Remote and non-invasive monitoring of elderly in a smart city context

Paolo Bellagente(1), Claudio Crema(1), Alessandro Depari(1), Paolo Ferrari(1), Alessandra Flammini(1), Giovanni Lanfranchi(2), Giovanni Lenzi(1), Marco Maddiona(2), Stefano Rinaldi(1), Emiliano Sisinni(1), Giacomo Ziliani(3)

(1) Department of Information Engineering, University of Brescia, Via Branze 38, 25123 Brescia, Italy.
Tel: (+39) 030 3715445, Fax: (+39) 030 380014, email alessandra.flammini@unibs.it
(2) CSMT Gestione S.c.a.r.l., Via Branze 45, 25123 Brescia, Italy
(3) Fabbrica d'armi Pietro Beretta S.p.A., Via P. Beretta 18, 25063 Gardone Val Trompia (BS), Italy

Abstract— **One of Smart City's goals is to reduce healthcare spending, also by prolonging the active and independent lives of the elderly. Often the elderly live alone; their lifestyle, including proper adherence to therapies, is often controlled by relatives or friends or caregivers by daily or weekly telephone calls. In addition to investigating energy and environment infrastructure and services, the project Brescia Smart Living wants to experience new remote monitoring services. The elderly is constantly monitored by a system of wearable and home sensors; a smartphone, acting as a home gateway, stores and elaborates data and reports events to one or more people chosen by the elderly person. The main result of the project is a very versatile and scalable sensory system, thanks to a framework that simplifies the management of several external devices in Android applications. An ambient assisted living application is presented, showing how the life style of an elderly person can be monitored in a non-invasive way.**

Keywords—Remote monitoring; Ageing; Smart City; Wellness; Sensors networks; Android; Embedded Systems; Home Automation

I. INTRODUCTION

In the last years, society is ageing in many countries. For this reason, governments support the development of innovative solutions to improve the quality of life and care of the elderly population through the development of new systems and services designed to facilitate mobility, active aging and reduce social isolation, including the creation of innovative diagnostic and therapeutic approaches to particularly critical diseases [1]. An example of this governmental effort is the Project Brescia Smart Living (BSL), supported by the Italian Ministry of Education, University and Research, started in 2015. BSL aims to combine the demand for safety and savings in energy and services by means of a "smart city" approach centered on the active involvement of citizens in the management of the territory, resources, living environment, and services, according to a smart, sustainable and inclusive growth [2]. The BSL project takes advantage of the opportunity to realize and experiment a comprehensive and integrated network of services in Brescia, northern Italy: district heating, water, gas, electricity, waste collection, street lighting, "smart homes" i.e. optimization of domestic energy consumption, but also security and protection services for frail persons. The sensor application discussed in this paper, for remote and non-invasive monitoring system for elderly citizens, will be experimented according to BSL project.

Academia and industry deeply investigate on remote elderly monitoring [3]-[6]. These research works are often the application of new, cost-effective technology solutions, such as sensors and wireless networks of sensors, smartphones and smart devices, cloud computing. In this context, we can found many applications (APPs) for Android or IOS, telemedicine services, medical devices, wearable sensory systems [7]-[11]. Localization services [12], [13], outdoor and indoor, have a growing importance, thanks to the availability of compact, low-power low-cost sensors and well-characterized communication networks [14]. Some commercial systems are already available, like the Caretek Adamo or the AdiTech LivOn, but our preliminary analysis highlight lacks in their use in mobility and a general inclination towards some degree of vendor lock-in. At the state of the art, the use of a smartphone-based solution could certainly improve the use of this kind of systems in mobility and contain costs. Anyway, some concerns about APP-based solutions for remote elderly monitoring still remain as well as new technological opportunities with their pros and cons have become available:

- The elderly reluctantly use the smartphone, because they do not have a digital culture, and therefore APPs requiring interactions are normally unwelcome [15].

- The elderly often do not like to wear sensorized clothing or T-shirts, which might be constricting and uncomfortable; in addition, sensorized clothing cannot be used during showering or similar activities, thus the elderly would be unmonitored in such situations [16].

- Emergency services operators involved in the project assert that many elderly persons they assist trust only a few people, do not like revealing their position, and are reluctant to rely on external welfare agencies to whom they should give home keys (helpline services).

- Some elderly persons often have economic problems and cannot afford home automation systems and ambient assisted living, even though they would appreciate them [17].

