







- *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.).

All collected data are sent to the City4Age platform, where elderly people's behaviors and, above all, their variations, are detected. In most cases, all data are conveyed through the smartphone that formats them according to a shared data format before send them to the shared platform, acting as a gateway. In other cases, this role is played by a smart box based on a single-board-computer.

#### IV. SYSTEM ARCHITECTURE

The proposed system architecture is composed of the two main components: (i) logical component, and (ii) hardware component.

##### A. Overall logical architecture

Fig. 1 shows the architecture of the developed system by highlighting the logical levels and its positioning related to the City4Age platform.

The two main components of the architecture are the Local Environment Building Block (LEBB) and the Cloud Building Block (CBB). The LEBB is responsible of (i) gathering raw data from the Sensor Network (SN) independently of both specific sensor technology and communication protocols, and (ii) of eventually processing them to calculate aggregated data for the upper layers. More in detail, the LEBB, represented by the user's smartphone, is able to abstract 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 pre-formats them as *Low-Level Elementary Actions (LEAs)*, including all the available information. A LEA is the finest grain atomic information used to detect behavior of elderly people. It relates to start/stop events of user basic actions and contains additional

information about time and position of the action that is being taken. All this information is enveloped in the defined Common Data Format and sent to the upper layer of the City4Age Platform.

The pre-formatted LEAs are then sent through REST APIs to the CBB, which is in charge to do some processing activities on them in order to include other available information. In some cases, in fact, the data collected by LEBB are not sufficient to calculate LEAs (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. MEASUREs are daily indicators that make sense from a geriatric point of view in order to assess changes of behavior that are relevant for assessing MCI or frailty. Examples of MEASUREs could be: the number of calls received and done (daily), the average speed of walking (daily), the number of walks (daily), the average time spent in a given room of the home (daily), the number of visited shops (daily), etc. Based on these daily MEASUREs, further indicators can be computed in order to define a risk profile of each elderly person on a monthly base. Finally, the CBB is in charge of sending both LEAs and MEASUREs to the City4Age platform, by exploiting the uniform interface composed of the Common Data Format, defined ad hoc in the same project, and the REST APIs provided by the shared repository provided by the City4Age platform.

The SN consists of several nodes equipped with different sensors, which deliver environmental parameters, positional information, etc. More in general, all devices with sensing and connectivity capabilities, able to provide and exchange information, could be considered nodes of the network.

The designed architecture aims to provide support to the following processes:

*Indoor & outdoor localization.* The use of a GPS receiver and a GPRS module, installed on a wearable device, allows the outdoor localization of the user. More in detail, the GPS module sends the position of the user, if s/he is in outdoor environment, to the GPRS module, which in turn sends it to the LEBB. If the user is located within an indoor environment, her/his position can be derived by exploiting BLE technology. We suppose that, within each indoor environment of interest (e.g., the user's house), one or more low-cost devices equipped with BLE interface are installed, named piBeacons. The piBeacon closest to the user transmits its geographical coordinates via BLE connection to the user's wearable device, which in turn sends it to the LEBB via GPRS module, similarly to the outdoor localization. The use of the BLE technology reduces the power consumption guaranteeing a longer battery life of the wearable device. In order to ensure further energy savings, the BLE module will be disabled in the outdoor localization scenario while in the indoor localization the GPS module will be switched-off.

*Ambient parameters collection.* The heterogeneous devices belonging to the low level transmit different types of information to monitor data concerning the quality of living condition in indoor and outdoor environments, like

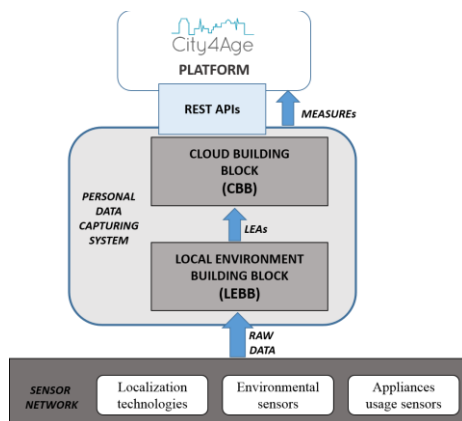


Fig. 1. Overall logical architecture.

temperature, humidity, ambient noise, rain, wind, etc. The main problem is related to the heterogeneity of the technologies supported by the network nodes. To overcome this limitation, the low-cost collector, named Smart Gateway, acts as a transparent concentrator.

