Lecture Notes in Electrical Engineering 544

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Ambient Assisted Living

Italian Forum 2018

Springer

Lecture Notes in Electrical Engineering

Volume 544

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ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-3-030-05920-0 ISBN 978-3-030-05921-7 (eBook)
https://doi.org/10.1007/978-3-030-05921-7

Library of Congress Control Number: 2018962393

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Active and Assisted Living (AAL) has been recognized for its crucial role in determining the quality of life in the future of our society. This principle has been confirmed by such institutions as the European Commission, an organization that clearly sees AAL as the "fundamental block" in addressing the challenges of demographic changes, sustaining people in productive and healthy work, keeping people at home healthy, independent, and integrated, and improving the delivery of care where and when needed. These are very demanding challenges for which AAL can guarantee products and services that improve the quality of life for people in all phases of life, combining new technologies and social environments. Recent advances in a number of research areas have helped the vision of AAL to become a reality and have allowed integration of new AAL technologies into human lives in a way that will benefit all.

All these aspects were explored during the Ninth Italian Forum on Active and Assisted Living (ForItAAL), in July 2018, Lecce, Italy. It is one of the most important annual events for researchers, professionals, developers, policy-makers, producers, service providers, carriers, and end-user organizations working in the different fields of AAL, who present and disseminate results, skills, prototypes, products, and services. The book presents the refereed proceedings of the Forum and reviews the status of researches, technologies, and recent achievements on AAL. Different points of view, from research to practice, cover interdisciplinary topics, combine different knowledge, expertise, needs, and expectations, and thus offer a unique opportunity to all those directly or indirectly interested and involved

in the field of AAL. The book discusses the promises and possibilities of growth in AAL. It lays out paths to meet future challenges and will provide crucial guidance in the development of practical and efficient AAL systems for our current and future society.

Lecce, Italy

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Maria Renata Guarneri, Alfonso Mastropietro, Maurizio Caon, Laura Fernandez Maldonado, Francesco Furfari, Giuseppe Andreoni and Giovanna Rizzo

Abstract Ageing population is growing faster in EU. ICT can provide solutions for Active Ageing; however, the success of novel ICT solutions depends on the user perception of their efficacy to support toward health promotion and global wellness. In this context, the H2020 project NESTORE (Non-intrusive Empowering Solutions and Technologies for Older people to Retain Everyday life activity) will develop an innovative, multidimensional, personalised e-coaching system to support healthy ageing by: (1) Generating and sustaining motivation to take care of health; (2) Suggesting healthy nutrition and personalised physical and mental coaching, as well as

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A. Leone et al. (eds.), *Ambient Assisted Living*, Lecture Notes in Electrical Engineering 544, https://doi.org/10.1007/978-3-030-05921-7_1

social interaction, to prevent decline and preserve wellbeing. NESTORE started in September 2017 and will last three years. It involves 16 partners from 7 European countries.

Keywords Ageing · Virtual coach · ICT

1 Introduction

Due to longer life expectancy and the declining fertility rates, the proportion of people aged over 65 years is growing faster in most of the developed countries. Some forecasts suggest that the population of elderly people will almost double from 87.5 million in 2010 to 152.6 million in 2060 [1].

The emerging social aspect related to ageing population introduces some crucial challenges to society and healthcare systems. Without adequate adjustments, i.e. social, economic and demographic policies as well as changes in people's behaviours, the process can trigger certain negative consequences in the long term. In order to maximise the wellbeing of older people and to reduce the economic burden of their care, the health systems should promote "healthy ageing" as much as possible. Healthy ageing is a common word that represents a complex intervention because it tackles all the human domains: physical, metabolic, cognitive, social, etc. Thus, a multidomain, multifactorial system to promote proper healthy strategies has to be designed and NESTORE project aims at this integrated vision as we will explain below.

Furthermore, promoting healthy ageing could represent a strategic opportunity for the economic growth thanks to the higher spending capacity of older people (over € 3.000 billion for the population <65). The EU has focused its attention on the concept of "Silver Economy" which is driven by the rise of new consumer markets and by the need to improve the sustainability of public expenditure linked to ageing.

