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A Semantic Web-of-Things Architecture for Monitoring the Risk of Bedsores

Rita Zgheib*, Rémi Bastide*, Emmanuel Conchon†
*University of Toulouse, IRIT/ISIS, F-81100 Castres
{rita.zgheib,remi.bastide}@irit.fr
† University of Limoges, XLIM, F-87060 Limoges cedex
emmanuel.conchon@xlim.fr

***Abstract*—Bedsores are a common injury that mainly plagues elders and frail persons, and are a major cause of concerns in medical institutions. We present a system based on the Internet-of-Things technologies, aiming at detecting the risk of bedsores using sensor fusion. This paper mainly focuses on the software architecture of the proposed system, based on the principles of weak coupling and of semantic data exchange. We present a model of the application in terms of the Semantic Sensor Network (SSN) ontology.**

***Index Terms*—Keywords: Bedsore detection, Home care, Internet Of Things, Semantic middleware.**

I. Introduction

Elders, whether they are staying at home, hospitals or retirement homes, often incur the risk of health symptoms and problems. In many cases, some form of monitoring is helpful to help the healthcare personnel preventing the degradation of the patient's health status.

In [1], a study has been established on the trends in disease and injury incidence, prevalence, and years lived with disability (YLDs) which it is considered as an essential input into health policies. This study estimated these quantities for acute and chronic diseases and injuries for 188 countries between 1990 and 2013. Based on the authors interpretation, ageing of the world's population is leading to a substantial increase in the numbers of individuals with disease after effects and injuries. The non-fatal dimensions of disease and injury will require more and more attention from health systems.

Bedsores (also called pressure sores or pressure ulcers) [2], are one of the dangerous diseases that an elder can face. Bedsores are a localized injury resulting from prolonged pressure on the skin. They plague persons who have a reduced ability to move and change positions, and who stay in bed or wheelchair most of the time. Bedsores are dangerous and can have important consequences, leading to long-term hospitalization. At more severe stages, bedsores become very painful, the patient is at risk of surgery and even of death.

Prevention techniques in hospitals and retirement homes today are still traditional, where the personnel spends a considerable amount of time regularly checking (usually every 15 minutes) the status of their patients and their changes in body position. The development of a pressure ulcer in a patient is considered a serious fault from the healthcare team.

Many research projects like openIoT [3], OM2M [4] are focused on smart home, smart cities and many IoT applications. These applications are based on intelligent sensors deployed on a smart space in order to gather real time information that can be treated and correlated to infer useful information.

In the context of home care for dependent elderly people, and due to the risks of the bedsores that can damage the daily life of elderly, it is important to have an accurate bedsore detection system based on real time sensors deployed in the patient's environment e.g. her bed or wheelchair.

We present in this paper an innovative e-Health system dedicated to monitoring the risk of development of bedsores for elders staying in a hospital or retirement home. This paper mainly focuses oh the description of the software architecture of this system, which is based on a combination of Internet-of-Things and semantic technologies.

In the proposed system, data is gathered from many ambient sensors. A semantic technique based on the use of ontologies is described in order to overcome the interoperability challenges introduced by the variety of sensors potentially used. Sensor's data is handled by a knowledge-based, semantic middleware which routes this data to the appropriate decision modules.

The paper is organized as follow: In Section 2 we describe the general approach of Braden Scale. The architecture with ontology and middleware processes are described in Section 3. We present then, OpenIoT project in Section 4. We discuss the related work in Section 5 before concluding in Section 6.

II. Bedsore Detection

Several assessment scales [5] have been studied in the literature in order to quantify the risk of bedsores, among which are the Norton scale, the Waterlow scale and the Braden scale. The Braden scale is the most used method in clinical settings, since it results from a simple calculation based on 6 risk factors: sensitivity, mobility, nutrition, activity, moisture and friction. For each patient, a nurse creates a dashboard collecting the following information:

- Sensitivity: to what extend the patient is able to respond to pressure-related discomfort;
- Mobility: to what extend the patient is able to change and control her body position;
- Nutrition: the patient's usual diet, and it's adequacy to her state of frailty;
- Activity: the degree of the patient's physical activity;

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- Moisture: the degree to which skin is exposed to moisture;
- Friction: whether the patient has a potential problem moving or maintaining a good posture in bed or chair.

For each risk factor the nurse enters a value in the scale [1..4], corresponding to the intensity of this factor for the patient. A global score is calculated and determines the risk of developing a pressure ulcer. The lower the score, the higher the risk Fig 1. In the current medical practice, the risk factors are assessed by nurses or medical aids, through clinical examination or interviews with the patient.

