An AAL system based on IoT Technologies and Linked Open Data for elderly monitoring in Smart Cities

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***Abstract*—The average age growing of the urban population, with an increasing number of 65+ citizens, is calling for the cities to provide global services specifically geared to elderly people. In this context, collecting data from the elderly's environment and his/her habits and making them available in a structured way to third parties for analysis, is the first step towards the realization of innovative user-centric services. This paper presents a city-wide general IoT-based sensing infrastructure and a data management layer providing some REST and Linked Open Data Application Programming Interfaces (APIs) that collect and present data related to elderly people. In particular, this architecture is used by the H2020 City4Age project to help geriatricians in identifying the onset of Mild Cognitive Impairment (MCI) disease.**

Keywords—Ambient Assisted Living; BLE; Embedded System; Internet of Things; Linked Open Data; Sensors.

I. INTRODUCTION

As a result of the growth of urban population worldwide [1], cities are consolidating their position as one of the central structures in human organization. This concentration of resources and services around cities offers new opportunities to be exploited. Smart Cities [2][3] are emerging as a paradigm to take advantage of these opportunities to improve their citizens' lives. Smart Cities use the sensing architecture deployed in the city to provide new and disruptive city-wide services both to the citizens and the policy-makers. The large quantity of data available allows improving the decision making process, transforming the whole city in an intelligent environment at the service of its inhabitants. One of the target groups for these improved services is, so-called, the "young-old" category, whose age varies from 60 to 69 [4], who are starting to develop the ailments of old age. The early detection of frailty and Mild Cognitive Impairments (MCI) is an important step to treat these problems. In order to do so, the Ambient Assisted Living (AAL) [5][6][7] solutions must transition from the homes to the cities.

City4Age[1] is a H2020 research and innovation project with the aim of enabling age-friendly cities. The project aims to create an innovative framework on ICT tools and services that can be deployed by European cities in order to enhance the early detection of risk related to frailty and MCI, and provide personalized intervention that can help the elderly population to improve their daily life promoting positive behavior changes. As part of the tools created for the framework, we have developed an IoT sensor platform based on unobtrusive sensors enabling the large-scale collection of personal data in home and city environments and a city-wide context-data management system that serves as a central information repository for the project. In the past, we have worked on developing platforms to capture data and manage the context [8] in intelligent environments [9][10][11], but limiting ourselves to a single home or building. In the case of City4Age, the infrastructure presented in this paper is able to simultaneously manage and integrate the information produced by several cities, while being flexible enough to allow each city to decide the level of abstraction of the provided data.

The objectives of the City4Age data acquisition and managing infrastructure presented in this paper are twofold. The first one is focused on the unobtrusive acquisition of personal data, achieved using sensors that do not require direct interaction with the user [12]. The second one is to provide a data repository for all the information generated in the cities (i.e. activities of daily living, behavior patterns, detected MCI and frailty risks, proposed interventions, etc.), giving semantic meaning to the stored information, and to share it with third parties while preserving the user privacy. To achieve these goals, we have designed an architecture with two main elements: (i) an IoT infrastructure able to provide a range of ICT services that, in a completely unobtrusive manner, gathers a large amount of personal data from elderly, both at home and public spaces; (ii) a combination of a high performance REST application programming interface (API) that allows to manage large quantities of data easily and a Linked Open Data (LOD) API that maps the information in the database to OWL [13],

[1] http://www.city4ageproject.eu/

providing semantic meaning to the stored data and making it easier to share. Following the Linked Open Data [14] paradigm, we ensure that the provided data will be easily understandable and usable by third parties, being those either humans or machines.

This paper has the following structure: Section II reviews previous work related with smart cities. Section III introduces the architecture and characteristics of the City4Age infrastructure. Section IV presents the evaluation of the system. Finally, Section V draws some conclusions and outlines future work.

II. Related Work

The development of an improved city model that takes advantages of the data that it produced has been the focus of several research works [2]. The need for the modernization of what we understand as a city is clear. Shapiro [3] analyzed how the Smart Cities improve both the quality of life and the productivity of their inhabitants, providing a significant economic growth. Schaffers et al [16] studied how Smart Cities act as an open and user-driven innovation environment in the development and validation of Future Internet-enabled services. Chourabi et al [15] defined what compose a Smart City, identifying eight factors that influence them: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment.

