AAL open source system for the monitoring and intelligent control of nursing homes

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***Abstract*— IoT can dramatically improve the quality of life of aged population. In this regard, Ambient Assisted Living (AAL) and Active and Healthy Aging (AHA) are fields with an enormous potential to benefit from the current growth of IoT within our society. We present SAFE-ECH, an innovative intelligent AAL open source system for monitoring nursing homes. SAFE-ECH creates an Ambient Intelligent environment in a residence by collecting and storing sensor monitoring data, performing intelligent data analysis and specific actions to enhance the safety, comfort and efficient care of aged people. Our system allows caregivers to access the system to retrieve monitoring information and perform control actions. Our system implements open standards of the Open Geospatial Consortium complying with Observations & Measurements Schema (O&M), SensorML and Sensor Web Enablement (SWE) specifications. A key element is a Sensor Observation Service (SOS) for sensor data collection and management from heterogeneous sensor networks. A Complex Event Processor represents the intelligence of the system. Our system adapts to the specific needs of each nursing home, integrating the required sensors, actuators, rules and services. It is scalable and allows the management of several residences simultaneously.**

Keywords—Ambient Assisted Living; Internet of Things; Active and Healthy Aging; Ambient Intelligence; Sensor Observation Service; Sensor Web Enablement; Open Geospatial Consortium; open source system; interoperability

I. INTRODUCTION

The continuous growth of aged population in the modern society [1], in addition to the special caring needs of the elderly has motivated a growing interest in Ambient Assisted Living (AAL) and Active and Healthy Aging (AHA) [2] during the last years [3][4]. AAL aims to improve the quality of life of aged people by means of emerging and innovative technologies such as Internet of Things (IoT) [5][6] [7].

AAL represents an area of Ambient Intelligence (AmI), an emerging field of information systems, that has the aim of making quotidian environments sensitive to human interaction, in addition to provide them with intelligence [5][8] to facilitate some aspects of daily life. AAL involves areas such as e-Health [9], Elderly Smart Home [10], and Active and Healthy Ageing (AHA) [2]. These areas can be enormously leveraged and boosted through the use of IoT technologies. A clear example of this can be the use of Body Sensor Networks (BSN) in e-Health [11], which allow the remote monitoring of human signs for medical purposes by using IoT wireless sensors.

Ambient Intelligence requires the use of sensor networks for collecting information of the environment in a transparent way for the end user. However, that transparency hides an inherent complexity at many levels. Sensor networks in IoT typically present vast heterogeneity. Sensors have different specifications, vendors and measurement patterns. Moreover, sensors can present mobility, and not be located in a fixed spatial position. Data collected from sensors is transmitted through very diverse technologies and protocols, such as: Wi-Fi, Bluetooth, Zig-bee, 6LowPAN, UDP, LoRa, TCP, MQTT etc. The integration of sensors and their data is not a trivial issue due to this heterogeneity, and the same applies to the access and management of this data [11][12]. The massive amount of data that IoT Sensor Networks generate requires (additionally) massive storage, typically located on the cloud [13][14], along with the necessity to retrieve and manage it. This represents an additional challenge for IoT systems.

There are few standardized initiatives addressing and giving solutions to this interoperability issue. One of them that receives considerable attention is the Sensor Web Enablement (SWE) [15] framework of the Open Geospatial Consortium (OGC), that enables the integration of sensors and the data generated by them. In particular, the Sensor Observation Service (SOS) as a part of the SWE specification plays a major role in this integration by defining an interface for accessing to sensor data and metadata [16]. The SOS provides a standardized web service interface that allows clients to interact with registered sensors and their measurements [16], and also to register new sensors and observations, or delete them.

Mobility is a key feature in IoT. Even in fixed sensors, the spatial position of a smart object can be relevant in the analysis of the sensor data. Many sensors are mobile, and this feature allows different monitoring of environmental aspects, that otherwise cannot be addressed with fixed sensors. Mobile phones are a clear example of the massive presence of mobile smart objects in IoT. Mobility aspects in smart objects should be addressed for roaming among different networks, and to understand in a more complete way monitoring information. Mobile networks of sensors in special environments can even require the use of mobile gateways [17]; in such IoT systems information about the gateway and sensor position is obviously crucial for the system operation and the analysis of monitoring data. Mobility aspects can be especially interesting for AAL, as location information and tracking can be critically useful for many services within a nursing home or in the smart homes for elderly people. The use of geospatial metadata can solve the aforementioned issues. In this sense OGC provides standards

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that support the geolocation of sensors and sensor measurements.