- Low-cost and low-power sensors and communication systems, managed by a smartphone or a tablet, start to be commonly available on the consumer market as an economical solution for inexpensive home automation solutions.

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- The development time of the APP, which should manage devices from different manufacturers to avoid vendor lock-in [19], still represents a significant cost, even considering the multitude and the diversity of available devices and sensors.

- Upgrade and configuration of the solution must be very simple, in order to be autonomously performed by the caregiver or the reference person of the elderly. Therefore, the ideal solution should be non-invasive, very simple to use for the elderly, easily configurable and upgradeable, integrated with commercial devices and solutions.

This paper describes and discusses the smartphone-based prototype for remote and non-invasive elderly monitoring, designed for the BSL context, in order to evaluate its capability to address the previously described issues. The paper is structured as follows: in Section II, the overall architecture is presented; Section III describes the use of Framework SAndroidE as the facilitator for the APPs development; Section IV presents some results of an application for ambient assisted living; finally, conclusions are reported in Section V.

II. The Proposed Architecture

Fig.1 shows the block diagram of the proposed architecture. In the following, the elder person will be referred as "user", whereas the caregiver or the relative authorized by the user as "caregiver". A smartwatch with Android Wear OS and three Android smartphones are used: the user smartphone, which manages wearable sensors and the smartwatch and tracks the user indoor and outdoor; the home smartphone or tablet, which handles home sensors and devices for ambient assisted living; and the caregiver smartphone, which receives alerts and allows monitoring the user life style. The caregiver's smartphone receives data directly from the home smartphone and from the user's smartphone. In this way, the caregiver can receive events and alerts and can monitor the user (wherever he/she is) as well as the entire home. In the following, the three contexts, i.e., user, home and caregiver will be described.

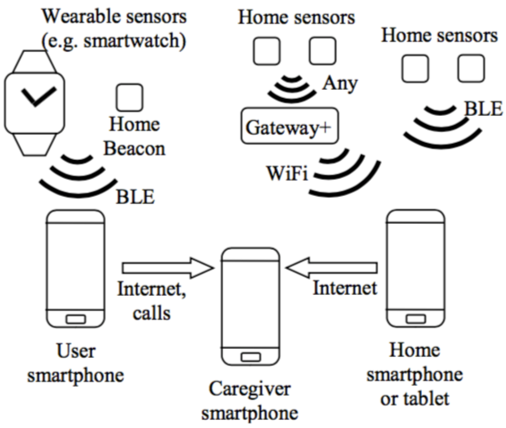


Fig. 1. Block diagram of the proposed architecture.

For the sake of simplicity, we use HomeAPP to refer to the APP running on the home smartphone, CaregiverAPP to refer to the APP on the caregiver smartphone, and UserAPP to refer to the APP running on the user smartphone and smartwatch. The three APPs share information thanks to a central server, and Google Firebase is used for notifications and backend services; all communications are encrypted using the HTTPS protocol. Particularly, the HomeApp provides information to CaregiverAPP about alarms, events, and home lifestyle, automatically or on request, whereas the UserAPP provides information to CaregiverAPP about the user health and position, automatically or on request. The central server, realized in PHP with MySQL, is the data repository of information coming from UserAPP and HomeAPP; artificial intelligence tools could be used for further elaboration, but this is out of scope of the paper. Each elderly person can authorize one or more caregivers to access his/her own personal data. The caregiver receives alerts and warnings in case of voluntary or automatic help requests from the user; moreover, it has access to information about the life style of the user, e.g., correct medicament assumption, indoor air quality, user location. Furthermore, the caregiver can set one or more "safe" areas, to preserve the privacy of the user and to receive alerts only when the user is inside these areas.