In this direction, the rapid development of the ICT, and in particular mobile technologies, offers an important opportunity for addressing the development of integrated solutions to support active and healthy ageing. The availability of new integrated ICT technologies and its widespread diffusion could contribute dramatically to the implementation of a sustainable silver economy. Moreover, ICT solutions allow, in an innovative manner, introducing the possibility of a new technological framework to re-design the healthcare system model.

In this context, the **project NESTORE** (Novel Empowering Solutions and Technologies for Older people to Retain Everyday life activities), funded by EU H2020 programme, was designed and developed [2].

The project aims at the development of an integrated solution, based on non-obtrusive interaction with the person, which will support healthy older people to sustain their healthy life by promoting personalised pathways to wellbeing. The personalised support will be provided by an intelligent e-coaching system, which leveraging monitoring technologies, social connectivity and gamification mechanics

are able to support older people to maintain independence by encouraging them to become co-producers of their wellness (patient empowerment) by:

- **generating self-awareness** (understanding risks associated with ageing),
- **enhancing and sustaining motivation to take care of their health** (solutions that support healthy lifestyles and are able to evolve as the person ages).
- **support the healthy ageing process** based on healthy nutrition and adequate physical and mental activity/exercise.

2 The Wellbeing Dimensions of NESTORE

Ageing is a multi-domain process. It involves the social, economic, physical, psychological and mental spheres and all these domains are strongly interconnected. Some crucial factors that affect the wellbeing and the quality of life of the subjects are the nutritional habits, physical activity, mental health and social capital.

Good nutrition plays a significant role in the wellbeing of healthy older people and in delaying and reducing the risk of contracting diseases. General dietary recommendations on what should be eaten are relevant and important for older people. They should, for example, not choose food that has a high salt or sugar content; they should choose soft fats instead of hard fats, choose food with good carbohydrates and large amounts of fibre, and prepare their food with as little cooking fat as possible. Other important dietary components include vitamin D and calcium, especially considering the high prevalence of osteoporosis and hip fractures.

Ageing can be related to **psychological and cognitive decline** [3]. Mental Health was defined by the WHO as "a state of wellbeing in which the individual realises his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community". In order to ensure a mentally healthy status, some interventions should be provided considering many aspects, such as participation in meaningful activities, strong personal relationships, physical health.

Ageing is characterised, among other things, by **motor function impairment** such as coordination difficulty, increased variability of movement, slowing of movement, and difficulties with balance and gait in comparison to young adults [4]. These deficits have a negative impact on the ability of older adults to perform activities of daily living and may result in social exclusion as well as in an increased risk of traumatic events (i.e. falls). Even if dysfunctions of the central and peripheral nervous systems are not involved, progressive and generalised loss of skeletal muscle mass and strength (sarcopenia) may play an important role [4]. Physical activity is believed to be the most effective of all interventions proposed to counteract skeletal muscle impairment in older adults, improving quality of life and functionality [5, 6].

Another important aspect is the preservation of the social capital provided by older people. The socio-economic status, social integration and high personal competencies are related to higher subjective wellbeing. The quality of the **social contacts**

is, as well, an important factor to consider for a better wellbeing [7]. Moreover, the voluntary work, as well as the educational and social activity group interventions, can improve the mental health and prevent social isolation and loneliness among the older people.

3 Scope of NESTORE and Key Innovations

NESTORE proposes the development of a multi-dimensional system that covers all main domains affected by the ageing process, able to provide services, applications and a rewarding system to support active and healthy ageing with a user-centred approach.

While leveraging the state-of-the-art technologies, the innovation brought about by NESTORE relies, first, on its integration capacity. We can see NESTORE according to different perspectives:

1. As a platform, providing a set of basic services that can be leveraged by different apps, potentially offered by different stakeholders;
2. As a companion, offering personal and personalised support according to the user needs and interests;
3. As a social support, easing communication with family and friends as well as with carers, but also able to propose external service offerings based on "group" interests.