Several authors have focused their work in the creation of ICT frameworks for Smart Cities. Hernandez-Muñoz et al [17] propose a platform model that fulfills basic principles of open, federated and trusted platforms (FOTs) combining the Internet of Things (IoT) and Internet of Services (IoS) paradigms. Zanella et al [18] also analyze the enabling technologies behind the urban IoT systems, discussing the technical solutions and best-practice guidelines adopted in the Padova Smart City project. The combination of IoT and Smart Cities have been used by several other authors, like Sanchez et al [19] in the Santander use case, Perera et al [20] and Vlacheas et al [21]. Other two paradigms that have had significant influence in the development of Smart Cities are the usage of Big Data and Linked Open Data (LOD). Batty et al [22] recognize the shared knowledge within the city as one of the pillars for the Smart Cities. Domingo et al [23] propose the usage of open, public sensor data to improve the decision making process. Janssen et al [24] also analyze the usage of open data for the energy and mobility scenarios.

In this paper, we present a system that combines strengths of both the IoT and LOD approaches, providing a flexible and scalable infrastructure able to deal with the data of multiple cities at the same time.

III. System Architecture

The City4Age infrastructure is divided in two main blocks (see Fig. 1.):

- The *IoT infrastructure*, which is installed in each city, unobtrusively gathers and processes raw data coming from heterogeneous sensors. In most cases, these data are low-level signals that need interpretation and/or aggregation before becoming meaningful from a geriatric point of view.
- The *central repository* (composed of the REST and LOD APIs), which integrates the data received from the IoT infrastructure and provides a semantic meaning to that data following the Linked Open Data paradigm. This process also enriches the gathered data applying spatial and temporal knowledge eliciting rules, which improve the semantic knowledge easing consequent inference and querying processes.

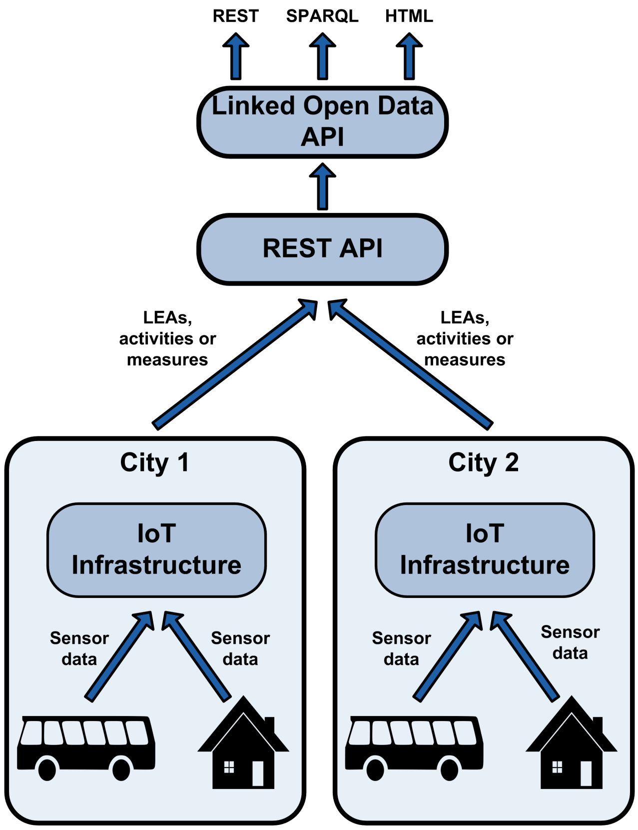

Fig. 1. City4Age system architecture

A. *City4Age IoT infrastructure*

The City4Age IoT infrastructure is responsible of (i) gathering raw data from sensors spread in physical environments, independently of both their specific technologies and communication protocols, and (ii) processing them to calculate aggregated data for the upper layers. The IoT infrastructure consists of several logical blocks, as shown in Fig. 2.

The physical environment includes both home environment and city spaces and data that it generates can be grouped into the following categories:

- User motility: data related to user body activities, such as motion, rest, sleep, walking, etc.

