An IoT-aware AAL System for Elderly People

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***Abstract*— The rapid aging of the population occurred in recent years has encouraged the development of several solutions aimed to guarantee a healthy and safe lifestyle to the elderly. In this paper, an Ambient Assisted Living (AAL) system has been designed in order to create better living conditions for older people. In this way, people can live independently longer in their own house with an improved quality of life. The proposed system includes several features. On the one hand, it is able to continuously monitor the health status of the elderly through data coming from heterogeneous sources (i.e., environmental sensors and medical devices). On the other hand, it is able to guarantee outdoor and indoor localization aimed to know the real-time position of the elderly both inside and outside their home. A remote reasoning system processes all collected data with the aim of generating appropriate events and alerts. The architecture was validated from a functional point of view through a proof-of-concept.**

***Index Terms*— Ambient Assisted Living; Bluetooth Low Energy; Enterprise Service Bus; Internet of Things; NFC.**

I. INTRODUCTION

In recent years, there has been a rapid introduction of new assisted living technologies due to a rapidly aging society. In fact, it is estimated that 50% of the population in Europe will be over 60 years old in 2040, while in the USA it is estimated that one in every six citizens will be over 65 years old in 2020 [1]. In addition, people over 85 years usually require continuous monitoring. Therefore, taking care of elderly people has become a challenging and very important issue. Ambient Assisted Living (AAL) approach is the way to guarantee better life conditions for the aged and for people with chronic diseases and in sickness recovery status by the development of innovative technologies and services. AAL technologies can also provide more safety for the elderly, offering emergency response mechanisms [2], fall detection solutions [3], and video surveillance systems [4]. Moreover, other AAL technologies were designed in order to provide support in the daily life, by monitoring the activities of daily living (ADL) [5], by generating reminders [6], as well as by allowing older adults to connect with their family and the medical staff.

Moreover, recent advancements in mobile and wearable sensors helped the vision of AAL to become a reality. All recent mobile devices are equipped with different sensors such as accelerometer, gyroscope, Global Positioning System (GPS) and so on, which can be used for detecting user mobility. Furthermore, recent advances in electronic and microelectromechanical sensors (MEMS) technology promise a new era of sensor technology for health [7]. Researchers have already developed noninvasive sensors in form of patches, small holter-type devices, wearable devices, and smart garments to monitor health signals. For example, blood glucose, blood pressure, and cardiac activity can be measured through wearable sensors using techniques such as infrared or optical sensing. Some other measurements, such as Electroencephalography (EEG), still require invasive sensors such as electrodes.

Indoor and outdoor localization is another key component in AAL systems that allows to track, to monitor, and to provide fine-grained location-based services of the elderly. GPS is the most widespread and reliable technology to deal with outdoor localization issues. Nevertheless, in indoor scenarios, GPS has a limited usage due to its limited accuracy and the impact of obstacles on received signals. Therefore, a number of alternative indoor positioning systems have been proposed in the literature [8]. Among these technologies, vision techniques guarantee high accuracy levels. In the context of homecare, in [9] a video-based monitoring system for the elderly care is proposed. The main objectives of this system are to preserve the elderly independence and increase the efficiency of the homecare practices. The main disadvantage of the video technology lies in the cost, which is still too high, especially for systems with very high precision. For this reason, with the spread of mobile devices, the interest in indoor location systems using smart phones equipped with video camera [10], [11] is increased. The infrared (IR) technology is also widely used for indoor localization, as shown in [12] and [13], though multipath effect drastically reduces the localization accuracy.

Radio Frequency Identification (RFID) is one of the most popular wireless technologies for tracing and tracking [14], [15], [16]. The main advantage of this technology is the capability to work in absence of Line of Sight (LoS) condition.

Bluetooth (BT) technology represents a valid alternative for indoor localization [17], [18]. It is able to guarantee a low cost since it is integrated in most of the daily used devices such as tablets and smart phones. Moreover, the spread of the emerging Bluetooth Low Energy (BLE) technology makes the BT also energy-efficient, which is a key requirement in many indoor applications. The recent rise of iBeacons by Apple has contributed to the rapid spread of this technology, used to provide information and location services [19] in a completely innovative way.