The proposed ambient assisted living scenario is well-known: HomeAPP is a Bluetooth Low Energy (BLE) monitoring service which acts as a gateway by sending data collected from Bluetooth devices and delivering them to a web server where data are stored within a MySQL database. Data includes: information coming from push buttons, motion sensors placed on doors, temperature, humidity and air quality sensors, and so on. No cameras or microphones have been considered for this architecture: although the user agrees to be monitored, people visiting the user might wish for not being monitored. The caregiver is not interested to know every movement or action of the user, but, as an example, a lack of prolonged activity could be considered as sign of a possible problem with the user. It should be noted that HomeAPP does not have a real user interface, except for configuration and diagnostics; it only analyzes possible emergencies, which can be different depending on the user lifestyle. In the proposed architecture, we take advantage of Estimote Stickers, i.e., very simple sticker-like and low-cost motion sensors, acting as BLE beacons. A beacon is a very simple and low-energy device periodically sending a data connectionless self-identifying broadcast packet, in this case through BLE technology. Estimote Stickers have an embedded tri-axial accelerometer allowing motion detection. As an example, during configuration, a Sticker can be attached to the refrigerator door, another one to the pillbox and another one to the pedal of the exercise bike; in this way, an alert can be programmed to be issued, for example, if the user is not moving the pillbox at least two times a day or if the user is at home and the refrigerator is never opened. Additionally, the use of the exercise bike can be tracked. In the Internet of Things (IoT) era, more and more sensors and devices are available; nowadays, the challenge is how to realize simple, self-configuring APPs managing information from devices of different manufacturers. Estimote Stickers could be a mean to monitor the activity of any physical object by simply sensing its motion, regardless if the object is a smart object with a proprietary APP and protocol (e.g., smart refrigerator of vendor X) or a plain mechanical object (e.g., pillbox). This may be a simple solution to "connect" to the IoT traditional "unconnected" physical objects.

In case home sensors are far from the home smartphone or the communication stack is not supported, a gateway can be added. The smartphone natively supports WiFi and Bluetooth, but the latter is definitely the winning communication solution for distributed wearable systems and domestic IoT [18]-[23]. The recent availability of Bluetooth 5 [24], which increases the transmission range, further highlights this trend. In the proposed architecture, most of the communication links between the devices for the ambient assisted living and the smartphone are BLE-based; if other technologies (e.g., Z-Wave, very widespread in home automation) are also employed, an appropriate gateway can take care of transporting the information on BLE or WiFi. When adopted, the gateway handles the connection with the home WiFi router; alternatively it can act as the home router (see gateway+ in Fig.1), thanks to a mobile data connection.

Normally, the elderly person uses the smartphone mainly for phone calls; if the user is not feeling well, but still in a conscious state, he/she can be able to independently call the relative or the caregiver. In some cases, the smartphone can be out of the range of the elderly person or the user can be unable to perform the call. For this reason, we have chosen to host the functionality for emergency in the smartwatch, thanks to an always-active APP. In this way, the user can send a voluntary alarm by means of the smartwatch, without the need of interacting with the smartphone. Moreover, it should be noted that the smartwatch is a wristwatch, which is an object of common use and thus more easily accepted by people with a non-digital culture. The procedure for sending an alarm starts with touching the main screen of the smartwatch; this initializes a countdown, which lasts 15 s. Any time during the countdown, the user can cancel the procedure by touching the screen one more time. At the end of the countdown, the smartwatch automatically interfaces with the smartphone and generates the alarm, which is sent to the caregiver through two channels. The first channel is a phone call which is automatically activated from the smartphone; the latter uses the smartwatch as a hands-free device, allowing the user to speak with the caregiver. The second channel is a data packet sent to the caregiver smartphone via the Internet. Moreover, suitable procedures have been implemented in case of failure (retransmissions, App auto-reboot, and alarm from phone).

The caregiver can access user-related information, such as the available vital parameters (e.g., the heartbeat measured by the smartwatch) and his geographical location. In case the user is at home, localization is achieved thanks to a BLE beacon installed at home and paired with the UserAPP. When the user smartphone does not detect the beacon signal, it supposes that the user is not at home. In such a case, the user smartphone activates the locatilization service, based on GPS, of UserAPP. The user geographical position is periodically acquired; in case the acquired coordinates are out of a previously defined area, the UserAPP automatically sends an alert to the caregiver. Furthermore, on caregiver request, the position of the user can be accessed any time. It should be highlighted that no interaction between the user and user smartphone is required; the user smartphone can be considered as a "Smart stone" [25] and the user duties are to recharge it at night and carry it when going out of home. The user is warned about a lost connection between smartwatch and user smartphone by means of a smartwatch vibration.

