IoT Platform for Ageing Society: the SMART BEAR Project

Smart Big Data Platform to Offer Evidence-based Personalised Support for Healthy and Independent Living at Home

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***Abstract* — People over 65 years old represent a constantly increasing age-group in Europe and worldwide. Hearing loss, cardio-vascular diseases, cognitive impairments, mental health issues and balance disorders are the most prevalent health challenges experienced by older population. These conditions result in a quality-of-life worsening (e.g., inactive lifestyle, missed self-sufficiency, loneliness) and life threats (e.g., physical injury, disability, and hospitalization). Moreover, their management is burdensome for healthcare institutions with high and rising costs, and gaps in quality, safety and access. Internet of Things (IoT) technology may offer a valid aid with its innovative and connected solutions. In such context, SMART BEAR Horizon 2020 European project aims to design and develop an IoT platform to: (*i*) integrate off-the-shelf smart consumer and medical devices for a smart health environment, (*ii*) provide an affordable, secure, and privacy-preserving service to older subjects promoting autonomy and healthy living, and (*iii*) increase the efficiency of healthcare delivery reducing resource waste. The present study is intended to comprehensively illustrate the project. In particular, it summarizes rationale and features of SMART BEAR project with a finer description of the platform components, clinical scenarios, and interventions.**

Keywords - ageing population; IoT platform; personalized interventions; independent living; healthy lifestyle.

I. INTRODUCTION

Ageing population represents a major challenge in nowadays societies. According to [1], 151 million of the European population will be over 65 years old by 2060 with a particularly rapid increase in number of people over 80 years old. The physiological and progressive decline due to the ageing in physical abilities (e.g., osteoporosis, frailty) and cognitive skills (e.g., memory and visual-spatial difficulties) leads to a reduced independency and a need of care. Such conditions, in turn, usually cause a deterioration of individual's mood and social participation (e.g., older people are at higher risk of depression and poor self-rated health when compared with younger subjects). As a result, multiple comorbidities of chronic and neurodegenerative diseases are simultaneously faced by older population with heavy repercussions on health policies and programs as well. Actions across multiple sectors enabling older people to remain a resource for their families, communities and economies are therefore needed. The World Health Organization (WHO) has lately set as a priority the promotion of "ageing well" [2] intended as the process for fostering and maintaining the individual's functional ability that includes managing their own basic needs, making decisions, being active, building and maintaining a social life, and contributing to the society [3].

Smart Healthcare (SH) systems addressed to older adults represent valuable solutions as they monitor and track individual's behavior and health status. They can also help in managing medical conditions effectively with a consequently reduced burden on caregivers, and lastly, they can motivate subject to stay physically and cognitively fit so to enhance wellbeing and increase Quality of Life (QoL).

Thanks to the recent advancements of technology, SH systems are increasingly proposed. From 2016 onward [4], a significant increase in the development of smart platforms tailored on ageing population with applications devoted to neurology, cardiology, psychiatry, and psychology has been observed. Those platforms [5] include Internet of Things (IoT) devices that can be worn by subjects (e.g., wearable sensors and medical devices) and/or installed in house settings (e.g., smart home devices). The data collected by the devices are then sent to a cloud system and here analyzed through sophisticated Machine Learning (ML) and Artificial Intelligence (AI) algorithms to properly assess the status of older individual and provide him/her feedbacks or real-time alerts. Although those infrastructures may appear simple, they hide tough tricks because of [5]: *a*) wide heterogeneity of equipment (i.e., wearable sensors, home sensors and medical devices), *b*) big volumes of data usually acquired in uncontrolled environments, *c*) multifactorial selection of the most suitable algorithm for the specific topic to figure out and *d*) privacy and security issues related to the processing of subjects' data.

Within such context, SMART BEAR project, funded by the European Commission under the Horizon 2020 program, aims to design, and develop an innovative platform (i.e., SB platform), integrating state-of-the-art devices, addressed to older adults [6] to offer evidence-based support for healthy and independent living at home. The project involves 27

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European partners among universities, research centers, hospitals, collective structures, local administrations, small and medium-sized enterprises and big companies and it will be concluded in 2024 after 60 months of synergistic work.

The aim of the present paper is to provide an exhaustive bird's-eye view on the SMART BEAR project. The document is organized as follows. Section II reports rationale and goals of SB platform. Section III addresses project pilot sites. Section IV illustrates the devices comprising the platform and the principal features of the cloud system. Interventions and related clinical scenarios are described in Section V while conclusions are reported in Section VI.

II. RATIONALE

Within the European ageing population, Hearing Loss (HL), Cardio-Vascular Diseases (CVDs), Cognitive Impairments (CIs), Mental Health Issues (MHIs), and Balance Disorders (BDs) are prevalent conditions [7].