We present an innovative open source AAL system, SAFE-ECH, that aims to enhance the quality of life of elderly people living in nursing houses. Technology can leverage the effectiveness of care services to the elderly and optimize the environmental conditions in the residence, through the creation of an Ambient Intelligence environment. Our system is based in open standards and follows the Sensor Web Enablement (SWE) framework of the Open Geospatial Consortium (OGC). It uses the SOS as a key element for integrating sensors and measurements, and retrieving this data. SAFE-ECH supports Active and Healthy Ageing, and aims to attend the needs of the elderly people in nursing houses, by providing services to enhance their quality of life, health care, safety, mobility, and comfort, among other aspects. Our system has good scalability and it is adaptable to the different topologies and needs of nursing houses.

This paper is structured as follows. Section II explains open OGC standards and the SWE framework. Section III gives a general overview of our system in an AAL context. Section IV describes our architecture proposal and details the elements of the proposed architecture from a component and software perspective. As well SAFE-ECH architecture is described from a service oriented approach. Section V explains the security measures of our system. In Section VI flexibility and scalability features of the system are detailed. Finally, Section VII presents our conclusions and outlook.

II. OGC Sensor Web Enablement (SWE)

Sensor Web Enablement [18] is a framework and a set of standards of the OGC that allow the exploitation of sensors and sets of sensors connected to a communication network. SWE is based on the concept of Web Sensor. “A Web Sensor refers to web accessible sensors networks and archived sensor data that can be discovered and accessed using standard protocols and Application Program Interfaces (APIs)” [19]. It aims to make all kind of sensors and sensor data accessible by using standard protocols and application interfaces, through the use of Internet Web protocols and the XML language. Thus enabling the capability of publishing sensor features such as sensor interfaces, capacity and position. This information can be used by applications to geolocate and process data collected by the sensor without the need to previously know the sensor system. The SWE is a group of specifications covering sensors, related data models and services that offer accessibility and control over the Web. The SWE architecture is composed of two main models: the information model and the service model [18]. The information model describes the conceptual models and encodings used, whereas the service model specifies related services specifications. In the information model, the conceptual models are: transducers, processes, systems and observations. The encodings are: Observations & Measurements Schema (O&M) [20][21], Sensor Model Language (SensorML) [22][23] and Transducer Markup Language (TransducerML or TML) [24].

The service model describes services within the SWE framework that allow applications to access in an interoperable way to sensor information, and perform management operations on it. SWE service model includes specifications for five services: Sensor Observation Service (SOS) [16], Sensor Alert Service (SAS) [25], Sensor Planning Service (SPS) [26], Web Notification Services (WNS) [27] and Catalogue Service Web (CSW) [28]. SOS and SAS services are described below.

A. *Sensor Observation Service*

Sensor Observation Service (SOS) is a part of the SWE framework that defines a common model for all sensors, sensors systems and their observations. The model is horizontal as it can be applied in any IoT domain, and it is independent from specific applications [29]. “The SOS is the intermediary between a client and an observation repository or near real-time sensor channel. Clients can also access SOS to obtain metadata information that describes the associated sensors, platforms, procedures and other metadata associated with observations” [30]. The most recent SOS version is 2.0 (2012) that among other updates allows the use of both JSON and XML messages and four profiles of operations (Core, Transactional, Enhanced, and Result Handling).

Several SOS implementations have been developed. The most complete and widely utilized is the 52°NORTH SOS [31]. Under the GPL license (GNU General Public License), the 52°North SOS is implemented in Java, thus it is platform agnostic, and supports all SOS operational profiles. It offers extensive on-line documentation and receives constant support from an active and large community. The SOS is part of a suite of sensor web service implementations of 52°North. [32]. Other implementations are PySOS [32], MapServer SOS [33], and Deegree SOS [34]. PySOS is the only python-based implementation of the OGC SOS standard, developed by the oceanic research community. All these implementations offer limited functionality and no current support.

SOS implementations typically require considerable computational resources to cover the needs of all feasable scenarios. Following the recommendations of OGC for a Lite SOS for Fixed Sensors [35], SOSLite [36] is a lightweight implementation of the SOS.