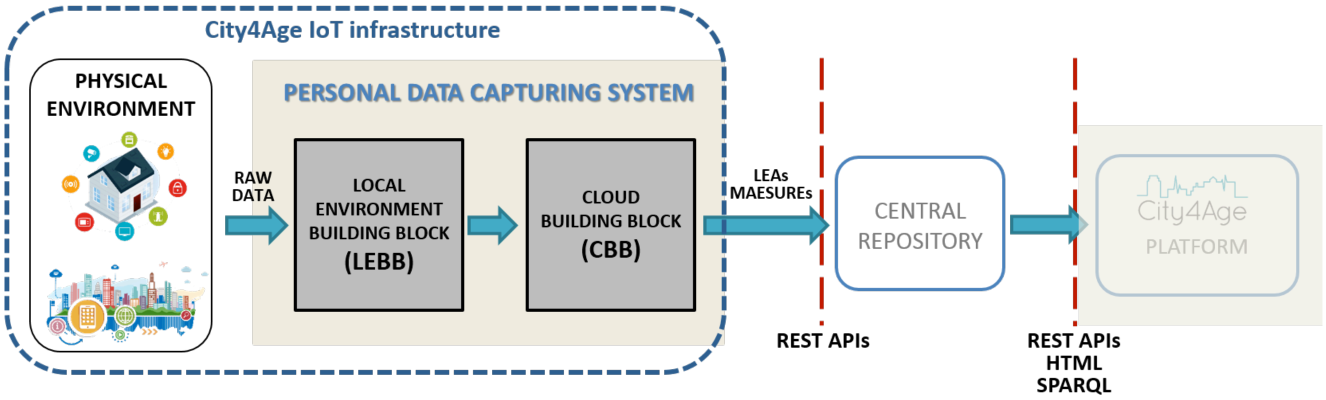

Fig. 2. City4Age IoT infrastructure

- Indoor/Outdoor localization: data involved in the process of determining the position of the user inside a private or public indoor place, such as user's homes or shopping malls, pharmacies, churches, etc., or data related to the position of the user in outside places, like streets, parks, etc.
- Ambient parameters: data concerning the quality of living condition in indoor and outdoor environments, like temperature, humidity, luminosity, weather conditions, etc.
- User/Environment interaction: data related to user interaction with the surrounding environments, especially with home appliances (TVs, HVACs, etc.) and public services (products bought in a supermarket, services utilized with public transportation, etc.).

The main component of the IoT infrastructure is the *Personal Data Capturing System* that consists of two blocks: the *Local Environment Building Block* (LEBB) and the *Cloud Building Block* (CBB). The LEBB, usually represented by the user's smartphone or by a home gateway, abstracts the heterogeneity of the physical technologies, providing a common vision of data to the core logic. To do so, LEBB is equipped with appropriate software modules, which are able to communicate with the sensing technologies according to the respective standards and protocols. This feature allows to easily extend LEBB's functionality to new technologies by developing the corresponding modules. The data collected by each module are then handled by the LEBB's core logic that translates them into *Low-level Elementary Actions* (LEAs) (see Section III.B) and sends them, through a well-defined REST APIs, to the CBB. It is in charge to do some processing activities in order to include other available information and fill in the Common Data Format (CDF) data object. In some cases, in fact, the data collected by LEBB are not sufficient to format LEA's CDF (e.g., if some information on user's personal profile is needed), so the LEA formatting process is completed at CBB, which has access to a wider range of information. Furthermore, the CBB performs other computations in order to calculate MEASUREs based on the given LEAs. The concepts of LEA and MEASURE are better explained in the following sub-section. Finally, the CBB is in charge of sending both LEAs and MEASUREs to the City4Age platform, by exploiting the uniform interface composed of the related LEA and MEASURE CDFs (Table I and Table II) and the REST APIs provided by the shared central repository.

TABLE I. LEA'S COMMON DATA FORMAT (CDF)

Property	Description
action	Name of the action
user	ID of the user involved in the action.
pilot	Identifier of the Pilot that uploaded the action
location	Location where the action is executed.
position	Geographical position at which the action took place
timestamp	Date and time at which the action was executed.
payload	Object containing additional sub-properties, as needed to further describe the action.
rating	Value defining the uncertainty of the inferred action (1.0: certain, 0.0: unreliable)
extra	Object containing additional, Pilot specific information that Pilots may want to add.

TABLE II. MEASURE'S COMMON DATA FORMAT (CDF)

Property	Description
user	ID of the user to which the measures relate.
pilot	Identifier of the Pilot that uploaded the Measure
interval_start	Timestamp of the start of the time interval to which the measure relates.
interval_end	Timestamp of the end of the time interval to which the measure relates. *Note: the following property* duration *can be used in alternative to this one*
interval_duration	Duration of the time interval to which the measure relates. *Note: the previous property* interval_end *can be used in alternative to this one.*
payload	Set of measures values.
extra	Object containing additional, Pilot specific information that Pilots may want to add.