#### *User-Environment interaction data collection.*

Data related to elderly interaction with home appliances (TVs, appliances, etc.), cooking habits, and care of personal hygiene are important geriatric indicators useful to detect deviations from normal behavior and then highlight risk factors related to mental fragility.

The main peculiarity of the sensing network is its unobtrusiveness. Ambient parameters are gathered through sensors included in wearable devices. Indoor localization is achieved mainly through an unobtrusive wireless system based on the BLE technology, while outdoor positioning system is based on the GPS technology. Finally, indoor user-environment interaction is achieved by exploiting ad-hoc sensors, such as humidity sensor or gas sensor to detect cooking habits or smart devices, such as smart plugs in order to detect the use of TVs or appliances. All these devices are characterized by low cost of purchasing and management. To obtain reliable information about the user's interaction with the environment, data coming from ad-hoc sensors are combined with other information, e.g. localization data. For example, in order to deduce that the elderly is watching TV, at least two information are necessary, i.e. the power consumption measured by the smart plug that is connected to the TV plug and the presence of the user in the room. Similarly, to detect cooking habits, information coming from several sensors in the kitchen are combined with user's localization data.

#### *B. Hardware components*

Fig. 2 shows the Smart Gateway (Fig. 2.a) and the prototypes used in the validation scenario in order to emulate the wearable devices (Fig. 2.b and 2.c). The main actor of the sensing middleware scenario is the Smart Gateway, a data collector realized using a low cost Single Board Computer such as a

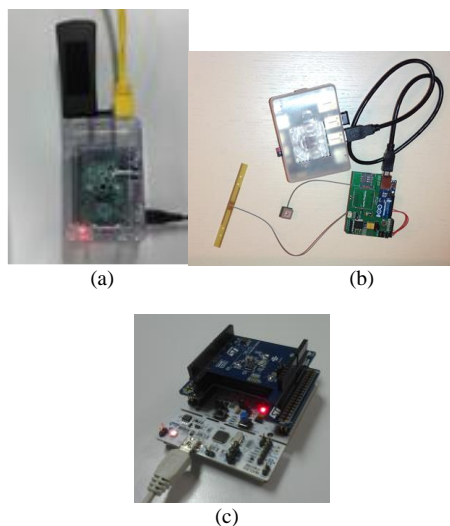


Fig. 2. Prototypes used in the validation scenario: a) Smart Gateway; b) and c) wearable devices.

Raspberry Pi [30]. The Smart Gateway performs various tasks, such as (i) data collection, (ii) data forwarding, and (iii) instructions forwarding from/to the SN. It has several input and output interfaces. In particular, the input interfaces are:

- Classic BT module: it is used to communicate with all classic BT devices;
- BLE module: it is used to communicate with all the BLE devices;
- The output interfaces used to forward the collected data are:
- Wi-Fi module: it allows the Internet access;
- Ethernet interface: installed on the Raspberry Pi board, it is used to realize a network connection via Ethernet cable.

In order to emulate the smart wristband worn by the elderly patient, two prototypal devices were realized. Fig. 2.b shows the first prototype used for the elderly indoor/outdoor localization. It was obtained by combining both Odroid [31] and Arduino [32] devices equipped with BLE, GPS and GPRS modules. This wearable device exploits the GPS technology for outdoor localization and BLE technology for indoor localization. The second prototype (Fig. 2.c) used for the detection of ambient parameters, was realized by using Nucleo Board [33] with MEMS and BLE shields [34]. In particular, MEMS shield is equipped with several sensors such as accelerometer, gyroscope, inertial modules, and environmental sensors.

The present work aims to define and test a prototype wearable device. It also may be replaced with a commercial product (e.g., the Sensor Tag [35]) that communicates values gathered from its sensors to the smartphone. By using these kind of commercial products it is possible to obtain similar results and preserve low-power and low-cost features.