B. *Sensor Alert Service*

Sensor Alert Service (SAS) [25]: is an event notification service based on the pattern of Publisher & Subscriber. A Producer can include and configure events, and the Consumer can subscribe to them, to be automatically notified each time the event occurs.

III. SAFE-ECH system overview

SAFE-ECH is an innovative and intelligent AAL system that aims to enhance the quality of life of elderly people living in nursing homes. Our system creates an Ambient Intelligent environment in a residence by means of a collection of sensors that monitor the nursing home, the intelligence of the system to analyse the monitoring data to decide actions with the aim of facilitating the daily life of residents, a set of actuators that performs those actions, and a Human-Machine Interface (HMI) that is accessible by the carers. The caregivers can use the HMI to access to monitoring information, receive notifications and alarms, configure the system and perform control actions in the residence to enhance the safety, comfort and efficient care of aged people.

Our system has two modes of functioning: Local Management, that enables the monitoring and control of a single residence, and Global Management, that allows this monitoring in several residences simultaneously. These two modes present high flexibility. A Global Management SAFE-

ECH system can integrate several Local Management systems, and even other Global Management systems that include several residences. Global Management allows access to the local HMI of each Local Management system that is integrated within.

IV. System Architecture

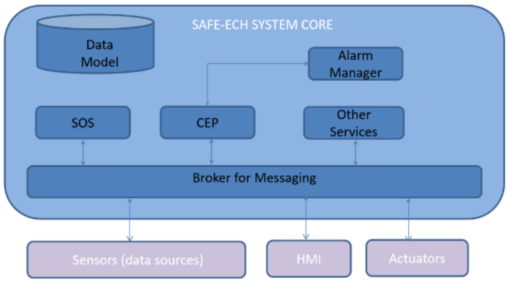

Fig. 1. Sytem Architecture

The architecture of our system from a high level approach is shown in Fig.1. and is explained in this section from a component perspective. Additionally, the software architecture of the open source central system is presented as well.

The different elements that compose SAFE-ECH are detailed as follows:

- Sensor Network: the set of sensors placed in a nursing house for monitoring purposes. They are the main source of information of the system, and allow the creation of a sensitive Ambient Intelligence environment in the nursing home. Their function is to monitor the residence of the elderly and send the data generated to the Sensor Data Acquisition Module. This Module collects the sensor data and sends it to the central system. Sensors and sensor observations have associated geolocation metadata that follows the specifications of the OGC. This feature enables additional mobility and positioning functionality.

- Actuator system: the collection of actuators within the nursing house. They perform orders given from the central system, that they receive through the Actuator Module.

- Central system: the core of our system is able to collect and store data from the sensors, analyze it, and perform specific actions in case its intelligence considers that they must take place in response to specific situations. Those actions can be notifications visible through the HMI, orders to the actuators and the launching of alarms. It implements specific services of the SWE framework: a Sensor Observation Service and a Sensor Alarm Service.

- HMI: Human-Machine Interface that can be accessed on-line through a web interface. Authorized users can visualize monitoring information, configure the system services, and perform management and control actions.

The Central System is composed by other components that are described in detail below. Additionally, software specifications of the open source central system are given, thus detailing the software architecture.

- A Sensor Observation Service (SOS) is the element responsible for the sensor data gathering, storage and retrieving. It follows the Open Geospatial Consortium (OGC) standards, and provides a standard interface for managing and retrieving the data and meta-data of sensors and sensor observations [37]. For this purpose, the SOS offers a set of operations that clients of this service can utilize independently from their domain or associated applications. By these way, the data is accessed way by other system elements that can perform data analysis, display monitoring information and enable the AAL services that SAFE-ECH offers. It allows access to any sensor system, either in-situ, remote, fixed or mobile sensors, enabling interoperability. SOS is based on widely accepted web technologies like XML, JSON and SOAP, typically used in IoT. Registered sensors can introduce their observations in the SOS, that stores them in a database with geospatial support. The SOS complies with the "Observations & Measurements Schema" (O&M) [21] [22] specification for modeling sensor observations, and with the Sensor Model Language (SensorML)[23] specification for modeling sensors and sensors systems. Our system uses 52º North SOS implementation [31], the most important implementation of the SWE OGC SOS in terms of usability, acceptation and support, that is capable of executing any operation supports all operation. Our SOS utilizes PostGreSQL database with PosGis support for geospatial metadata.