B. City4Age central repository

The second main element of the City4Age infrastructure is the central repository[2], which provides access to the semantized information in the system. The central repository has three objectives: (i) to allow the cities to integrate with the City4Age system at different levels of data abstraction, (ii) to provide a scalable and highly-responsive infrastructure, and (iii) to provide semantic meaning to the stored information to ease its usage by third parties. To achieve these objectives, the central repository is composed of two main elements: the REST API, which receives the data gathered by the IoT infrastructure, and the Linked Open Data API, which provides semantic meaning to the captured data and shares it following the LOD paradigm.

The REST API provides a high-performance and flexible data endpoint to the cities integrated in the City4Age system. The central repository is able to manage the data from several cities, integrating the information of thousands of users. It defines three different levels of data integration:

- *Low-level Elementary Actions* (LEA) are simple, short actions detected by a sensor (e.g. opening a cabinet, getting into a shop, using the bus or switching on an appliance). The same action can be detected by different sensor types (e.g. using an appliance can be detected with a movement sensor or a smart-plug), which simplifies the data model. This is why the LEA-s are the most basic information level on City4Age.
- *Activities* are complex events composed of several LEAs which take place in a period of time (e.g. preparing a meal, shopping or visiting the doctor's office)
- *Measures* are aggregated information meaningful for the geriatricians, which is calculated using actions and activities performed by the users (e.g. distance walked weekly or number of activities of the daily living performed each day).

Depending on their needs and the pre-existing infrastructure, the cities can choose what type of information they will share with the system. For example, in the case of the City4Age project some cities have a mature software and hardware infrastructure, with their own activity recognition mechanism, and opt to send activities or measures to the central repository, while other systems with no infrastructure use the complete system and send LEAs.

Once the data has been added to the REST API, the LOD API maps it to a network of domain ontologies, providing semantic meaning to the stored data. This process is done in several steps. First, we use D2RQ[3] to transform the data in the relational database to an OWL/RDF ontology [25]. This is done using a mapping file that defines how the individual fields in the database are converted to ontology properties. Once the ontology has been created, we use the Jena Rule Engine[4] to make explicit the implicit knowledge, in a process similar to the one that we defined in [26]. This allows us to enrich the existing data with temporal and spatial relations that facilitate any subsequent semantic inference and querying. The final enriched ontology is served using Fuseki[5]. This allows us to offer three different endpoints to access the data: REST, SPARQL and HMTL interfaces. The citizen data offered to third parties is properly anonymized following the rules defined in the City4Age project to comply with both local and European legislation and the LOD API also implements an authorization that allows each user to control how their data is shared in the system.

IV. Proof of Concepts

In this section, some use cases of the City4Age Project are presented, in order to provide an example of the kind of data produced by the City4Age IoT infrastructure and managed by the central repository that can be used by upper architectural layers to perform MCI risk analysis.

The first use case is related to the Indoor/Outdoor localization sub-system. Supposing that each room of the elderly's house is equipped with a BLE Beacon emitting a unique ID associated with that room, when the user enters the room with the BLE radio of his/her smartphone turned on, then the smartphone can read the room ID and send this information to the local CBB. Finally, the CBB can fill in all the available fields of the CDF containing the LEA and send it to the City4Age central repository. The LEA produced is shown in Fig. 3. The same pattern can be applied when the user leaves the current room to move to an adjacent one, producing the LEA shown in Fig. 4. By analyzing the timestamp values of each couple of ROOM_ENTER and ROOM_EXIT LEAs (containing the same value in the instanceID field), it is possible to compute several measures, like the number of room changes, the permanence time in each room and so on. An example of a CDF containing ROOM_CHANGES and BEDROOM_TIME MEASUREs is shown in Fig. 5.

Once these LEAs and MEASUREs get to the City4Age central repository, they are elaborated as explained in Section III.B and they can be accessed as shown in Fig. 6.