## V. SYSTEM VALIDATION

### *A. Proof of concept*

In order to validate the proposed architecture from a functional point of view, a proof-of-concept approach has been used. In particular, the proposed scenario refers to the monitoring of an elderly in her/his home and in her/his outdoor daily activities. The elderly wears a smart device equipped with several MEMS such as accelerometers, gyroscopes, inertial modules, and environmental sensors. Another wearable device, exploiting the GPS and BLE technologies, provides indoor and outdoor localization functionalities. Furthermore, both wearable devices support data transmission capabilities. Fig. 3 shows a hypothetical indoor test scenario. A piBeacon, identified by a unique MAC address, is located in each room.



Fig. 3. Indoor test scenario.

The wearable devices operate as nodes of the SN, delivering several data to the Smart Gateway, placed in the indoor environment. Each piBeacon communicates its coordinates via BLE. The second wearable device constantly checks the presence of piBeacons and selects the nearest by comparing the Received Signal Strength Indicator (RSSI) of detected piBeacons.

An ad hoc implemented algorithm, running on the device, is responsible for maximizing the probability of selecting the closer piBeacon. By exploiting the RSSI, the wearable device computes a proximity index  $d$ , using the following formula:

$$RSSI = -(10n \log_{10} d + A) \quad (1)$$

where  $A$  is the received signal strength at 1 m,  $n$  is a signal propagation constant depending mainly on the environment, and  $d$  is the distance from the sender. The piBeacon with the lowest value of  $d$  represents the user's current indoor location. The indoor positional information is sent to the gateway (i.e., the elderly smartphone) through GPRS module.

When the patient leaves the indoor environment, by assuming that s/he wears the wristband, the GPS replaces the BLE module. The wearable device transmits the outdoor position retrieved by the GPS to the elderly smartphone via GPRS module, as in the case of the indoor localization.

Once received the elderly positions, the smartphone is responsible for formatting and sending these data to the CBB in order to make them available to the City4Age platform. Fig. 4 shows an example of the locomotor activity, with a detail of the room (Fig. 4.a) in which the elderly is detected and the position of the elderly in outdoor environment (Fig. 4.b), displayed by accessing to a localization Web server. In Fig. 5, a flow chart summarizes the main steps involved in the indoor/outdoor localization process.

Finally, the Smart Gateway may collect data from several environmental sensors measuring temperature, humidity,

pressure, etc. Environmental data and positional information could be used in order to generate commands and instructions

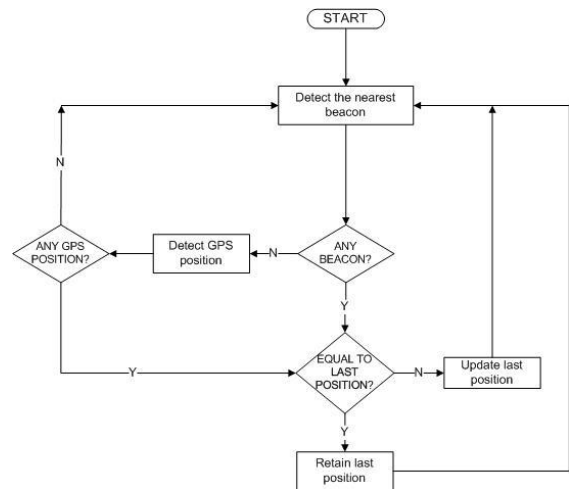


Fig. 5. Flow chart related to the indoor/outdoor positioning process.

addressed through the Smart Gateway to home devices in order to adapt the indoor environment to the needs of the elderly.

### B. Validation of the indoor positioning feature

A further validation phase has been carried out in order to prove the effectiveness of the indoor positioning sub-systems.

First, a one-to-one mapping between BLE beacons and rooms has been considered, so that the room represents the granularity of the positioning algorithm. That said the correct user's localization has been tested in two different cases (Fig. 6). In the first case, referred as *best case*, the BLE devices of two consecutive rooms have been placed on the partition wall and not in line of sight of each other. In the second case, referred as *worst case*, the devices have been placed in line of sight at 5 meters from the separating door. The results shown in the Fig. 7 were obtained by positioning the wearable device (or smartphone) at three different distances from the door. The measurements allowed us to identify the Successful Localization Probability, which is the probability of correct localization of the user inside the room. The Fig. 7 shows how the results obtained are optimal in the best case and next to the ideal ones in the worst case.

