it is possible and safe. To this end, steps must be taken to provide them with the necessary assistance, ensured by exploiting new technologies.

In the Internet of Things (IoT) [1], intelligent sensors are deployed on a smart space in order to gather real time information. This information can be treated, recorded and correlated to infer new data faster and more accurately, which leads IoT to be an important driver of health care [2]. The combination of assisted living spaces and healthcare applications has been found to provide safe and quality care at home, especially for elders who often incur the risk of many pathologies symptoms and problems.

¹ WHO: World Health Organization, <http://www.who.int/ageing/en/>

As the number of sensors is increasing rapidly and encompasses a large number of measurements (temperature, moisture, etc.), many IoT applications have arisen [3]. The matter of most of these applications focus on data and it does not include the way these data can be gathered or shared. That means data are becoming proprietary for each application. For example, to monitor elders who often incur the risk of many pathologies, a lot of same sensors is required to provide the necessary data to the different applications [4]. For that a semantic and interoperable architecture is needed to enhance information sharing and reusability [5].

In this paper we propose an IoT architecture for healthcare applications providing the following features: 1. the same sensor can potentially be used for several applications reducing the number of connected sensors. And 2. The same information can potentially be provided by different sensors ensuring the redundancy of data in the case of an out of service sensor. For that our architecture is based on semantic representations of sensors and publish/subscribe architecture, ensuring the interoperability between system components.

The remainder of this paper is organized as follow: In section 2 we present the main principles of the proposed architecture, followed by a review of the related work in section 3. We then present our proposal for a semantic middleware architecture for IoT health care application in section 4. Section 5 provides an implementation of the case study which has been used to validate our architecture. We conclude by describing the future directions of this work..

2 Principles of the proposed architecture

In the context of home care applications, the aim of our research is long-term monitoring of elders by detecting and monitoring their Activities of Daily Living (ADL) using ambient sensors. In [6] authors show that smart objects and IoT are an essential factor for Ambient Assisted Living (AAL) to support elderly people in their daily routine and to allow an independent and safe lifestyle as long as possible.

In the IoT environment, most applications use a set of dedicated sensors, and each solution has its specific architecture. In order to provide a loosely coupled communication for all IoT system components and to enable information sharing between them, we propose a semantic web of things middleware for healthcare applications. This architecture complies to the principle of "Independent and weakly coupled software components driven by semantic data". It relies on three concepts: semantic interoperability; loose coupling and information pooling; and health requirements.

2.1 Semantic Interoperability

Connected sensors and systems in an IoT environment will have specific technologies and infrastructures. The data sent by any sensor can potentially be

used by several different monitoring applications. Likewise, a specific monitoring application should not be concerned about the physical sensors, and should even be able to treat homogeneously data sent automatically by sensors and data collected by other means (e.g. by clinical examination and manual entry in a software system). To promote the semantic interoperability between system components, a semantic and homogeneous representation of sensor's data is required. While IoT middleware solutions present a lack of semantic representations [7], ontologies for describing sensor network have been widely used in the literature. Moreover, in [8] authors propose ontologies for knowledge representations and the predominant technique OWL (the Web Ontology Language) for knowledge representation in the web.

For the purpose of representing formally sensors data, we will rely on ontology concept for sensors description. SSN (Semantic Sensor Network ontology) will be used as a base ontology. A location variable the **PatientLocation** (room number and bed) is added to SSN taking into consideration health requirements and the need of tracking a patient at hospital or retirement home. Therefore, the system will be able to exchange localized observations.

2.2 Loosely coupling and Information pooling

In IoT solutions presenting a strongly coupled data provider and receiver, each application uses its specific sensors. For example, two monitoring applications that require temperature variable use two temperature sensors for the same patient. And if a sensor breaks, these applications lie with lacks of data accuracy and availability, and they can't handle quickly the arrival of new sensor.

In our work, we are interested in improving sensors sharing between applications, therefore the same sensor can be used by several applications and the same information can be provided by several sensors. For that purpose, a loosely coupled concept between system components is mandated. Likewise, in a multi-pathologies case the pooling of physical devices is required in order to decrease the number of sensors used.

To this end, we propose the use of a middleware, structured as a software communication bus which promotes the interoperability among heterogeneous sensors and allows for the pooling of physical devices.