HL [8] is the third most common condition affecting older adults and the fifth leading cause of disability worldwide. It increases the risk of cognitive decline, mental illness, and depression, and it leads to social isolation.

CVDs [9] are the main causes of death globally. They have a physical, social, and emotional impact on older adults and a significant economic impact on European economy as reported by the European Society of Cardiology (ESC).

CIs [10] are prevalent in adulthood, especially after heart failures. They affect several domains as memory, attention, executive functions, and psychomotor speed thus compromising the ability to think, learn and remember.

MHIs [11] include social isolation, sleep disturbances, anxiety, and depression. They have an impact on physical health and vice-versa. In addition, they increase the risk of converting mild cognitive impairments to dementia.

BDs [12] are consequences of age-related progressive loss of sensory information functioning and body movement control. They result in falls, disability, and death (one older adult deaths because of a fall every 29 minutes).

The above-mentioned conditions have hence huge impact on older subjects' QoL and healthcare institutions' finances. Preventing and/or slowing the development of those impairments is therefore beneficial for older people, caregivers, clinicians, and hospitals. Therefore, the main objective of SB platform is to integrate heterogeneous sensors and assistive medical devices that will enable continuous and non-continuous monitoring in older adults' everyday life. The monitoring will be done in both indoor and outdoor environments, depending on every device's feature, and will help to gain evidence needed to plan personalized interventions promoting an independent and healthy lifestyle. The secondary objective, instead, is to identify subgroups' patterns across different countries and urban areas with different extensions, local services, environmental, and socio-economic conditions.

III. PILOT SITES

Throughout the project, the SB platform will be employed and assessed in five large-scale pilots (i.e., Greece, Italy-Portugal, France, Spain, and Romania) with the overall involvement of 5100 older adults living at home and in collective structures (Table 1). The high sample size considered enables a large-scale validation of the platform while the multiple geographic areas selected offer a great heterogeneity of conditions allowing comparisons suitable for patterns detection among and within regions.

TABLE I. SMART BEAR PILOTS

Pilot Sites	**Sample Population**	**Sample Size**	**Geographic Area**
Greece	Independent older adults living at home/ Older adults living in collective structures	1000	Region of Peloponnese, Municipality of Palaio faliro
Italy-Portugal	Independent older adults living at home/ Older adults living in collective structures	1100	Milan metropolitan city, District of Crema, Madeira Island
France	Independent older adults living at home/ Older adults living in collective structures	1000	Ile-de-France (the Paris Region), Nouvelle Aquitaine and Bretagne
Spain	Independent older adults living at home/ Older adults living in collective structures	1000	Barcelona, Madrid, Sevilla areas, Pais Vasco, Galicia and Balearic Island
Romania	Independent older adults living at home/ Older adults living in collective structures	1000	Bucharest, Cluj Napoca and Constanta metropolitan areas

IV. SMART BEAR DEVICES AND CLOUD SYSTEM

SB platform integrates sensors and devices able to record data from the daily living of its older users. The technological devices of platform can be divided into:

- personal devices (Figure 1);
- smart home devices (Figure 2).

All of them communicate through Bluetooth and/or Wi-Fi with a dedicated mobile application (i.e., SB mApp) installed on a Samsung Galaxy S10 smartphone and available in iOS environment, too.

Figure 1. Personal Devices

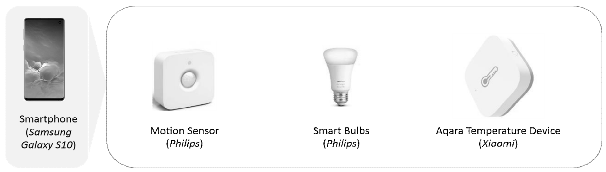

Figure 2. Smart Home Devices

All the personal devices shown in Figure 1 includes:

- ***Samsung Galaxy S10***: smartphone (Samsung Electronics Ltd., South Corea) with a RAM of 3GB up to 1000 GB with a micro SD.
- ***Phonak Marvel-50***: smart-hearing aids (Phonak, Switzerland) rechargeable via batteries with a battery life up to 5-7 days depending on usage.
- ***BPM Core***: smart-blood pressure monitor (Withings, France; dimensions: 560x165x450mm; weight: 430g) rechargeable via micro-USB cable with a duration of approximatively 6 months.
- ***Thermo***: smart-thermometer (Withings, France; length: 116mm, diameter: 66.2mm; weight: 75g) rechargeable via AAA batteries with a battery life up to 2 years.
- ***Garmin VivoSport***: smartwatch (Garmin, USA; width: 21mm, thickness: 10.9mm; weight: 24.1g) with a memory of 14 days of activity tracking and rechargeable via micro-USB cable with a duration of 8 hours in GPS mode and 7 days in basic smartwatch mode.
- ***Body+***: smart-scale (Withings, France; dimensions: 325 x325x23mm; weight: 2100g) rechargeable via AAA batteries with a battery life up to 18 months.
- ***iHealth Air***: smart-pulse oximeter (iHealth Labs Inc, USA; dimensions: 62x33x28 mm; weight: 42g) rechargeable micro-USB cable with a duration on a time scale of weeks.