Several smart sensors, already available on the market, can potentially be used to automate the data collection for several factors of the Braden score. Therefore, in order to alleviate the nurse's job by getting real-time accurate values, we propose to deploy smart sensors in the patient's bed or chair in order to monitor several of the Braden scale's criteria. For instance, the friction criteria is monitored by a pressure sensor and the moisture criteria by temperature and humidity sensors. These sensors will send real-time data to the semantic middleware we propose, while other indicators can be extracted via clinical examination and submitted on the middleware using manual data entry on a mobile computer system. All data is routed to and analyzed by decision modules in order to calculate the Braden score, and potentially trigger an alarm in case the score is worrisome (i.e. ¡= 10), which will urge the nurse to change the patient's posture.

Many components share and exchange data through the proposed system. On one side, several ambient sensors placed in the environment of the person are sending data (observations, position, sound, light sensors, switches...) in real-time. Decision modules and applications, on the other side, are receiving and using this data to calculate the Braden score, and potentially trigger alarms. In this paper, we focus mainly on the software architecture needed to manage the data exchanges and the triggering of alarms.

Score	≤ 10	> 10 et ≤ 14	> 14
Risk	high	medium	low

Hight risk => alarm

Fig. 1. The Braden scale for assessing the risk of bedsores. Blue factors can be replaced by intelligent sensors and purples one can be extracted via clinical exam.

III. Semantic Web-of-Things

Internet-of-Things (IoT) technologies aim at supporting a huge number of connected sensors, which will have specific technologies and infrastructures. In order to promote interoperability among these heterogeneous sensors and to allow for the pooling of physical devices, an adequate architecture is mandated. 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, low-level details of the required 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). This cooperative resource management is an answer both to financial concerns (avoiding the accumulation of redundant sensors when several monitoring applications are used simultaneously) and to a patient's desire to avoid the installation of too many devices in his home. To this end, we propose the use of a middleware structured as a software communication bus.

As the main resource for decision is the data that is exchanged through the middleware, we argue that a neutral and formal data representation is required. The system we propose uses a knowledge-driven approach based on ontologies in order to enable interoperability at the semantic level between the sensors and the decision modules.

A. Message Oriented Middleware (MOM)

As stated above, a proper middleware architecture is mandated to providing the interoperability of our system. Moreover, it is likely that information from one sensor might be used for several different purposes, by unrelated systems. For instance, movement sensors can be used for measuring overall activity within the home, and also to detect activities of specific interest, e.g. feeding or toilet use.

Considering the constant evolution of technological supply, it is also likely that new sensors will be introduced into the running system, to replace, complement or supersede existing ones. A sustainable software architecture must accommodate for obsolescence and improvements of its components, and allow for replacing and introducing new components in a deployed system with minimal impact to the existing applications.

Middlewares for wireless sensor network are presented in [6]: *SStreaMWare*, *USEME*, *SensorWeb 2.0*, *OASiS*, *B-VIS*, *MiSense*, *SOMDM (SI)*, *SOA-MM* and *ubiSOAP*. These solutions are based on the Service Oriented Architecture (SOA), which focuses on services provided by the system, each service using proprietary sensors for data gathering. Contrasting to the SOA approach, Message Oriented Middleware (MOM) [7] architectures follow a message-based model which focuses on the information itself, and provide a better fit with the requirements stated above.

MOM architecture with its publish/subscribe mode promotes low coupling between software components, because the source of a specific event (e.g. a sensor) is not mandated to know where, how or for what purpose this data will be processed. Conversely, some specific information (e.g. sleep disorders) can be detected through different means (e.g. pressure sensors under the mattress, or movement detectors). A system interested in this information does not need to be aware of the means used to infer it.

A main objective of this architecture is to provide a scalable and loosely coupled system ensuring interoperability of software components. These components can be viewed as data providers or *Publishers* and data consumers or *Subscribers*. All components communicate through a communication bus, the *broker*. The publisher and receiver exchange messages for a specific field of interest called *topic*.

Broker: In MOM architecture publishers and subscribers are coupled with the mediation of a broker, thus creating a system of loosely-coupled components. With this kind of solution, it is then possible to switch from a provider to another without notifying the consumers/providers as long as the produced data remains available. The addition or the removal of a component is transparent for other components as long as the information is still produced. It provides a strong flexibility and enforces the capacity of the system to evolve.