Publish subscribe architecture: We rely then, on a Message Oriented Middleware (MOM) with a publish/subscribe architecture. In regards to SOA architecture which is often used in IoT solutions, it follows a message-based model. It focuses on the information itself and supports sending and receiving of messages between distributed systems. Among this architecture, data sources (publishers) and destinations (subscribers) are decoupled and anonymous, data objects are filtered and delivered to destinations based on predefined topics expressed as subscriptions. Each subscriber receives over time a personalized set of data related to a specific topic.

The publish/subscribe messaging architecture is therefore a perfect communication and data processing mechanism for IoT environments. It introduces a

huge number of heterogeneous devices and applications that are continuously connected to the Internet and able to send and receive real-time data.

2.3 Domain requirements

Semantic representations are widely used in health applications most of them based on ontology concept for example: Open Biomedical Ontologies (OBO) consortium ontologies, SNOMED [9], etc. Moreover health is an application domain for Internet of things where sensor's value is critical information used by health applications to establish analysis and derive health factors and status. Therefore, it is important to have many **information** sources and then, the application can choose the appropriate one and in a faulty sensor case, another can easily take over. But in a multi-pathologies case, avoiding the accumulation of redundant sensors when several monitoring applications are used simultaneously is necessary to respond to financial concerns, and to the **desire of patients** which prefer to avoid the installation of too many devices in their home.

Time and geographical variables are significant factors for establishing health reports. Time is an important element for an efficient continuous care and follow-up for patients, especially in the context of prevention applications like bedsores risk detection [10]. **Geographic** parameters like latitude and longitude can't be pertinent information, patient's room and bed is more useful information to localize a patient.

By combining the three concepts semantic interoperability, loosely coupling and information pooling and health requirements, we can establish a new semantic MOM architecture principle that introduces an "Independent, weakly coupled software components driven by semantic data" for IoT health care applications.

3 Related work

This work deals with two main concepts: Semantic representation of sensors data and middleware solutions for IoT applications. These two concepts, the pillar of our proposed architecture, are linked and connected to create a new IoT environment: a semantic middleware for health applications.

3.1 Ontologies for sensors description

Ontologies for describing knowledge have been widely used in many IoT applications and artificial intelligence systems. **SSN ontology** (Semantic sensor Network ontology) [11] is a generic and domain-independent ontology introduced by the W3C in 2011. This ontology is compatible and compliant with OASIS (OASIS Group Consortium) standards at the sensors and observations level. It allows the accurate description of sensors and allows the introduction of new domains with the addition of dedicated vocabularies. With SSN, sensors data can be described reflecting the deployment, System, Operating restriction, Platform

site, Device, Process, Data and Measuring Capability.

SSN presents some limitations in describing time, space and communication. However it is performed to be compatible with all domains in representing sensors data then, extensions can be added relatively to the needs of areas. According to their domain, many extensions have been created. WSSN in [12] is an extension which addresses the communication limitation. Another SSN extension has been proposed by Roda et al. in [13] for intelligent data analysis, SSN relies on existing extensions to model time and reasoning.

Even if lots of SSN extensions have been provided over the years, there is still no extension that fully meet our requirements. Therefore it has been chosen in this work to propose a SSN extension allowing the description of patient's location to comply with medical location requirements such as in hospitals and retirement homes for instance.

- **OWL representation:** We rely on ontologies in this paper to represent sensors networks, physical aspect and infrastructure. A main advantage of using them is the possibility to generate OWL representations. The Web Ontology Language (OWL) built upon a W3C XML standard can easily be integrated in many programming languages like Java through APIs (Jena or OWL-API).

3.2 Publish/subscribe middlewares for Internet of things

There are many attempts of middleware solution for IoT in the literature. A recent review [7] has analyzed in details several existing solutions according to their architecture type: Event-based, Service-oriented (SOA), Agent-based, database, etc.

Many IoT projects propose publish/subscribe solutions. For instance, CenceMe project [14] aims to automatically infer people's activity (e.g dancing in the party) based on sensor-enabled smart phone; and to share this activity through social media like Faceook. Another example supporting easy access to sensor data on mobile phones is Pogo [15], a publish/subscribe middleware infrastructure for mobile phone sensing. It uses simple topic-based subscriptions to manage access to sensor data and reports significant energy gains due to topic-based filtering of sensed data on mobile devices.