The UserAPP gathers information from the smartwatch, from its own GPS, if outdoor, and from home beacons, if at home. To optimize the energy consumption, the BLE scan for beacons is automatically activated only when the user is detected within a range of 1 km from home; this information is obtained by exploiting the GPS signal. It should be underlined that the use of the smartwatch as a wearable device for the elderly could be furthermore facilitated by the presence, in the very new smartwatches, of sophisticated sensors for health and localization, as well as mobile data connection With such new features, the system architecture could be simplified, since the user smartphone is not essential any more.

In the actual implementation, the smartwatch is used to send automatic alerts as well. The employed smartwatch (LG Watch Urbane 2 with Android Wear 2.0) has a heart rate monitor and a tri-axial accelerometer, both controlled by the smartwatch UserAPP. The user smartphone UserAPP can analyze smartwatch sensor data and evaluate if a dangerous situation is occurring; e.g., abrupt changes of the heart rate or a sudden acceleration, followed by a state of quiet (possible signs of fall or fainting). Suitable low-pass filtering applied to sensor data can help preventing false alarms. In any case, before sending the automatic alarm, the application warns the user via a vibration and the previously-described countdown mechanism is activated, allowing the user to abort the automatic alarm procedure. The user smartphone sends the automatic alert to the caregiver in the same way of the voluntary one, i.e., via phone call and internet data packet.

It should be noted that many other wearable sensors and medical devices are being developed or already available on the market [26], e.g., for heart or respiratory rate monitoring or for diabetes, offering very interesting opportunities in the monitoring of elderly. However, often these devices are stand-alone solutions and it is very difficult to integrate them in a system managed by a single APP. On the contrary, the management of smartphones' and smartwatches' embedded sensors is quite simple and straightforward. This is because Android and Android Wear take care of the communication layer and the data access mechanisms. To simplify the integration of external sensors in Android-based systems, the SAndroidE framework has been recently proposed [27] and experimentally tested [28].

III. THE SANDROIDE FRAMEWORK

SAndroidE, Sensors for Android Embedded [29], is a framework to allow data collection and management of external BLE connected devices, sensors and actuators, in the same easy way Android manages embedded devices.

SAndroidE extremely eases the work of APP developers by transparently handling all the communication stack and protocols, thus exempting the developers from all these tasks. SAndroidE aims to provide support for as many devices as possible and allows developers to access external resources in a seamless way, by using the same primitives, regardless of the specific device manufacturer.

SAndroidE currently supports several devices: programmable devices like Raspberry Pi3, the tiny Nano from RedbearLabs, or Arduino; BLE devices accessible by means of a vendor provided APPs like Flic buttons; beacons; BLE devices whose data is only accessible using a REST API provided by the vendor, like Fitbit activity trackers.

SAndroidE is based on the following components, also shown in Fig. 2:

- An Android library written in Java language, which must be included within the Android application project and provides the primitives to allow an Android APP developer to access data coming from external devices and sensors, regardless of their manufacturer or their type.

- A set of XML/JSON files, called Device Descriptors, describing the communication protocol, primitives and features allowed for each device included in the SAndroidE supported devices list.

- A set of some XML/JSON files, called API descriptors, which are the means to describe a vendor's HTTP REST API and access data from sensors using an Internet connection instead of a direct BLE connection. This, unfortunately, is necessary to support those devices whose manufacturer does not allow direct BLE collection of data, but only provides data access through a REST web service.

- A SAndroidE configuration application, provided with the framework, to detect nearby BLE devices and to assign to each of them a unique name. The latter is used as reference inside of a SAndroidE powered application, in order to access that specific device.

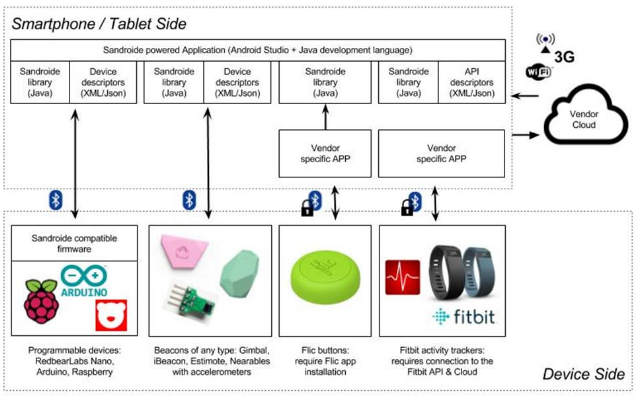


Fig. 2. Main components in SAndroidE.