## VI. DISCUSSION

In order to demonstrate the effectiveness of the proposed architecture, it was compared with similar architectures proposed in the literature. In order to carry out this comparison, some parameters were selected, i.e., the recognized activities, the typical environment in which the system works, the complexity and cost of the system. In Table I, the results of this comparison are reported.



Fig. 4. Screenshots of localization system: a) indoor scenario b) outdoor scenario.

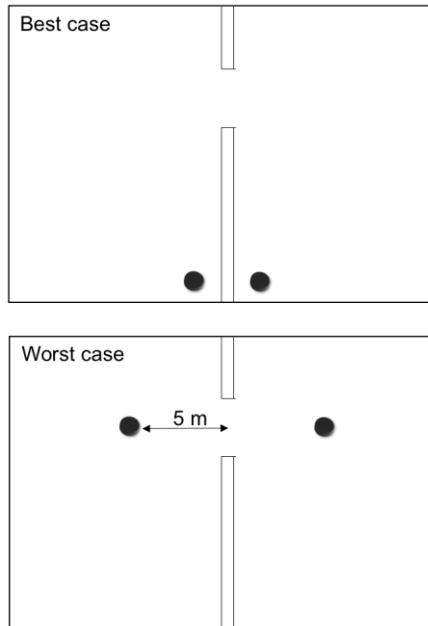


Fig. 6. Experimenting scenario of the positioning sub-system.

The main advantage of the proposed architecture is its ability to automatically recognizing behavioral changes in elderly people in an unobtrusive, low-cost and low-power modality. Furthermore, it guarantees hardware and technology

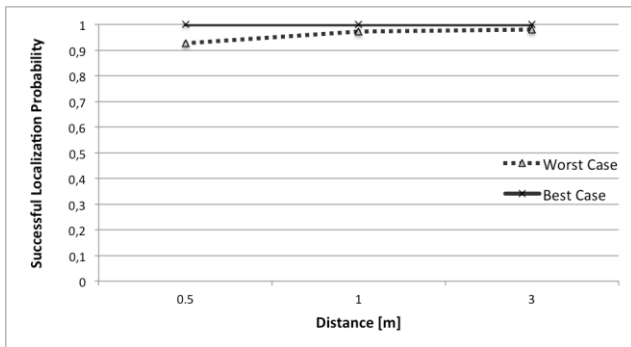


Fig. 7. Successful Localization Probability with the worst and best disposition of the BLE devices.

abstraction, since all low-level details are addressed by the adapter components included in the LEBB module, which provides as output a data object whose format is independent from any particular technology. At the same time, the proposed solution ensures high modularity and scalability, since any new technology can be added to the system simply by implementing the related adapter in LEBB. By doing so, any kind of raw data coming from heterogeneous devices can be properly handled by the system.

## VII. CONCLUSION

This work proposes an architecture aimed to monitor elderly people in their daily life. It aims to support social/health services in dealing with mild cognitive impairments and frailty

TABLE I.  
COMPARISON AMONG ELDERLY MONITORING ARCHITECTURES

	<i>Recognized activities</i>	<i>Typical environment</i>	<i>Complexity</i>	<i>Cost</i>
[23]	User-Environment interaction	Indoor	Medium/Low	Medium/High
[24]	Usage of medical devices	Indoor	Medium/High	Low
[25]	Locomotor activities	Indoor	Low	Low
[26]	Locomotor activities	Indoor/Outdoor	Medium/Low	Low
[27]	Fall	Indoor/Outdoor	Medium	Low
[28]	Fall	Indoor/Outdoor	Medium	Low
<i>Proposed architecture</i>	Indoor/Outdoor localization, Ambient parameters collection, User-Environment interaction	Indoor/Outdoor	Low	Low

in the elderly population. The proposed system is able to guarantee three important features: (i) continuous localization in both outdoor and indoor environment, (ii) continuous monitoring of ambient parameters, and (iii) continuous monitoring of appliances usage. The system is able to transparently collect sensor data coming from heterogeneous devices and forward them to the central repository within the City4Age platform through REST APIs. From here, by applying Big Data analytics, potential risky behaviors can be identified and highlighted.

As ongoing work, we are working to realize a low cost system able to both capture the elderly cooking habits and understand if s/he take care of her/his personal hygiene. This system exploits smart plugs and other sensors connected to a single-board computer (e.g., a Raspeberry Pi).

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