MQTT (Message Queuing Telemetry Transport) [7] is a lightweight publish-subscribe messaging protocol used in IoT applications. It has been standardized by OASIS since 2014. Several research works have been investigated on publish/subscribe middlewares among which is CUPUS [16]. A comparative study of CUPUS and MQTT have been established by Antonic et al. in [17]. The study shows that MQTT offers basic functionalities of exchanging messages and notifications while CUPUS presents advanced features to manage sensors over the cloud and to process in real-time big data streams.

To summarize, publish/subscribe middleware is used mainly for data acquisition from IoT resources. In our context, MQTT fits our basic requirements since patients will be either at home or in hospital. We are not working in large geographic scope and at the time of writing there is no plan to provide a cloud hosting for patient data.

3.3 Semantic middlewares

In most of existing IoT solutions, middleware architectures have not been designed with considerations of semantic annotations. Only few attempts address the semantic topic in their proposals. In [18], authors propose a Semantic Middleware for IoT aiming to resolve the interoperability issue between different kinds of protocols (Bluetooth and UPnP). This solution is based on a SOA architecture. SMArc [19] the Smart Middleware Architecture is another SOA-based solution that focus on smart city energy management for smart grid environments.

LinkSmart [20] relies on a semantic model-driven architecture and enables the use of devices as services, the semantic description of devices is based on ontologies using OWL, OWL-s. OM2M [21] is an advanced semantic middleware based on SOA architecture. It is a Machine-to-Machine service based on autonomic computing and semantic annotation to provide an inter-operable system to connect billions of devices.

Another example is the European project OpenIoT[22] that has developed an open-source middleware platform providing a "cloud-of-things". OpenIoT aims to propose on demand access to cloud-based IoT services for internet-connected objects. Trying to use sensing as a service, OpenIoT architecture embeds the CUPUS middleware as a cloud-Based publish/subscribe processing engine and relies on SSN for sensors description. It can be viewed as a federation of several middlewares interconnected with each other targeting applications for smart cities or campus.

As previously mentioned, to provide a loose coupling and information centric solution, SOA-based solutions are not relevant. OpenIoT could have been a good candidate to target IoT health applications but, its complexity due to the variety of middlewares used in its framework can be a major drawback for programmer. Therefore, a new lightweight solution that can provide an effortless programming environment is needed to exchange health related semantic data in a local area network (or even home area network).

4 Semantic Middleware architecture

The proposed IoT health care architecture, presented in Figure 1, relies on a message oriented middleware enhanced with a semantic representation of exchanged data. In this architecture, *data sources*, defined as *semantic publisher* send over time personalized data, based on a specific *topic*. These data are delivered to consumers, defined as *semantic subscribers*, based on these specific topics. A *semantic message broker* is responsible of carrying data from a publisher to a subscriber. A semantic representation of all exchanged data is therefore, necessary to promote the interoperability. Therefore, five concepts are defined: **semantic sensor, virtual semantic publisher, semantic subscriber, semantic subscription and semantic message broker.**

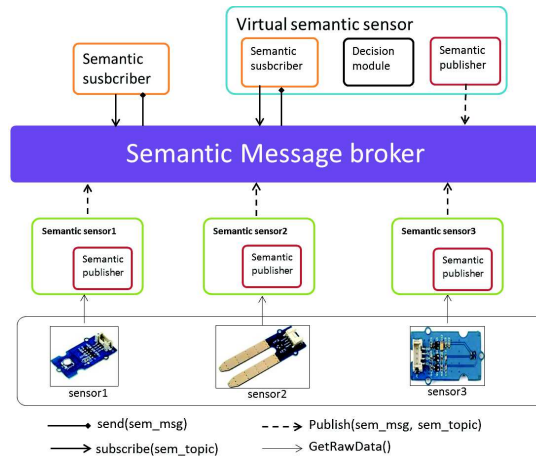


Fig. 1. High-Level semantic Web of Things architecture

```

Bedsore:TemperatureObservation1 rdf:type ssn:Observation;
ssn:featureOfInterest Bedsore:waist_skin;
ssn:observedProperty Bedsore:Temperature;
ssn:observationResult
  [rdf:type ssn:SensorOutput;
   DUL:hasDataValue [qudt:numericValue "27"];
   DUL:isClassifiedBy Bedsore:Celsius];
ssn:observedBy Bedsore:BD_TemperatureSensor1
  [ssn:OnPlatform [:hasPatientLocation [rdf:type Bedsore:PatientLocation;
   Bedsore:room "2";
   Bedsore:bed "1" ]]];
  