As shown in Figure 2 the smart home devices are:

- ***Motion Sensors***: three sensors (Philips, The Netherlands; height: 5.5cm; length: 3 m; width: 5.5cm; net weight: 65g) for motion detection, temperature and level of lighting rechargeable via AAA batteries.
- ***Smart Bulbs***: sensor (Philips, The Netherlands; height: 11.8cm; width: 6cm; weight: 65g) for lighting adjustments including color, brightness and color temperature with an average life up to 25 years.
- ***Aqara Temperature Device***: three sensors (Xiaomi, China; dimensions: 36x36x9 mm, weight: 110g) for temperature, humidity and pressure with a battery life up to 2 years.

A total of 7 sensors, with a Raspberry Pi computer with a micro-SD card and a Zigbee adapter, constitute the home automation component of SB platform. It results fully compatible with any IoT platform, and it can be successfully linked with major AI technologies available on the market including Amazon Alexa, Google Assistant and Apple Homekit.

The parameters collected by personal devices of SMART BEAR are summarized in Table II while the measurements provided by home sensor devices of SB platform are shown in the Table III.

TABLE II. PERSONAL DEVICES PARAMETERS

Device	Parameters
Phonak Marvel-50	Duration of active use [hours or minutes]
	Average duration of active use per day [hours or minutes]
	Duration of exposure at environmental noise levels per day and per week [minutes]
	Percentage of active use in soft/medium/high intensity sounds [percentage]
Body+	Body weight [kilogram or pound]
	Body muscle mass [kilogram or pound]
	Body bone mass [kilogram or pound]
	Body fat mass [kilogram or pound]
	Body fat free mass[kilogram or pound]
	Body fat ratio [percentage]
BPM Core	Diastolic Blood Pressure [mmHg]
	Systolic Blood Pressure [mmHg]
	Heart Rate [beats per minute]
	ECG signal [μV, time series]
Thermo	Body Temperature [Celsius or Fahrenheit]
	Skin Temperature [Celsius or Fahrenheit]
iHealth Air	Blood oxygen saturation [percentage]
	Pulse rate [beats per minute]
Garmin VivoSport	Number of steps [dimensionless number]
	Distance traveled [meters]
	Calories burned through activity [kCal]
	Calories burned by Basal Metabolic Rate [kCal]
	Intensity Minutes [minutes]
	Duration of vigorous/moderate/low activity [seconds]
	Floors climbed [dimensionless number]
	Average heart rate on last 7 days [beats per minute]
	Average heart rate at rest [beats per minute]
	Sleep quality [label]
	Sleep duration [seconds]
	Time spent in deep/light/REM sleep [seconds]

TABLE III. SMART HOME DEVICES MEASUREMENTS

Devices	Measurements
Motion Sensors + Smart Bulbs + Aqara Temperature Device	Room Light Intensity [illuminance]
	UV Index [integer]
	Outdoor/Room Temperature [Celsius or Fahrenheit]
	Outdoor/Room Relative Humidity [percentage]
	Outdoor/ Room Atmospheric pressure [hectoPascal]
	Wheather conditions (i.e. wind speed, wind direction, rain volume, snow volume and visibility)

The main components of SMART BEAR cloud are the database and its underlying information model, the clinical

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repository interfaces, the big data engine, the synthetic data generation element, and the analytics. Therefore, a strong semantic underpinning and a standards-based data representation with comprehensive and homogeneous datasets are leveraged to ensure efficient use of data for implementing high-quality and personalized interventions improving QoL. In particular, the HL7 FHIR standard is used to provide the specification of the data model, and FHIR resource profiles are employed to define constraints and extensions to the FHIR model capturing the required information in a standard structure and with rich semantics. A federated and active learning approach is applied for the analytics since it allows training algorithms across multiple systems or devices holding local datasets without the need of exchanging data. That ML approach allows preserving data privacy while enjoying large-scale aggregation benefit. Moreover, it enables an optimization of local models while maintaining a high performance for the global model as asynchronous approach. Lastly, to ensure an accurate health monitoring and the consequent appropriateness of interventions provided by the platform, the quality of collected data is assessed in each training rounds and validation loops are introduced to detect any performance degradation and mitigate any performance drift.