The main outcome of NESTORE is an e-coaching system [8], which may be implemented through a dedicated mobile App and also embodied in a smart object offering tangible interfaces in relation to the user's preferences. This e-coach will suggest and guide the user toward different "wellbeing pathways" providing tailored interventions exploiting personalised preferences and capabilities. The target population will include "fit older people" (i.e. good physical performance and low risk of near-future disabilities).

Key innovation element is the development of a multi-domain "cloud-based intelligence" able to interpret different signals coming from an extensive sensing system, to provide feedback that is meaningful, timely and relevant to the user. The effectiveness of the feedback will be assured by the adoption of well-assessed psychological developmental regulation and health behaviour change models, such as the SOC model [9] and the Health HAPA approach [10]. Emotion analysis and recognition, emotional computing, tangible and affective interfaces, will be used to ensure user engagement with the e-coaching system. According to such models, we have developed the concept of "pathways of interest" able to provide hints, suggestions and services according to the user's elective preferences while ensuring that all the five dimensions of wellbeing are satisfied to maximise the overall health status.

The coaching on the different pathways will be supported by different techniques, leveraging multimodal communication in order to provide an engaging and playful user experience: (1) natural dialogue with the user; (2) tangible interfaces for self-reflection and behaviour change; (3) social and environmental support through the social platform; (4) serious games and gamification; (5) apps for self-monitoring.

From the user point of view, NESTORE can be seen according to two different perspectives: friend and coach.

As a friend, NESTORE fully understands the emotional status and the wishes of the user; it is able to establish a personal and long-lasting relationship with the user interacting in a natural way.

As a coach, NESTORE understands the "weaknesses" of the user and proposes actions and activities that compensate shortcomings, re-establishing a status of well-being and maintaining such status in time. NESTORE is a ubiquitous conversational agent acting as a caring coach that will interact with the user assuming many forms, will use different modalities (voice, text, apps, tangible interfaces), and will be adapted to the user's preferences and to the contextual information.

In order to ensure user acceptance of the e-coaching system, co-design and participatory approaches will be adopted and used throughout the project duration. Such tools and methods will seek to engage and elicit information related to perception, acceptance and usability of technology to support healthcare and wellbeing.

4 The NESTORE Methodological Approach and Validation

The NESTORE scientific and technical approach is modelled around two guiding principles: (i) combining agility and structure and (ii), adopting Co-Design and UCD (User-Centred Design) as methodological approaches for the overall definition of the NESTORE solution [11].

i. *Agility and structure*. NESTORE is driven by a combination of Agile Development methods and techniques with the structure necessary to a large and distributed collaboration effort.
ii. *Adoption of Co-Design and UCD*. NESTORE methodology incorporates the overarching principle of having users as active, participating actors in the project in the typical approach of UCD.

This general approach has been translated into the following strategic planning choices:

1. The iterative process structured along major milestones is enriched by intermediate working releases (with varying, incremental set of features);
2. The system architecture development is linked to the integration work in which all the different modules and elements are made available for technical and users' short or long-time evaluations. The NESTORE Integration strategy is entrusted also with the mission of maintaining a unifying technology view;

3. The user point of view is championed and maintained through a co-design approach that will be adopted for the definition of the system requirements and for the user testing that will be performed by means of small-scale pilots;
4. Agility steers the work by avoiding a once-in-a-time, "big design upfront" effort, and making instead service design a continuous task in the project lifetime, to guarantee that technological innovations and user feedback are effectively translated in the NESTORE features;
5. Scenarios and requirements will be used as flexible design tools. From the business and end-users point of view, NESTORE will work with mock-ups and working prototypes.

The strategic planning choices listed above strongly shape the scientific and technical approach followed by the project. The structure of the project has been designed to satisfy the above principles with technical work-packages working in close cooperation, guided by a set of user-based requirements that are implemented in an incremental manner and verified with the users in a continuous cycle. The NESTORE structure has been organised according to the workflow described and depicted below:

Requirements Definition, for defining the functional requirements taking into accounts the ageing process.

Iterative Design of NESTORE Solution, for providing the user point of view and refine requirements according to a co-design methodology.