Publisher: A publisher publishes (sends) information about a specific topic via the broker. Sensors are the most obvious data providers (publishers) for a e-health solution dedicated to home care. They can be split in two categories: ambient sensors disseminated in the house or body sensors carried by the patient to provide physiological data for instance. In the current version of our system, several sensors have been deployed: moisture sensors, smart cushion with pressure sensors, temperature and movement sensors, embedded in the patient bed or chair. These sensors can use either a wired or a wireless link to provide their data.

Subscriber: A subscriber registers to a specific topic via the broker. It uses the raw data provided by producer to compute new data (usually with a richer semantic content) that can be sent back to the bus. For example, a bedsore detection subscriber uses sensors data to compute the risk and send it to the bus in order to trigger an alarm.

An example of MOM architecture is presented in the picture Fig. 2. Publisher and subscribers are connected to MQTT broker [8]. One of the subscribers, the *ADL module* interested in the *humidity topic* subscribes to this topic via the broker and wait for the information. *Humidity sensor*, the publisher, sends humidity values to the humidity subscribers via *Publish(msg, Humidity)*. Then Subscriber1 and ADL module will receive data sent by the provider.

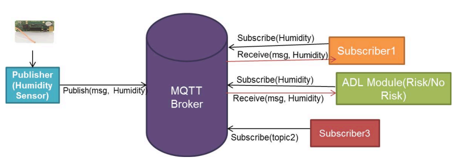

Fig. 2. MOM architecture: The publisher(humidity sensor) sends messages and humidity subscribers(ADL module) receives the messages.

B. Semantics

Components (publishers/subscribers) connected to the middleware are exchanging messages which are sensor's observations values in most cases. While the use of sensing devices is currently increasing, it is accompanied by an increasing volume of data, as well as increasing heterogeneity of devices, data formats and measurement (for instance a temperature value can be represented in Celsius(C) format or Fahrenheit (F)). Moreover, we are interested in the information exchanged via the middleware, representing this information in a formal way using normalized annotations is then, an essential requirement to improve the interoperability of communicated data.

Ontologies for describing knowledge have been widely used in many IoT applications and interoperable systems and several definitions for ontologies have been proposed by the Knowledge Engineering community. Gruber in [9] defines an ontology as "an explicit specification of a conceptualization". He considers that it is necessary to define a common vocabulary in which shared knowledge is represented (by classes, relations, roles and other objects) to improve the sharing and reuse of formally represented knowledge among Artificial intelligence systems, the specification of this vocabulary is called "ontology".

Ontologies can be described in the formally defined language OWL (Ontology Web Language) [10], a knowledge representation language recommended by the W3C(World Wide Web Consortium). It is an updated format of RDF(Resource Description Framework) representation language that provides a classical notation of an entity–attribute–value model within object-oriented design.

Due to its considerable efficiency in ensuring interoperability and clarification of knowledge structure, we rely on ontologies in this paper to represent sensor's networks, physical aspect and infrastructure. Ontologies can also be used to describe sensor's observations after stimulus detection and data flow.

Several surveys put attention on the important contribution of ontologies to describe a sensor network. Authors in [11] and [12] cited many ontologies like Sensei O&M [13], CSIRO [12], OntoSensor [14] and SSN ontology [15] created in 2011 by the W3C. Most surveys argue that SSN is one of the most efficient ontology to describe sensors accurately.

SSN ontology created by the W3C uses OWL to describe sensors: capabilities, measurement process, observations and deployments. SSN is built around the sensor Ontology Design pattern (ODP): it describes relations between sensors, stimulus and observations "Stimulus-Sensor-Observation" and can be seen from 4 main perspectives:

- Sensor perspective: Which sense? How and Why?
- Observation perspective: Observed data and meta-data
- System perspective: Sensor's system and its deployment
- Feature and property perspective: Relations between Sense and Observation or Oservation and property

While the SSN ontology has a great value in representing sensor's data, it also presents some limitations in describing time, space and communication. Many SSN extensions try to improve these limitations: Bandadouche [11] addresses the communication limitation, and introduces a new ODP (Ontology Design Pattern) *Stimulus-WSNnode-Communication* describing the communication process (for example how a communicating device works).

Another solution composed of several ontologies *SSN, SWRLTO, TAO and DOLCE* [16], has been proposed to improve time's limitation in SSN. This ontology was created for intelligent data analysis, SSN is used for sensor's measurements; SWRLTO is used for temporal modeling and reasoning, TAO ontology designed to capture the semantic temporal abstractions and DOLCE ontology is used for the alignment. This framework uses temporal reasoning to search and classify temporal patterns that help to infer the process state or condition.