In the following, some examples are provided to support the validity of the SAndroidE framework for accessing external sensor data in an easy and straightforward way. Fig. 3 shows a section of the source code for connecting a Nano device with SAndroidE; an object of class *SandroideDevice* (provided with SAndroidE library) is created for the device identified by the name "nanoservice_sandroide_device" and then the callback to execute on the connection event is defined. In Fig. 4, an example of a digital output pin declaration is given; a virtual pin is declared as an object of class *SandroidePin*, which is associated to the virtual device previously defined as *nano* and to the physical pin in position #29, as defined in the datasheet. The virtual pin is then declared as a digital output, and set to the high value. Fig. 5 shows an example of handling an analog input pin; an object of class *SandroidePin* is created and linked to pin 6 of the *nano* virtual device, then declared as analog input, its sampling interval is defined, and then the callback to execute when a new value is received is defined.

```
SandroideDevice nano = ((SandroideDevice)
BLEContext.findViewById("nano_sandroide_device"))
      .setOnDeviceConnected(new
SandroideDevice.OnDeviceConnectedListener() {
   @Override
   public void onEvent(SandroideDevice device) {
      // do something on device connection event
   }
});
```

Fig. 3. Source code to connect a device.

```
SandroidePin nanoDigitalOut = new SandroidePin()
   .setDevice(nano,29)
   .setMode(SandroidePin.PIN_MODE_DIGITAL_OUTPUT)
   .setValue(true)
```

Fig. 4. Digital output pin declaration.

```
SandroidePin nanoTrimmer6 = new SandroidePin()
      .setDevice(nano,6)
      .setMode(SandroidePin.PIN_MODE_ANALOG_INPUT,1)
      .setDeltaThreshold(0.2)
      .setSamplingInterval(400)
      .setOnValueReceived(new
SandroidePin.OnValueReceivedListener() {
         @Override
         public void onEvent(final Object newValue,
Object oldValue) {
         }
      });
```

Fig. 5. Source code to handle an analog pin.

IV. THE AMBIENT ASSISTED LIVING CONTEXT AND RESULTS

The project Brescia Smart Living includes an extensive experimental stage to he held in the city of Brescia, Italy. The proposed architecture has been implemented for experimental evaluation. In particular, Fig. 6 shows the setup of the implemented test case, i.e., a house of a 81 year old woman living alone.

Three Z-Wave sensors have been used: an emergency push button, FGPB-101 by Fibaro close to the bed, an air quality sensor (dust sensor), SENSOAIR by Siegenia; and a door&motion&temperature sensor, PST02 by Philio Tech, placed on the bathroom door. The push button communicates on event, the dust sensor is sampled every 30 minutes and the door&motion&temperature signals events and communicates temperature every 10 minutes. A gateway, realized with a Raspberry Pi3 [30] board, programmed in Phyton, with a razberry [31] Z-Wave interface (connected to the serial link of the Raspberry) has been provided to send information from the

Z-Wave sensors to the HomeAPP by a WiFi link. Particularly, the gateway is connected to the home router as well as the Home smartphone, allowing sharing data by means of the web server. SAndroidE has been used to manage two IP67 push buttons by Flic and two Stickers by Estimote. The two smart buttons have been placed in the shower and in the bathtub; the two Stickers have been used to detect motion of the pillbox and of the kitchen cabinet door. HomeAPP also realizes a log that can be used in future works. Fig. 7 shows a log about a preliminary test of devices.

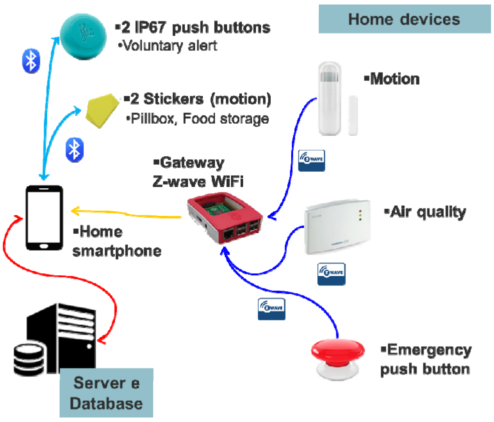


Fig. 6. The setup in the house used as a test case.