A large number of solutions have been proposed in the literature in order to create smart environments and applications to support elderly people. The main purpose is to provide a level of independence at home and improve elderly quality of life. In [20], a solution for tracking the daily life activities, by using mobile devices and Cloud computing services, is presented. This system can collect heterogeneous information from the sensors located in the house and share them in the Cloud. The system monitors the elderly persons, their activities (by using cameras and RFID tags), and can generate reminders for scheduled activities and alerts for critical situations to care givers and family members, so reducing the health expenditures. A solution for monitoring patients with specific diseases such as diabetes using mobile devices is discussed in [21]. This system provides continuous monitoring and real time services, collecting the information from healthcare and monitoring devices located in the home environment and connected to BT mobile devices. The sensor data are transmitted to a central database for medical server evaluation and monitoring via 3G and Wi-Fi networks. An ad hoc application, installed on a mobile phone, allows the remote control of all their patient's health status whilst the patient can receive any notifications from the health care professionals via the application running on her/his mobile phone. In [22], a monitoring and tracking system for people with medical problems is proposed. The solution includes a system for performing biomedical measurements, locomotor activity monitoring through accelerometers and Wi-Fi networks. An interactive approach involves the user, through a smart TV. The locomotor activity of the elderly people is deduced by the analysis of the Received Signal Strength Indication (RSSI) measurements, i.e. by determining through an algorithm the received signal power from different access points located in the house. Mobile accelerometers are used to analyze the movement of the user and detect steps. In this way, it is possible to obtain adequate precision at a low cost. Single board computers, such as Raspberry Pi, are used to collect data coming from the different sensors wirelessly connected to obtain real-time context-aware information such as gas, temperature, fire, etc. or to get information from biomedical sensors such as, oxygen meter, blood pressure, ECG, accelerometer, etc. Moreover, Raspberry Pi can be connected to the TV in order to transmit warnings or notifications coming from the health care professionals.

In this work, we propose an AAL system for elderly assistance applications. On the one hand, unlike the main localization systems presented in the literature, it is able to provide both outdoor and indoor localization by using a single wearable device. This prototypal device exploits the GPS technology for outdoor localization and BLE technology for indoor localization. It is able to recognize the type of environment (i.e., indoor or outdoor), automatically switching between the two technologies. The system is also able to collect all information coming from the heterogeneous sensors located in the indoor environment, such as position, environmental or biomedical information, and to forward it towards a remote service. The remote service is able to trigger events. These events can include sending both external feedbacks (e.g., push notifications to families or caregivers) and notifications to the same indoor environment that will change its status (e.g., firing an alarm or changing the status of the lights). The proposed system has been validated through a functional approach and, for this purpose, a proof of concept has been described by supporting an elderly people in his daily activities.

II. System Architecture

The present Section describes the two main components of the proposed AAL architecture: (i) logical component; (ii) hardware component.

A. Overall logical architecture

Fig. 1 shows the architecture of the proposed AAL system by highlighting the logical levels.

The Integration Middleware, represented in this scenario by the Enterprise Service Bus (ESB), interconnects the lower level, represented by the Sensing Middleware, with the higher levels (i.e., the persistence and the reasoning levels). The ESB is a software infrastructure that provides coordination, security, and routing features. Its main goal is to guarantee the interoperability among heterogeneous technologies. This component forwards the heterogeneous data, collected by the Sensing Middleware, to the remote server for data analysis. In particular, the Reasoner Server (RS) exposes the business logic operations through a Web Service. It processes the data coming from the sensor network (SN) via ESB, and recognizes appropriate events, eventually by returning instructions to the nodes of the SN through the ESB. Push notifications related to an occurred event can also be sent to mobile devices of all subscribed users and further commands can be sent in the opposite direction.

The SN consists of several nodes equipped with different sensors, which deliver environmental or biomedical parameters, positional information, alarm signals, etc. BT medical devices (i.e., wristbands, blood pressure meters, medical thermometers, health checks, etc.) and smart phones equipped with several sensors and readers (e.g., NFC) can be also considered nodes of the SN. In other words, all devices with sensing and connectivity capabilities, able to provide and exchange information, are nodes of the network. All information and data generated by each node are collected by a

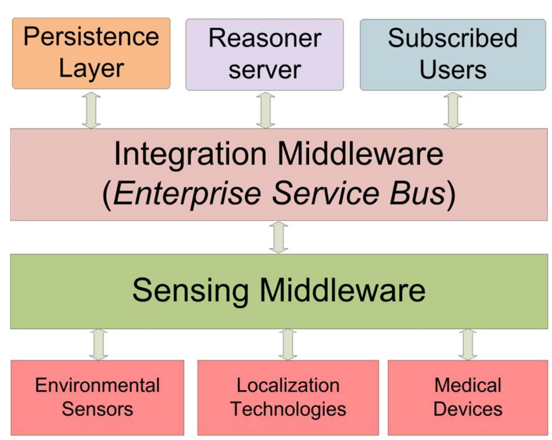


Fig. 1. Overall logical architecture.

collecting system and forwarded to the RS.