V. SMART BEAR SCENARIOS & INTERVENTIONS

Based on the data gathered by personal and smart home devices, the cloud-level data analysis and the guidance of clinical staff, SB platform supports interventions that may help the management of every targeted medical condition. In particular:

HL. Interventions/notifications are aimed to *a*) increase the usage time of hearing aids (HA), *b*) obtain higher satisfaction with HA usage, and *c*) reduce the number of visits to the audiologist for HA fine-tuning.

CVDs. Interventions/notifications are aimed to *a*) increase the adherence to the therapy, *b*) improve older adult's outcomes and *c*) help in managing medical condition.

CIs. Interventions/notifications are aimed to *a*) meet the compliance with the clinician's recommendations (e.g., training time), *b*) assess factors that are likely to influence the progression of cognitive impairment, and *c*) improve older adult's outcomes as a result of interventions.

MHIs. Interventions/notifications are aimed to *a*) enhance user's motivation in physical activity, cognitive games and socializing, *b*) ensure a better compliance to daily activities, and *c*) improve older adult's outcomes and sleep parameters as a result of interventions.

BDs. Interventions/notifications are aimed to *a*) increase the adherence to the therapy and training, *b*) assess factors that are likely to influence the disease outcomes and the falling risk, and *c*) improve older adult's outcomes and as a result of interventions.

For every above medical condition, comorbidity and combination of them, existing medical guidelines and data stored in both FHIR and non-FHIR databases are considered, and clinician-driven interventions are generated by SB platform for each user individually. Such interventions, that may be adjusted based on the assessment of individual's actions in response to the treatment, are then transmitted via a security component to the older subject. The latter can access the own list of interventions through SMART BEAR mApp where, each intervention is displayed with its related medical conditions, priority level (i.e., Low, Medium, High), status (i.e., Active, Inactive), and notification text (e.g., "Repeat the measurement"). A version of the mApp is also available for the clinician that can thus insert new useful measurements, monitor the user's health status, and verify whether an intervention was successfully completed.

VI. CONCLUSIONS

In the era increasingly devoted to the promotion of "ageing well" and personalized medicine, SB platform represents a valuable tool to improve seniors' QoL. Firstly, this project will explore if the SB platform is an ideal tool for the continuous health monitoring of older adults with one or more than one medical conditions (e.g., HL, CVDs, CIs, MHIs, and BDs). Secondly, the SB project will plan and propose personalized interventions promoting an independent and healthy lifestyle. This is a project of Horizon 2020 that started in 2019 and is still ongoing. Therefore, all the results will be presented after the project's completion in 2023.

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REFERENCES

[1] R. Suzman and J. Beard, "Global health and aging", NIH Publ., vol. 1, no. 4, pp. 273-277. 2011.

[2] WHO, Active Aging: A Policy Framework, 2002.

[3] R.J. Scheidt, D.R. Humpherys, and J.B. Yorgason, "Successful aging: what's not to like?", J. Appl Gerontol, pp. 277-82, 1999.

[4] F. Sadoughi, A. Behmanesh, and N. Sayfouri, "Internet of things in medicine: A systematic mapping study", J. Biomed. Inform, pp. 103, 2020. doi: 10.1016/j.jbi.2020.103383

[5] S. V. P. Darcini, D. P. Isravel, and S. Silas, "A Comprehensive Review on the Emerging IoT-Cloud based Technologies for Smart Healthcare", pp. 606-611, 6th ICACCS, 2020.

[6] V. Bellandi, et al., "A design methodology for matching smart health requirements", CCPE, pp. 1–16, 2020.

[7] GBD Collaborators, "Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015". Lancet. pp. (388): 10053, 2016.

[8] B.R. Rutherford, K. Brewster, J.S. Golub, A.H. Kim, and S.P. Roose, "Sensation and Psychiatry: Linking Age-Related Hearing Loss to Late-Life Depression and Cognitive

Decline", American J. of Psychiatry, vol. 175, no. 3, pp. 215-224, 2018.

[9] WHO, CVDs Key Facts, 2017.

[10] M. Moryś, M. Pąchalska, J. Bellwon, and M. Gruchała, "Cognitive impairment, symptoms of depression, and health-related quality of life in patients with severe stable heart failure", Int J Clin Health Psychol, vol. 16, no. 3, pp. 230-238, 2016.

[11] F. Jessen et al., "A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease", Alzheimers Dement, vol. 1, no. 6, pp. 844-52, 2014.

[12] D.L. Sturnieks, R. St George, and S.R. Lord, "Balance disorders in the elderly", Neurophysiol Clin, vol. 38, no. 6, pp.467-78,20

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