This will guide the:

Development of NESTORE platform and components: this work is organised according to three lines of research: (i) the "passive" sensing system based on wearable sensor technologies and environmental sensors, (ii) the interpretation and reasoning algorithms, and (iii) the user interface at large, the interaction with the virtual coach and the engagement of the users via a social platform as well as series of serious games.

The above components will be brought together through the:

– **Integration of the NESTORE System** that will provide the overall technical solution for the provision of the user services (see Fig. 1),
– **Evaluation and User Feedback**: this phase will generate insights about the service value from the user point of view and will feedback in a new updated loop.

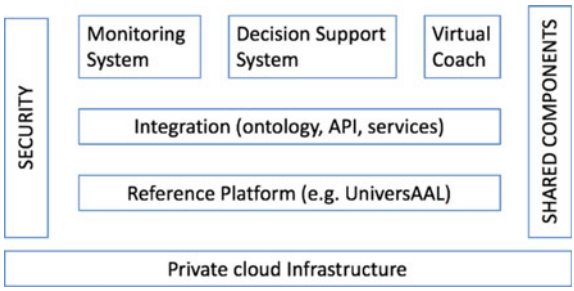

Fig. 1 Integration architecture

The integrated system will be tested in three pilot sites (Italy, Spain and The Netherland).

The piloting test will evaluate the *usability, sensors and devices functionality, and overall user acceptance*. In particular, experience of the participants with the system will be evaluated, considering different aspects such as: **quality of technology** (efficiency, effectiveness, usefulness, completeness and accuracy), **reliability of the system** (reliability, security, interoperability and ease of repair and maintenance), **usability and acceptance** (ease of use, graphic design acceptance, user satisfaction, navigation, user control, time, user experience, mental effort, support, learning and acceptance), **use of monitoring** (frequency, modus operandi, user profile, context in the platform's use), **problem solving** (useful alerts, false alarms, emergency calls, quality life improvement, isolation problems solution, cognitive stimulation and physical activity motivation).

In the pilots, the *efficacy of the system will also be evaluated in each one of the wellbeing domains* (physical-physiological, nutritional, cognitive, mental, social) included in NESTORE: validated clinical measurements, like additional questionnaires, medical imaging and signals, clinical geriatric evaluation in supervised sessions, will be considered to provide quantitative metrics of validations on:

- Physiological status and physical activity behaviour (Sedentariness, muscle strength and cardiorespiratory fitness, sleep quality, and active physical behaviour);
- Nutritional behaviour (quality of diet and quantity of food)
- Cognitive function (memory, processing speed, reaction time, verbal fluency)
- Mental status and social behaviour (depressive symptoms, life satisfaction, social relation and integration).

Some complementary measurements will help to provide information on possible positive effects on the body produced by using the NESTORE platform.

Moreover, *techno-economics will be evaluated*, as well as the feasibility of different organisational and business models aimed at achieving the sustainability of the NESTORE solution.

5 Cost-Effectiveness and Sustainability of NESTORE

Past literature pointed out that the interventions addressed to increase the awareness about physical-physiological, nutritional, cognitive, mental and social conditions of 60+ citizens are cost-effective from the national healthcare system perspective: indeed, they allow, for instance, to reduce the number of avoidable hospitalisations and drug consumption as well as to improve the management of chronic diseases and citizens' quality of life.

According to this perspective, the Pilots will gather evidence on the fact that the NESTORE technological solutions enable citizens/users to improve their conditions (physical, cognitive, mental and social) as well as their behaviours (e.g. eating habits,

etc.). With regard to the effectiveness, the focus will be also on the wellbeing as well as on users' empowerment, health literacy and capability of self-care. Indeed, regardless of the IT literacy, NESTORE is expected to improve all these aspects.

The necessary condition for generating cost-effective impacts on the system will be the effective usage of NESTORE solutions by the citizens/users.

Past studies highlighted that most of the technological solutions aimed at maintaining lifestyle and supporting self-care and care management are not used regularly by users/citizens and thus their results fall far behind their promises or what measured in 'Lab' contexts. The main reasons, as known, are two: (i) they are not considered relevant/useful, (ii) they are not easy to use.