- A Complex Event Processor (CEP), that processes events that are detected registered and through the SOS. The CEP has several rules that allow the detection of specific patterns of events, and define the actions to be triggered in response. Auxiliary tables, such as schedules for performing specific actions, can be used in CEP rules. The set of rules is adapted to the specific needs of each residence. In this regard, an administrator of the system can add, change or remove CEP rules, as well as to create or modify auxiliary tables, through the system HMI. Rule definitions can entail high complexity. The CEP engine used is ESPER, an Event Stream Processing (ESP) [38].

- An Alarm Manager that handles alarms and certain incidences of high priority detected by the Complex Event Processor. Alarms are handled separately from other events due to its high priority. The Alarm Manager used is Sensor Alert Service (SAS) within the SWE specification [25]. The SAS launches alerts via XMPP and optionally via other transport protocols. It works on a publisher/subcriber basis: producers can include and configure events, and consumers can subscribe to them, to receive a notification each time the event happens. The 52º North community provides an enhanced implementation of the SAS called Sensor Event Service (SES), that adds new functionalities (i.e. advanced filter capabilities). It supports the identification of different types of events, that can be the generation of an observation, an state message from a sensor (i.e. battery state), or a more complex pattern. Our system incorporates the aforementioned 52º North SES [39].

- A broker that enables communication among the different elements of the Core system. It is as well the interface between the core system and the external information sources. We use the open source RabbitMQ broker, that relies on AMQP protocol for messaging [40].

- Other elements of minor importance and relevance that for the sake of simplicity are not included in the general description of our system.

A. Service Oriented Architecture

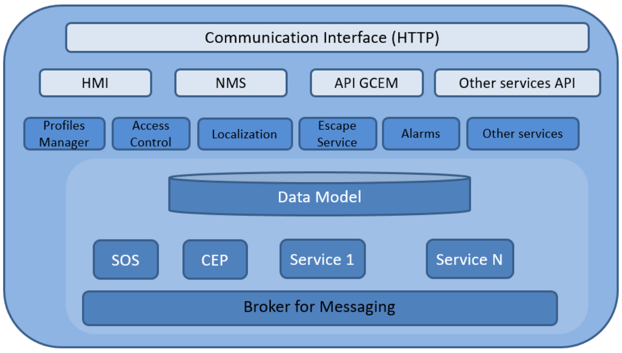

Fig. 2. Service Oriented Architecture

A Service Oriented Architecture describes in an optimal way the AAL Ambient Intelligence environment that the system creates, as a set of services that receive the residents (end-users) in addition to the services that help the caregivers for enhancing the efficiency of their caring to the elderly. An Ambient Intelligence approach typically focuses on the services and intelligent interactions provided in the environment, in a transparent way. It releases underneath technologies and components to a background plane.

The different levels of our system from a SOA perspective can be seen in Fig. 2. Following a top-down description, the components of our system are the following:

- A communication interface based on the HTTP protocol. Human agents (carers and administrators) can access the server services through the HTTP interface provided by a web service of the system. Security measures for authentication and authenticity are implemented.

- Beyond the communication interface (HTTP), our system has a front-end interface that allows caregivers the access to different administration services:

    - HMI: Human-Machine Interface that can only be accessed by authorized users. It displays monitoring information, launches alarms and notifications, and allows to perform system configuration and control actions in the residence.
    - NMS: Network Management System that enables management operations on the network of the system.
    - API: Application Program Interface for the configuration, monitoring and administration of a single residence (Local Management) or multiple residences (Global Management), and other services.

- The final services of SAFE-ECH are in a lower level of the SOA model. The elderly residents, as the end-users of the system, benefit directly and indirectly from these AAL services, designed to enhance the comfort and quality of life of the residents. These services allow carers to improve their awareness to situations in the nursing home that require their attention, as well as to leverage the quality and efficiency of the caring service that they provide to the residents. Typical important services are: Intruder Detection, Access Control, Tracking service, Alarm Service, and Diaper Service. More innovative services in the ambit of AAL in nursing houses are Geolocation services. In the scope of AAL and AHA these services are especially useful. It must be noted that the use of open OGC standards and geospatial metadata support allows the use of tracking-based services, and the improvement of other services through the use of additional geospatial information.

In addition to the Central System, SAFE-ECH requires the existence of two external modules: the Sensor Module and the Actuator Module. The Sensor Module is responsible for providing monitoring information to the Central System from the network of sensors, to be introduced through the SOS interface and stored in the SOS database. On the other hand, the Actuator Module is responsible of performing the actions and orders of the Central system on the actuators.