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 to the GPRS module, which in turn sends it to the ESB. 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 ESB 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.
- *Environmental & biological parameters processing*. The heterogeneous devices belonging to the low level transmit different types of information, collected and forwarded by the ESB to the RS to monitor environmental and/or biological parameters or to detect the occurrence of particular events. Captured data are processed in order to trigger events or to generate notifications addressed to family members, medical staff or caregivers. 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. These data are collected, packaged and submitted to the RS via ESB, typically through REST interfaces.

B. Hardware components

Fig. 2 shows the prototypes used in the validation scenario in order to emulate the wearable devices (Fig. 2.a and 2.b) and the Smart Gateway (Fig. 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 Raspberry Pi [23]. 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;
- Near Field Communication (NFC) module: it is used for reading NFC tags.

The output interfaces used to forward the collected data are:

- Wi-Fi module: it allows the Internet access;

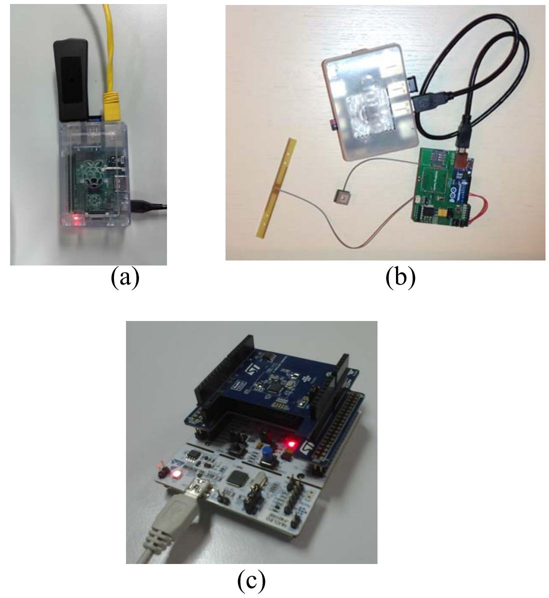


Fig. 2. Prototypes used in the validation scenario: a) Smart Gateway; b) and c) wearable devices.

- 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 [24] and Arduino [25] 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 critical events, such as the fall of the person, was realized by using Nucleo Board [26] with MEMS and BLE shields [27]. In particular, MEMS shield is equipped with several sensors such as accelerometer, gyroscope, inertial modules, and environmental sensors.

III. 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 patient suffering from Mild Cognitive Impairment (MCI) (e.g., Alzheimer) and subjected to a therapy plan. The elder 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 piBeacons identified by a unique MAC address is located in each room. 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

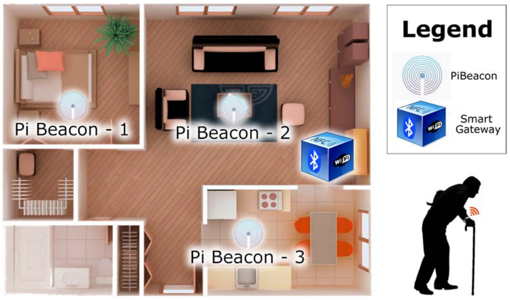
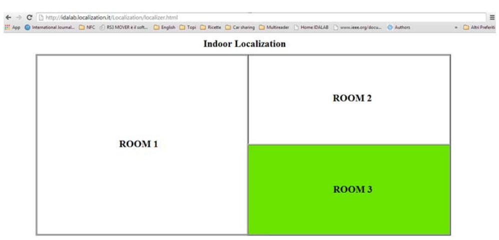


Fig. 3. Indoor test scenario.

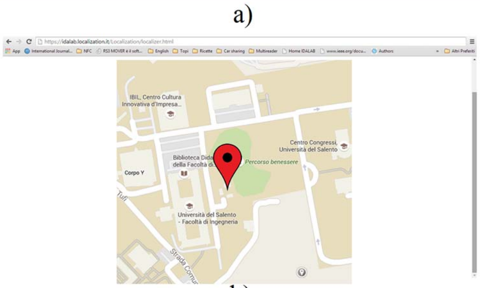
presence of piBeacons and selects the nearest by comparing the Received Signal Strength Indicator (RSSI) of detected piBeacons. An ad hoc implemented algorithm, running on the device, is responsible for maximizing the probability of selecting the closer piBeacon. The collected information (geographical, environmental, etc.) is forwarded to the RS via ESB, which analyzes the data and performs the indoor localization. The indoor positioning data may encourage behavioral analysis and so, when an anomaly occurs, alarm mechanisms are activated.