2017-07-14 10:15:49 receive fromRaspberry: timestamp: 2017-07-14 10:15:49
type: motion1 unit: bool level: on
2017-07-14 10:15:49 Movement in bathroom 2017-07-14 10:15:49

2017-07-14 10:15:49 receive fromRaspberry: timestamp: 2017-07-14 10:15:49
type: temperature1 unit: C level: 25
2017-07-14 10:15:49 Temperature level 25 at 2017-07-14 10:15:49

2017-07-14 10:16:38 bluetoothButton at 2017-07-14 10:16:38

2017-07-14 10:19:51 bluetoothMotion medication at 2017-07-14 10:19:51

2017-07-14 10:22:16 bluetoothMotion foodstorage at 2017-07-14 10:22:16

Fig. 7. Log of the HomeAPP.

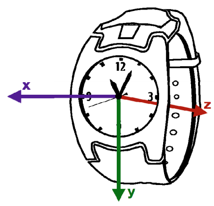
The first three lines are about motion detection in proximity of the bathroom door; the other three lines show the temperature measured by the same sensor during the event (same timestamp). The last three lines regard three different events: at 10:16:38 the IP67 button in the shower has been pressed; at 10:19:51 the pillbox has been moved; at 10:22:16 the door of the kitchen cabinet has been opened.

Three smartphones Samsung Galaxy A3 2016 with Android 7.0.1 have been used; memory occupancy by the three developed APPs are reported in Table 1.

TABLE I MEMORY OCCUPANCY OF THE THREE DEVELOPED APPS.

APP	Memory [MB]	RAM [MB]
HomeAPP	20.9	18
UserAPP	9.34	39
CaregiverAPP	25.5	44

As previously stated, the used smartwatch, LG Watch Urbane 2 with Android Wear 2.0, has a heart rate detection functionality and an accelerometer. In order to reduce power consumption, the heart rate is evaluated for 30 s every 150 s. More in detail, the Beats per Minute (BPM) samples with minimum and maximum values are discharged, then the mean value is computed. This BPM value is considered constant for the next 150 s. If an event occurs, e.g., a voluntary help request, the last ten values BPM are sent to the caregiver. In the considered test case, information about BPM is not so reliable, because the user could not wear the smartwatch in a tight way; for this reason, no automatic alarms are sent in case of BPM-related events. Data from accelerometers, expressed in m/s^2, are used in a very simple way and regardless the orientation, as shown in Fig.8. Sampling time can be set down to 10 ms and acceleration value VAL is computed every second and compared with a threshold of 5 g, in order to detect falls.



$$\mathbf{VAL^2 = x^2 + y^2 + z^2}$$

Fig. 8. The Accelerometer embedded in the smartwatch..

Accelerometers of the smartwatch have been characterized by the standard deviation computed on 100 samples while the smartwatch was placed on the table; a standard deviation of $0.22 m/s^2$ has been measured.

UserAPP has been configured in order to automatically recognize two indoor environments by two different beacons: user home and a relative's home, not far each other. CaregiverAPP has been realized in Italian. Fig. 9 illustrates two screenshots: on the left, the main screenshot with last events (motion in proximity of the entrance door, internal temperature value, medium air quality) is illustrated; on the right, the screenshot concerning assignment of the perimeter of a "safe" area is reported.

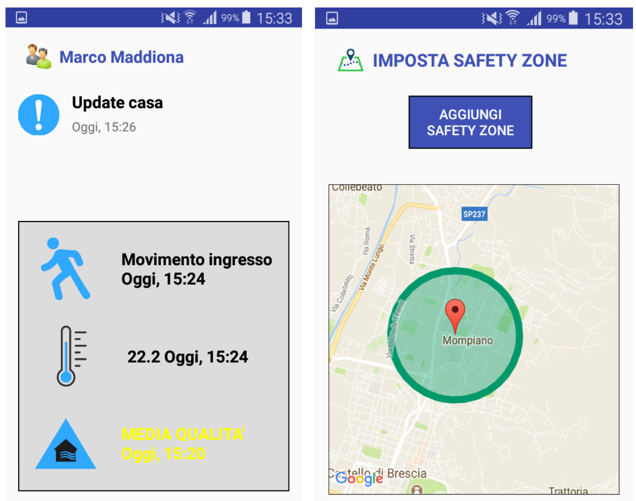


Fig. 9. Screenshots of CaregiverAPP.