```

Fig. 2. Semantic localized observation (in room2, bed1) sent by semantic Temperature sensor and received by a semantic subscriber

- **Sensors** represent the data sources. In our design, we distinguish three kinds of sensors: physical sensor, semantic sensor and virtual semantic sensor.
 1. **Physical sensor** is a sensing device capable of detecting stimulus from real world and of sending raw data like "open", "close" in case of contact sensor or "30 C" in case of temperature sensor.
 2. **Semantic sensor** is a software component that converts raw data into semantic data. The semantic sensor requests physical sensors for raw data, represents them using SSN ontology, generates their OWL classes and sends them to the semantic broker.
 3. **Virtual semantic sensor** in [22] authors present the virtual sensor as any entity (device, object or people) capable of observing properties around them. In our architecture, the virtual semantic sensor can be manifested in two roles semantic subscriber and semantic publisher. It is a semantic subscriber since it represents any entity capable of subscribing for semantic

sensor data. Data can be processed via a **decision module** and then, the virtual semantic sensor take the role of **semantic publisher** and publishes new OWL semantic data to the broker. For example an activity monitor is a virtual semantic sensor. It is a semantic subscriber since it receives OWL sensors measurements and analyses their data. It takes then, the semantic publisher role and sends the activity result(sleeping, preparing food, etc.) to the semantic message broker in OWL format.

```

<owl:NamedIndividual rdf:about="&ssn-Bedsore-Detection;Temperature">
    <rdf:type rdf:resource="&ssn-Bedsore-Detection;Property"/>
</owl:NamedIndividual>

```

Fig. 3. Semantic topic represented as an observed property of SSN ontology

In our architecture, the semantic sensor and the virtual semantic sensor are semantic data sources (publishers). An example of the semantic message generated by a semantic data source is presented in Figure 2: this message corresponds to an observation of a temperature sensor identified by "BD.TemperatureSensor1". The sensor is localized in a medical bed situated in room 2 - bed 1 and publishes data related to "temperature" topic which fits the "observedProperty" in the SSN vocabulary and has a data value 27 Celsius at a given time.

- **Semantic subscriber** represents the receiver component connected to the semantic broker. To receive information, the semantic subscriber has to register for the relevant topic. An example of a **semantic subscription** targeting the temperature topic is illustrated in Figure 3 with the OWL formalism.
- **Semantic Message broker** is the communication relay between all system components. It supplies the monitoring of semantic messages between semantic publishers and subscribers, it manages also semantic subscriptions and notifications.

5 Bedsore risk detection: A use case

5.1 Braden scale

To validate the proposed architecture, a prototype for bedsores risk detection has been designed. Bedsores (also called pressure ulcers) [23] are one of the dangerous diseases that an elder can face. It is a localized injury resulting from prolonged pressure on the skin. It plagues persons who stay in bed or wheelchair for a long period of time. Bedsores are dangerous and can have important consequences, leading to long-term hospitalization.

Bedsore prevention techniques today still rely on human intervention. The caregiver checks regularly (usually every 15 minutes) the status of the patients and

their changes in body position. In the context of home care for dependent elderly people, the frequent checking are not possible. It is important to have an accurate bedsores detection system based on real time sensors measurements. The Braden scale is the most used method in clinical settings, since it results from a simple calculation based on 6 risk factors as presented in Figure 4: sensory perception or sensitivity, nutrition, mobility, activity, moisture and friction. For each risk factor a value ranging from 1 to 4 is entered. This value corresponds to the intensity of this factor for the patient. The lower, the lesser risk. A global score is calculated to determine the risk of developing a pressure ulcer. Based on Braden calculation, we propose to deploy smart sensors in the patients bed or chair as presented in Figure 4. These sensors can potentially be used to automate the data collection for several factors of the Braden score. For instance, the friction and mobility criteria are monitored by a pressure sensor, activity is monitored by a pedometer and finally the moisture criteria by temperature and humidity sensors. All data is routed to the decision module to calculate the Braden score and potentially to trigger an alarm when the score is worrisome (i.e. ≤ 10). This alarm will then urge the caregiver to change the patients posture.