When the patient leaves the indoor environment, by assuming that s/he wears the wristband, the GPS replaces the BLE module, reducing the power consumption and then guaranteeing a longer battery life of the wearable device. It transmits its geographical coordinates to the RS via GPRS module. 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 patient in outdoor environment (Fig. 4.b), analyzed by the RS and displayed by accessing to the tracking Web server.

Furthermore, the Smart Gateway located in the patient's house is equipped with a NFC reader in order to support the monitoring of a therapy plan. In fact, according to the scheduling rules stored in the remote RS, at the programmed time for taking a medicine, the patient's smartphone (or,



a)



b)

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

alternatively, any IoT enabling device), receives a notification from the Smart Gateway, alerting the patient with an acoustic signal and displaying the drug's name. The system checks the correctness of the taken drug by exploiting the NFC reader embedded in the Smart Gateway. When the tagged drug box is placed near the NFC reader, the unique code stored in the NFC tag is sent to the RS through an API REST request. As shown in Fig. 5, when a particular situation occurs (e.g., the patient has not taken a drug), the system is able to notify family members or doctors through a dedicated app installed on their smartphone. Fig. 6 shows the interaction among the system components in the process of therapy plan monitoring.

Moreover, the ESB may recognize behavioral event such as the fall of the patient. By analyzing the positional information coming from gyroscope and accelerometer, it is possible to identify the fall event. In case of patient fall hypothesis, a push notification is addressed to family members, doctors, and health-service is informed by sending an alarm. The positional data can be also integrated with other data coming from environmental sensors and other home automation devices. For example, it is possible to collect biomedical parameters coming from BLE devices such as glucometers, pulse oximeter, blood pressures, etc. The Smart Gateway constantly checks for the presence of BLE and BT devices and retrieves information about the services of interest. They are forwarded to the RS in order to act promptly if a critical situation occurs.

Finally, the Smart Gateway may collect data from several environmental sensors measuring temperature, humidity, pressure, etc. The RS uses both environmental data and positional information in order to generate commands and instructions for the home devices that adapt the indoor environment to the needs of the elderly.

IV. Conclusion

This work proposes an AAL architecture aimed to support elderly people in their daily life. The proposed system is able to guarantee two important features: (i) continuous localization in both outdoor and indoor environment and (ii) continuous monitoring of the health status of the elderly, by crossing this information with the environmental parameters. In this way, the system can trigger specific events (e.g., to notify family members or medical staff) when particular dangerous situations occur (e.g., fall detection or presence of anomalous biomedical values).

Furthermore, the system is able to transparently collect sensor data coming from heterogeneous devices and forward them to the remote reasoning server, able to trigger appropriate alarms or generate notifications. An ongoing work concerns the interaction of the AAL system with home automation devices,

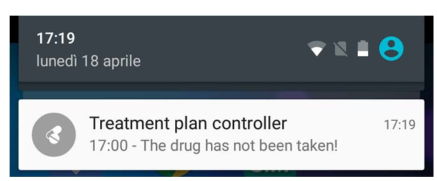


Fig. 5. Notification example related to the therapy plan.

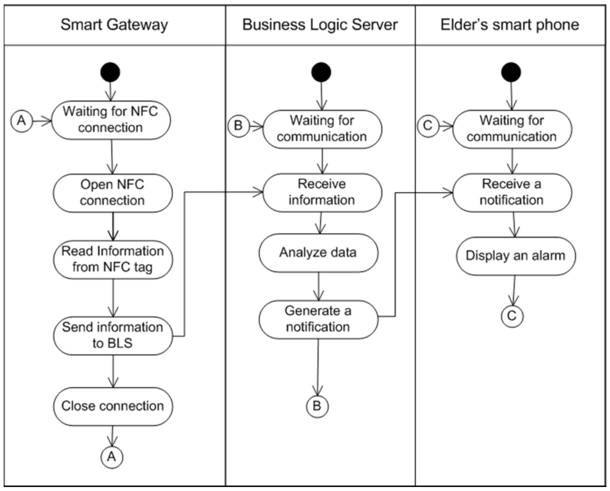


Fig. 6. Interaction between the system's components in the therapy plan monitoring process.

in order to facilitate the adaptation of the indoor environment to the needs of the elderly.

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