V. CONCLUSIONS

An ambient assisted living application is presented, showing how the lifestyle of an elderly person can be monitored in a non-invasive way. The architecture has been well accepted by involved user, because no privacy violation has been felt and the caregiver is a close relative. The proposed approach will be used for the BSL experimental phase with more users and real caregivers (all volunteers). The adopted smartwatch has been accepted as the wearable device, although the BPM function does not give reliable results because of the poor adherence with the user's wrist. The motion detection of the pillbox has been particularly appreciated by the user, since it was issuing reminders (vibration of the smartwatch) in the case of no motion within afternoon; in this case, the sticker has been positioned inside the medicine box. APPs' development and adjustment according to the user needs and configuration have been very simplified by the use of the SAndroidE framework.

REFERENCES

[1] Horizon 2020, Health, Demographic change and Wellbeing, https://ec.europa.eu/programmes/horizon2020/en/h2020-section/health-demographic-change-and-wellbeing

[2] Isam Shahrour, Lyes Alileche, Abdurahman Alfurjani, Smart cities: System and tools used for the digital modelling of physical urban systems, 2017 Sensors Networks Smart and Emerging Technologies (SENSET), pp.1-4.

[3] C. Crema, A. Depari, A. Flammini, E. Sisinni, A. Vezzoli, P. Bellagente, "Virtual Respiratory Rate Sensors: An Example of A Smartphone-Based Integrated and Multiparametric mHealth Gateway", IEEE Trans. Instrumentation and Measurement, Sept., 2017, Vol. 66, N. 9, pp. 2456-2463.

[4] M. Anwar Hossain; Dewan Tanvir Ahmed, Virtual Caregiver: An Ambient-Aware Elderly Monitoring System, IEEE Transactions on Information Technology in Biomedicine, Year: 2012, Volume: 16, Issue: 6, Pages: 1024 - 1031

[5] Luca Fanucci; Sergio Saponara; Tony Bacchillone; Massimiliano Donati; Pierluigi Barba; Isabel Sanchez-Tato; Cristina Carmona, Sensing Devices and Sensor Signal Processing for Remote Monitoring of Vital Signs in CHF Patients, IEEE Transactions on Instrumentation and Measurement, Year: 2013, Volume: 62, Issue: 3, Pages: 553 - 569

[6] B. Andò, S. Baglio, C. O. Lombardo and V. Marletta, "An Event Polarized Paradigm for ADL Detection in AAL Context," in IEEE Transactions on Instrumentation and Measurement, vol. 64, no. 7, pp. 1814-1825, July 2015.

[7] Sardini, E., Serpelloni, M., Pasqui, V. Wireless wearable t - shirt for posture monitoring during rehabilitation exercises (2015) IEEE Transactions on Instrumentation and Measurement, 64 (2), art. no. 6879 298, pp. 439 - 448.

[8] M. C. Stutzel, M. Fillipo, A. Sztajnberg, A. Brittes and L. B. da Motta, "SMAI - Mobile System for Elderly Monitoring," 2016 IEEE International Conference on Serious Games and Applications for Health (SeGAH), Orlando, FL, 2016, pp. 1-8.

[9] C. Crema, A. Depari, A. Flammini, M. Lavarini, E. Sisinni, A. Vezzoli, "A smartphone-enhanced pill-dispenser providing patient identification and in-take recognition", 2015 IEEE International Symposium on Medical Measurements and Applications Proceedings (MeMeA), Turin, Italy, May 7-9, 2015, pp. 484-489.

[10] R.S. Ransing and M. Rajput, "Smart home for elderly care, based on Wireless Sensor Network," 2015 Int. Conf. on Nascent Technologies in the Engineering Field (ICNTE), Navi Mumbai, 2015, pp. 1-5.

[11] S. P. Kumar, D. Akash, K. Murali and R. Shriram, "Call ambulance smart elderly monitoring system with nearest ambulance detection using Android and Bluetooth," 2016 Second Int. Conf. on Science Technology Engineering and Management (ICONSTEM), Chennai, 2016, pp. 89-92.

[12] L. Palopoli et al., "Navigation assistance and guidance of older adults across complex public spaces: the DALi approach," Intelligent Service Robotics, Springer, Vol. 8, no. 2, pp 77-92, Apr. 2015.

[13] A. Colombo, D. Fontanelli, D. Macii, L. Palopoli, "Flexible Indoor Localization and Tracking Based on a Wearable Platform and Sensor Data Fusion," IEEE Trans. Instrumentation and Measurement, vol. 63, no. 4, pp. 864 – 876, Apr. 2014.