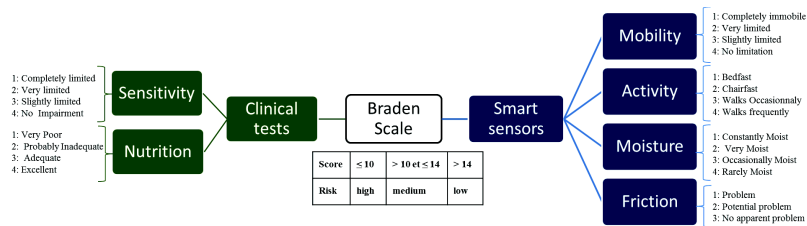


Fig. 4. Braden Scale

5.2 Use case's software architectural design

In accordance with the aforementioned design concepts (semantic interoperability, loosely coupling and information pooling, and health requirements), the bedsores use case has been implemented to validate the proposed architecture. Figure 5 depicts an implementation of our architecture using a UML deployment diagram. This implementation relies on the Mosquitto broker, a lightweight and open source message broker based on MQTT protocol. Mosquitto is available in many programming languages like Java and Python for instance. Regards to the bedsores use case, four physical sensors, a humidity a temperature a pressure and a pedometer sensors, are connected to a Raspberry Pi via Grove Pi. The semantic sensor requests the Raspberry Pi for physical sensor observations (temperature, moisture, pressure, friction in a specific room and bed) and then creates a corresponding semantic representation. It then publishes semantic sensors data on the semantic middleware (via the broker) in OWL format.

Bedsore risk monitor and Activity detection modules are virtual semantic sensors. The Bedsore risk monitor subscribes to the semantic topics related to mobility, activity, moisture and friction. The received semantic data related to topics will be processed withing the Bedsore module to apply Braden scale calculation. A score for the risk of Bedsore is then generated, represented in OWL format and republished on the semantic middleware.

The activity monitor module presented in the diagram is another kind of virtual semantic sensor used to detect person’s activity. Even if activity detection is out of the scope of this use case, this module is interesting to highlight the loose coupling and the information centric approach under use. Indeed, this module can subscribe to the same topics as the Bedsore risk monitor module and use the same information provided by the semantic sensors. The Database is used to get medical information about the patient. Indeed, to assess the Braden score, the database is needed to get information that can not be gathered by sensors such as sensitivity and nutrition. The mobile tablet module subscribes to the bedsore-Risk topic via MQTT_sub interface. It will receives in real-time the Braden scale score and in a high risk case, an alarm can be triggered to urge the caregiver.

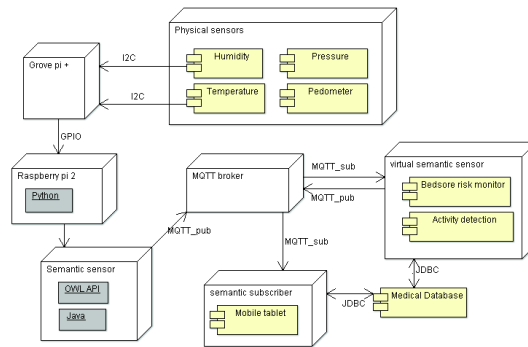


Fig. 5. Deployment diagram of the Web-of-things architecture using Bedsore risk detection use case

6 conclusion

In this paper, we have presented the principles of an IoT software architecture, based on Message Oriented Middleware and on semantic data representation. Our architecture is illustrated by a case study for the detection of bedsore risks. Our ongoing work follows two tracks: On the first hand, we plan to validate our bedsore application through controlled evaluations in a clinical environment, to assess its performance, reliability, safety and usability by the care personnel. On the second hand, we work on developing a reference implementation of our

proposed middleware, with the goal of providing a simple software API usable in various application domains, to alleviate the tasks of software developers using the architecture we propose.

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