Another extension for SSN based on *fuzzy logic* [17] proposed to support fault tolerance for large scale sensor network. It is a service oriented approach to build diagnosis and test services for wireless sensors. *ContoExam* [18] is an ontology developed to address the interoperability problem of sensor networks in the context of e-health domain applications. It contains specific expressions and specifications for medical use as examination vocabulary and expressions. *BFO* [19] is a spatio-temporal extension that can distinct between describing identities happening at a finite time and events like storms. It is a hierarchy system approach, sensors collect data from real world and send it to a clusterhead-node. For spatial information, sensors are equipped with GPS.

The ontologies cited before use SSN and add extensions to it in order to integrate and adapt the expressions of their domain. And despite the limitations of SSN, We acknowledge that it is commonly used by these projects and is still the most appropriate ontology that can describe our sensor system, which is why we chose it to describe our sensors.

Figure Fig. 3 present a part of humidity sensor designed with SSN which can be modeled via Protégé software. The bedsore detection node contains a humidity sensor node which has a system deployment, measurement capabilities and properties. In the property section, sensor's observations are described. Each **Observation** defines a sensor output and has humidity value defined in RH (Relative Humidity), this value is an important information in the system since it will be used to do the calculation of the risk. We presented also the minimum and maximum operating value in the measurement capability of the sensor class.

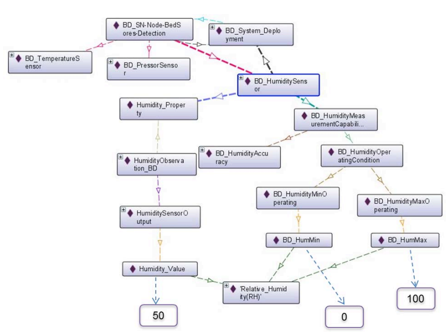

Fig. 3. Humidity sensor annotation via SSN ontology

C. Semantic Message Oriented Middleware architecture

Based on what we have presented in the previous sections, we propose a software architecture based on SSN ontology to describe sensors and MOM architecture to guarantee the interoperability between system components. This architecture is based on 3 engines: Semantic engine, Middleware engine and Analysis and Detection engine presented in Figure 4.

The *Semantic Engine* is in charge of the interoperability of devices to be integrated. Potentially interesting self-measuring devices are of great diversity, innovation in this sector is constant and the proposed environment must be able to easily integrate sensors that do not yet exist, or only as prototypes (e.g. biosensors implanted in clothing, etc.). Interoperability in this area is treated via semantic annotations and ontologies.

The *Middleware Engine* while respecting the principles of loose coupling, should allow for the design of varied applications, taking into account the constraints of the application domain including the constraints of scalability, security and privacy resulting from the transmission and processing of medical information. These constraints will be processed via the message oriented Middleware.

The *Analysis and Detection Engine:* is charged of data analysis to infer bedsores risk carried out by the monitored person, based on information from the sensors and Braden scale. This module will be charged also to trigger an alarm when the risk is high.

After designing this architecture, we found that the first 2 layers of this architecture are similar to the composition of an European IoT project (OpenIoT) which is based on the same principles that we just proposed.

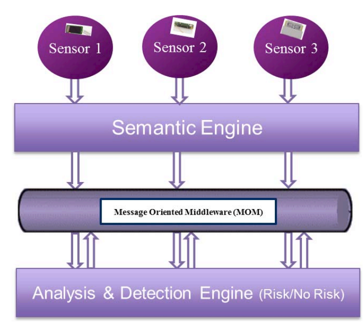

Fig. 4. Semantic Message Oriented Middleware architecture

IV. The OpenIoT Project

OpenIoT [3] is an FP7 European project that provides an open-source middleware platform to enable the development of IoT applications. Its main goal is to offer on demand access to IoT services of internet-connected objects via a web application. It relies on 7 main modules: **sensor middleware X-GSN** a semantic publish subscribe middleware; **LSM Light middleware** another middleware which behaves like a cloud database that stores the data streams carried by X-GSN as well as their semantic annotations; a **Scheduler** for services management that provides a sensor discovery mechanism and their associated data streams; a **Service Delivery and Utility Manager** that allows data streams combination as defined in the application workflow and mainly relies on SPARQL queries; a **Request Definition Module** supported by a GUI that enables on-the-fly specifications of new service requests and their submission to the scheduler; a **Request Presentation** component that eases the visualization of service's results and finally the **Configuration and Monitoring** component that enables a visual management of sensors and services.

In this paper, a focus is made on the X-GSN [20] middleware that provides both sensor's semantic annotations and a MOM architecture making it a suitable technical solution for our own bedsore detection system.