[14] L. Angrisani, E. Atteo, D. Capriglione, L. Ferrigno, G. Miele, "An efficient experimental approach for the uncertainty estimation of QoS parameters in communication networks", in Proceedings of 2010 IEEE International Instrumentation and Measurement Technology Conference, I2MTC, pp. 1186-1191.

[15] E. G. Price-Haywood, J. Harden-Barrios, R. Ulep, and Q. Luo, "eHealth Literacy: Patient Engagement in Identifying Strategies to Encourage Use of Patient Portals Among Older Adults," Popul. Health Manag., vol. 20, no. 6, pp. 486–494, Dec. 2017.

[16] Y.-M. Fang and C.-C. Chang, "Users' psychological perception and perceived readability of wearable devices for elderly people," Behav. Inf. Technol., vol. 35, no. 3, pp. 225–232, Mar. 2016.

[17] M. G. Melchiorre et al., "Social Support, Socio-Economic Status, Health and Abuse among Older People in Seven European Countries," PLoS One, vol. 8, no. 1, p. e54856, Jan. 2013.

[18] M. Rizzi, P. Ferrari, A. Flammini and E. Sisinni, "Evaluation of the IoT LoRaWAN Solution for Distributed Measurement Applications," in IEEE Transactions on Instrumentation and Measurement, 2017, vol. PP, no. 99, pp. 1-10.

[19] European Union, European Innovation Partnership on Smart Cities and Communities "Operational Implementation Plan", 2014 pp. 5-6

[20] L. Mainetti, V. Mighali, L. Patrono, P. Rametta and M. L. Stefanizzi, "An IoT-aware system for elderly monitoring," 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI), Modena, 2017, pp. 1-5.

[21] C. M. De Dominicis, D. Mazzotti, M. Piccinelli, S. Rinaldi, A. Vezzoli, A. Depari, "Evaluation of Bluetooth Hands-Free profile for sensors applications in smartphone platforms," Proceedings of the 2012 IEEE Sensors Applications Symposium (SAS), 7-9 Feb 2012.

[22] A. Depari, A. Flammini, S. Rinaldi, A. Vezzoli, "Multi-sensor system with Bluetooth connectivity for non-invasive measurements of human body physical parameters," Sensors and Actuators A: Physical, Vol. 202, pp. 147-154, 2013.

[23] K. Komai, M. Fujimoto, Y. Arakawa, H. Suwa, Y. Kashimoto and K. Yasumoto, "Elderly person monitoring in day care center using Bluetooth Low Energy," 2016 10th International Symposium on Medical Information and Communication Technology (ISMICT), Worcester, MA, 2016, pp. 1-5.

[24] www.bluetooth.com/specifications/bluetooth-core-specification/bluetooth5

[25] P. Bellagente, C. Crema, A. Depari, P. Ferrari, A. Flammini, S. Rinaldi, E. Sisinni, A. Vezzoli, "The "Smartstone": using smartphones as a telehealth gateway for senior citizens", IFAC-PapersOnLine - Proceedings of the 4th IFAC Symposium on Telematics Applications (TA 2016), Porto Alegre, Brazil, Nov. 6-9, 2016, Vol. 49, N. 30, pp. 221-226.

[26] Huadong Wu and M. Siegel, "Odor-based incontinence sensor," Proceedings of the 17th IEEE Instrumentation and Measurement Technology Conference [Cat. No. 00CH37066], Baltimore, MD, 2000, pp. 63-68 vol.1.

[27] S. Rinaldi, A. Depari, A. Flammini, A. Vezzoli, "Integrating remote sensors in a smartphone: The project "sensors for ANDROID in embedded systems"", 2016 IEEE Sensors Applications Symposium (SAS), Catania, Italy, April 20-22, 2016, pp. 468-473.

[28] P. Bellagente, C. Crema, A. Depari, A. Flammini, G. Lenzi, S. Rinaldi, A. Vezzoli, "Easy implementation of sensing systems for smart living", 2017 IEEE International Systems Engineering Symposium (ISSE), Vienna, Austria, October 11-13, 2017, pp. 337-342.

[29] es3.unibs.it/SAndroidE/

[30] www.raspberrypi.org/

[31] https://razberry.z-wave.me.