Considering this, the project will allow to test and assess with final users the perceived usefulness and the ease of use of the different NESTORE solutions in order to gather evidence on their actual usage; moreover, through qualitative and co-design approaches will be analysed the willingness of citizens to adopt these solutions in the long-term.

All data collected by the Pilots and during the co-design process will permit to assess the potential cost-effectiveness of NESTORE and its technological solutions compared to the current practices by means of a control group.

6 Conclusions

Within NESTORE, we attempt to support healthy ageing with an integrated, user-centred and non-obtrusive approach, tested in real-life environments, in order to achieve wide acceptance by the target users as well as to accelerate the digital innovation process. Therefore, we believe that this project has the potential of delivering sustainable innovation in the area of active and healthy ageing. Currently, the User's analysis was run and the matching among requirements from users, technology, and expert is running to provide the first version of the platform design.

Acknowledgements NESTORE is funded by the European Commission under the H2020 programme, GA769643. The authors wish to thank all the project partners for their contribution to the project.

The authors want to thank the NESTORE Consortium and in particular: Leonardo Angelini, Elena Mugellini (University of Applied Sciences and Arts of Western Switzerland, Switzerland); Simone Porcelli, Filippo Palumbo, Michele Girolami (Consiglio Nazionale delle Ricerche, Italy); Christina Roecke (University of Zurich, Switzerland); Josep Del Bas, Silvia Orte, Sebastian Idelsohn, Filip Velickovski (Fundació Eurecat, Spain); Martin Sykora (Loughborough University, United Kingdom); Petia Radeva (University of Barcellona, Spain); Emanuele Lettieri, Paolo Bertelè (Politecnico di Milano, Italy); Antoni Salvà (Fundació Salut i Envelliment, Spain); Estelle Huchet (AGE, Belgium); Giuseppe Baroni, Corrado Galzio, (Flextronics Design Srl, Italy); Ciprian Candea, Gabriela Candea (ROPARDO Srl, Romania); Paul Chamberlein, Claire Craig (Sheffield Hallam University, United Kingdom), Stephan Lukosch (Technische Universiteit Delft, The Netherlands).

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Multi-domain Model of Healthy Ageing: The Experience of the H2020 NESTORE Project

Alfonso Mastropietro, Christina Roecke, Simone Porcelli, Josep del Bas, Noemi Boquè, Laura Fernandez Maldonado and Giovanna Rizzo

Abstract Ageing is a complex multidimensional and multifactorial process associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan. With the aim of supporting healthy older adults in order to sustain their wellbeing and capacity to live independently, the NESTORE project was recently funded by the EU Commission. In order to take into account the complex interactions among different aspects involved in the ageing processes, a model of healthy ageing was developed in NESTORE. This model included three core dimensions related to older people wellbeing (Physical/Physiological, Nutritional, Cognitive/Mental/Social). The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: (i) the characterization of the

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A. Leone et al. (eds.), *Ambient Assisted Living*, Lecture Notes in Electrical Engineering 544, https://doi.org/10.1007/978-3-030-05921-7_2

older adults, (ii) the personalization of the coaching plans and (iii) the implementation of an effective ICT system.

Keywords Healthy ageing model · Multi-domain · NESTORE

1 Introduction

The European population aged 65 years and older is expected to increase from 17.4% to nearly 30% by 2060 [1] while the population of those aged 80 years and older is predicted to triple during the same period [2]. Ageing is associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan [3]. Importantly to note, despite many age-related changes and preconceptions of marked declines, many older adults in the early later adult decades are cognitively healthy [4]. In order to plan policies with the main goal of mitigating the effects of the increasing ageing population on the socio-economical system, the European Commission has identified **active and healthy ageing** as a major societal challenge common to all European countries.

In this context, the **NESTORE project** (Novel Empowering Solutions and Technologies for Older people to Retain Everyday life activities), which was recently funded by EU commission within the H2020 programme, was designed and proposed [5].

NESTORE aims at supporting healthy older adults in order to sustain their well-being and capacity to live independently by promoting personalized pathways to wellbeing. NESTORE's ambitious objective is to develop an innovative, **multi-dimensional**, cross-disciplinary and personalized **coaching system** that, leveraging ICT social connectivity, will support older adults by encouraging them to become co-producers of their wellness. NESTORE is a project that contemplates from early stages the end-user involvement to guarantee the reflection of real users' needs and preferences.