XGSN is an extension of the GSN middleware: a distributed architecture aiming at collecting, filtering and aggregating virtual or physical sensors' data. It is based on MOM architecture and uses SSN ontology for describing sensors, thus allowing the semantic interoperability among them. Through the dedicated wrappers (serial, UDP, etc.), XGSN collects data from sensors that can either be real sensors or virtual ones. In XGSN, a virtual sensor is the logical abstractions of one or more real sensors or objects or any entity that captures data. XGSN offers semantic representation of sensors and continuous data handling capabilities through extensible processors (Data correction, Data Clean...). It can aggregate, filter or process several observations over time and space and annotate them for further use.

The semantic annotation provided by XGSN facilitates the discovery of information emitted by sensors in an OpenIoT environment by annotating the provided sensors data streams with relevant metadata using an extension of the SSN ontology. This extension adds new concepts related to time and space.

In the current, we have designed a bedsore detection use case, using the OpenIoT platform. In this system, humidity, pressure, temperature and mobility sensors are modeled to detect the risk of bedsore for a specific patient. As previously mentioned, the Braden scale has information that still relies on human observation such as nutrition or sensitivity. Based on the annotated sensors' information and on human-based observation a new alert can be emitted on X-GSN providing a new kind of sensors. At the time of writing this sensors is rather simple as it is only based on fixed threshold to emit its alert.

V. Related Works

In this paper, we propose a semantic middleware solution for bedsores detection but our final goal is long-term monitoring of elders by detecting and monitoring their daily activities using ambient sensors or what we call ADL(Activities of Daily Living) detection. In this section we will present some related works related to bedsores detection systems, Semantic middlewares proposals and an idea on Activity detection.

A. Bedsores detection

Since bedsores is a delicate situation for elders and have serious effects on patient, many research projects have been conducted in order to find solutions for monitoring and preventing these effects. In [21] a bed detection system has been creating for bedsore monitoring in hospitals, it is based on Canny Edge detector to detect in real-time the location of patient's bad when a high risk of bedsores is detected, furthermore it allows visual surveillance via cameras. IntelliSense Bed [22] is a low cost Microcontroller solution for bedsores prevention, it relies on bed surface temperature as a criteria for occurrence of bed sores. While our study is based on non-intrusive sensors, it is dedicated for hospitals and home care environments and it is based on Braden scale which considers temperature as factor but also many other criterias that make the result more accurate. Then, solutions just cited can not fill our needs.

A Middleware for bedsore detection have been found also, in [23] authors defined a SOA architecture for bedsores detection and sleeping monitoring, the key idea of this work is collecting information from wireless and wearable sensors. Other monitoring system proposal in [24], it is based on body sensors connected to a smartphone via Bluetooth to get information like heart rate and body temperature.

Solutions presented in this section focus on information gathered from sensors and they don't put attention on the way of extracting these information. In our approach we argue that describing information with semantic annotation is needed to have an interoperable system.

B. Semantic middlewares

In most of IoT solutions, middleware architectures have not been designed with semantic annotations considerations sush as Hydra and UBIWARE. Neverthless, some projects addresses the semantic topic in their proposals, in [25] authors propose a Semantic Middleware for Internet Of Things aiming to resolve the interoperability issue between different types of protocols (Bluetooth and UPnP). This solution is based on SOA architecture as well as SMArc [26] the Smart Middleware Architecture focused on smart city Energy management as a solution for smart grid environments. LinkSmart [27] is based 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 [4] 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 interoperable system capable of connecting billions of devices.

We can see that all these projects are based on SOA architecture and focus on services rather than information. In a previous section, we have argued the choice of MOM architecture which complies better with our requirements which explain our preference to OpenIoT project.

C. ADL in semantic middlewares

In the context of home care, the aim of our solution is to provide an open source semantic middleware for ADL detection. Currently, our solution is capable of providing a solid semantic sensor's representation over a Message Oriented

Middleware. For handling activities and risk description we are working on a solution to integrate decision-making approaches such as Bayesian networks, Markov models and Complex Event Processing. We will rely on ontologies to annotate activities an example of these ontologies can be found in [28].

VI. Conclusion

We have presented a new solution for bedsore detection based on Braden scale as a risk assessment calculation. We have presented also the interest of using semantics in a Message Oriented Middleware to have an interoperable and scalable system in an IoT application. We have shown how OpenIoT project comply to our requirements for sensor's description and sharing information. However, to achieve our final goal which is activity detection, we plan to describe the activities by using ontology concept, and then an extension should be added to the existing ontology. For alarm triggers and decision-making requirement, we are working on a solution to integrate approaches like Bayesian networks to the existing solution.

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