V. Privacy and Security

In medical environments, as well as AAL and AHA, privacy has critical importance, due to the use of sensitive data. As well security, privacy and trust are major issues in IoT that must be taken into account in any IoT system design: the heterogeneity of IoT elements, the low resources of many smart objects, and the massive amount of devices and data generated represent important difficulties to overcome for ensuring security.

Main risks for privacy, security and reliability are the external manipulation of data and management orders, external interception of information, acceptance of messages and data from false and fraudulent sources, access of non-authorized users, among others. To avoid these problems, we applied several security measures at the different levels of our system.

As an intermediary element in the system, the SOS provides some security measures to allow only authorized access. External interaction with the SOS requires the use of the broker, in which relies the responsibility of completely ensuring security. However, although the SOS is only accessed internally by inner elements of the central system, its security measures can reinforce the overall security of the entire system. SOS only accepts sensor data from authorized IPs and this action has password protection. Moreover, the web service for retrieving information can have IP restrictions and password protection.

Sensors and actuators are physically protected, and not directly accessible, to impede non-authorized manipulation. Their configuration intends to maximize security. AES encryption is used in all WiFi communications. Regular cases of battery failure, interferences, communication error are taken into account, as well as the appropriate actions to be taken. The access to the system through the Human-Machine Interface (HMI), available from a web interface, is protected through log-in authentication, and optionally, through federated authentication (by the use of Identity and Service Providers).

Moreover, network error is taken into account in communications.

VI. Scalability and Flexibility

Not only SAFE-ECH is scalable in the sense of allowing multiple residence management. Our system design has good scalability and adaptability in the integration of very different and heterogeneous collection of sensors and actuators. It is easy to include new elements or modify those collections. As well, the decision patterns of the intelligence of the system are configurable, and it is easy to add, retire or modify services. Thus, it can be easily configured to set very diverse (a wide range of) Ambient Intelligence environments in the context of AAL and AHA. It can adapt to the specific needs of each residence for the elderly. Moreover, this flexibility enables a possible adaptation to the domain of Smart Home for elderly, and it is not only constraint to nursing homes. The use of open standards enables good interoperability, and facilitates the flexibility and scalability of the system. In particular, the interface provided by the SOS enables an easy integration of sensors.

VII. Conclusions and Outlook

We have presented our system as an AAL solution for the support of AHA, that follows open OGC standards. In this sense, it benefits from an inner standard and reliable access to sensor monitoring information, a reliable alert system, and geospatial data support that enables location functionalities. These functionalities allow the creation of innovative and very useful services in the context of Assisted Living, and the enhancement of existing ones by taking advance of additional geospatial information.

SAFE-ECH is an open source system that incorporates services within the SWE framework. SAFE-ECH aims to maximize the comfort, safety and service effectiveness and efficiency for aged people in residences through Assisted Living. For this goal, it utilizes a set of sensors and actuators to gather relevant information, it applies intelligent data analysis to decide and perform the best course actions and provides the caregivers a Human-Machine Interface to facilitate the management and monitoring of residences. The SOS of the SWE specification is a key element in the system for integrating and retrieving the data generated by the collection of sensors that represent the information sources of the Ambient Intelligence environment that the system creates. Another element adopted from the SWE framework is the SAS that allows a reliable alert management, that notifies caregivers of alarms and some specific events with the aim to improve the reaction time and efficiency of caring actions in response to those situations.

Our system provides complete flexibility in several levels: integration and configuration of sensors, management and actuation rules, and services for the elderly. Therefore, it can be adapted to any residence, and it could also be extended to other environments such as Elderly's Homes.

The main functionalities of our system have been validated not only from a theoretical scope, but in practice as SAFE-ECH has been deployed in actual residences in Spain, covering a variety of services such as localization, access control, scape alarm, medical and emergency alarms, intruder detection, diaper control, and others. The localization and other tracking based services, as well as former services that are improved in some way by using geolocation information, are possible through the use of geospatial support.

In the short future, we will increment our system functionality, and integrate it into public emergency services to decrease the reaction time to any medical emergency. We will explore the use of a lightweight implementation of the SOS in our system, such as SOSLite, that will allow faster and lighter data transmission and processing. This variation of the system will be optimal for special environments and in terms of resource optimization, and we will analyse its benefits in that scope.

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