Another interesting use case relates to the User/Environment Interaction sub-system, especially to detect when the user watches TV on an ongoing basis. To trigger this event, in fact, it is necessary that (i) the TV is ON – this can be


```
{
    "action": "eu:c4a:ROOM_ENTER",
    "user": " eu:c4a:user:123456",
    "pilot": "LCC",
    "location": " eu:c4a:Room:Bedroom",
    "position": "",
    "timestamp": "2017-03-20 22:08:41.013329",
    "payload": {
      "instanceID": 124
    },
    "extra": {
      "dataSourceType": [ "sensors"],
      "dataSourceObtrusive": false
    }
}
```


Fig. 3 ROOM_ENTER LEA example

2 https://github.com/aitoralmeida/c4a_data_repository

3 http://d2rq.org/

4 https://jena.apache.org/documentation/inference/

```
{
    "action": "eu:c4a:ROOM_EXIT",
    "user": " eu:c4a:user:123456",
    "pilot": "LCC",
    "location": " eu:c4a:Room:Bedroom",
    "position": "",
    "timestamp": "2017-03-21 06:10:41.013329",
    "payload": {
      "instanceID": 124
    },
    "extra": {
      "dataSourceType": [ "sensors"],
      "dataSourceObtrusive": false
    }
 }
```


Fig. 4. ROOM_EXIT LEA example


```
{
    "user": " eu:c4a:user: 123456",
    "pilot": "LCC",
    "interval_start": "2017-03-20 00:00",
    "duration": "DAY",
    "payload": {
      "ROOM_CHANGES": 24,
      "BEDROOM_TIME": 28920
    },
    "extra": {
      "dataSourceType": [ "sensors" ],
      "dataSourceObtrusive": false
    }
  }
```


Fig. 5. ROOM_CHANGES and BEDROOM_TIME measures conveyed in a MEASURE CDF packet

detected through a BLE-enabled smart plug bond with the user's smartphone, (ii) the user is currently in the room where the TV is located – detectable through the Indoor/Outdoor Positioning System, and (iii) the user is sitting – this body state can be detected through a BLE-enabled wristband monitoring the user's motility. Once these three conditions are all satisfied at the same time, the CBB can send the

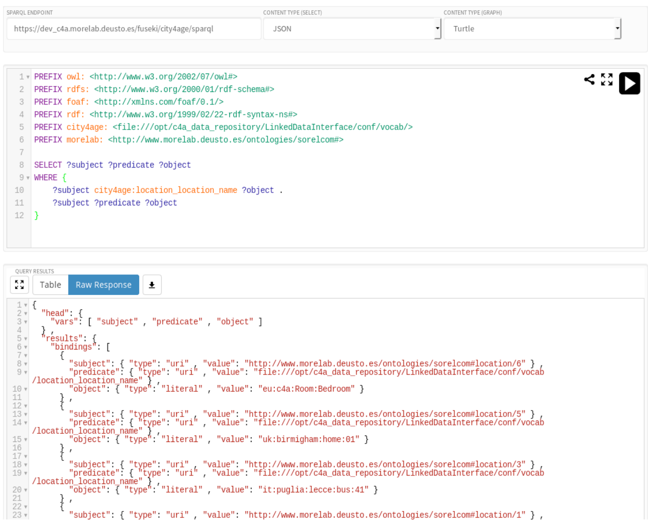

Fig. 6. Location information in the Linked Open Data API

WATCHINGTV_START LEA (and the related MEASUREs) to the City4Age central repository.

Similar LEAs are used in the outdoors scenarios with the POI_ENTER and POI_EXIT LEAs. This LEAs are used to control when a user enter and leaves the identified points of interest in the city, like shopping areas, family neighborhood, pharmacies, etc… As in the indoor scenario, the outdoor positioning is stored in the central repository using a semantic location instead of a coordinate system (i.e. GPS). The reason for this is that the geriatricians are more interested on how the users perform the instrumental activities and the activities of daily living (i.e. the user goes shopping frequently) instead of specific locations (i.e. the user goes to pharmacy X).

For the sake of space, it is not possible to discuss here the whole set of LEAs and MEASUREs defined in the City4Age Project, however the provided examples are sufficient to show the rationale behind these concepts and their management.

V. CONCLUSIONS

In this paper, we present the AAL infrastructure for Smart Cities developed in the City4Age H2020 project. This infrastructure combines the Internet of Things and Linked Open Data paradigms to provide a scalable and responsive system able to provide service to multiple cities concurrently. The presented infrastructure allows the cities to integrate their data on different abstraction levels, providing a semantic endpoint that offers an expressive data format for inference and querying purposes.

Currently the system is being deployed in five European cities (Lecce, Madrid, Montpellier, Athens and Birmingham) and in Singapore. As future work, we will develop a mechanism to automatically link the entities in the final ontology with other related datasets, in order to further enrich the information provided by the Linked Open Data API.

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