Since ageing is a complex multidimensional and multifactorial process, within the NESTORE project, a model of healthy ageing was developed. This model included three core dimensions related to well-being (Physical/Physiological, Nutritional, Cognitive/Mental/Social).

The NESTORE model of healthy ageing is described in detail in the next paragraphs.

2 NESTORE Model of Healthy Ageing

The NESTORE Model of Healthy Ageing was aimed at providing a structured knowledge, built on the expertise of the NESTORE experts (exercise physiologists, nutritionists, lifespan psychologists, geriatricians), able to characterize the person

in terms of both status and behaviour. In particular, the formalisation proposed in this paper is intended to provide organized information about healthy ageing-related domains that can be useful to support reasoning, to manage the information flow and to facilitate the interoperability between devices and platforms used to monitor older adults' status and behaviour. A similar descriptive model has been adopted in a previous European project aimed at counteracting obesity in young people [6], in order to provide structured information and ontological representation of physical/psychosocial/behavioural characteristics of the target user [7].

In NESTORE, the final user is an older adult (65–75) living an autonomous life and interested in maintaining or promoting her/his wellbeing and quality of life, without any clinically relevant impairment and/or pathology.

Based on this user definition, the model adopts a multi-domain classification, which includes: **Physiological Status and Physical Activity Behaviour, Nutrition, Cognitive and Mental Status and Social Behaviour**. For each domain, the model includes:

(a) The definition of the domain variables that are useful for the characterization and monitoring of the person.
(b) The relationships among the domain variables taking into account: (1) the direct causal relationships; (2) the indirect causal relationships; (3) the correlations between 2 variables; (4) the mathematical expressions for derived variables.

The development of a structured model was specifically thought to support the development of the NESTORE ontology and also for profiling activities and, consequently, for the personalization of coaching activities.

The characterization of a subject using such a holistic approach is aimed at improving the engagement of the users since it is helpful for a more effective implementation of the Selective Optimization with Compensation (SOC) [8] and Health Action Process Approach (HAPA) [9] models that will guide the NESTORE coaching system.

3 Physiological Status and Physical Activity Behaviour

With advancing age, structural and functional decline occurs in most physiological systems, even in the absence of evident disease. These age-related physiological changes involve a broad range of tissues, organ systems, and functions, which, cumulatively, can affect activities of daily living and the preservation of physical independence in older adults [10].

In NESTORE, the characterization of the physiological status of the subjects was structured in four subdomains: (1) **Anthropometric Characteristics** containing the main anthropometric variables describing body dimensions; (2) **Cardiovascular System**, which contains the main physiological variables that influence transport of nutrients, oxygen, carbon dioxide, hormones, and blood cells from the lungs to peripheral tissue and vice versa; (3) **Respiratory System**, containing the main physiological variables related to structure and function of the organs designated

Table 1 List of variables included in physical activity behaviour subdomain which is part of the physiological status and physical activity behaviour domain

Subdomain	Physical activity behaviour
Variables	Distance, exercise duration, exercise intensity, exercise type (cardiorespiratory, muscle strengthening, balance, flexibility), exercise frequency, fatigue accumulation, grade, activity energy expenditure, rate of perceived exertion, sedentariness, speed, steps (number of steps, stride), upper limb movements

to exchange blood gases between ambient air and blood cells; (4) **Musculoskeletal System**, which contains the key physiological variables related to the ability of skeletal muscle to generate force and power.

Moreover, a description of the variables describing the ability of a subject to perform exercise limited from the cardiorespiratory system (**Cardiorespiratory Exercise Capacity**) or musculoskeletal system (**Strength-Balance-Flexibility Exercise Capacity**) as well as the usual behaviour of a subject during every-day life (**Physical activity Behaviour**) was also included in the model. Finally, a description of the main factors related to sleep (**Sleep Quality**) was also included in this specific domain.

An example of a list of variables, included in the Physical Activity Behaviour subdomain, is reported in Table 1, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 1.

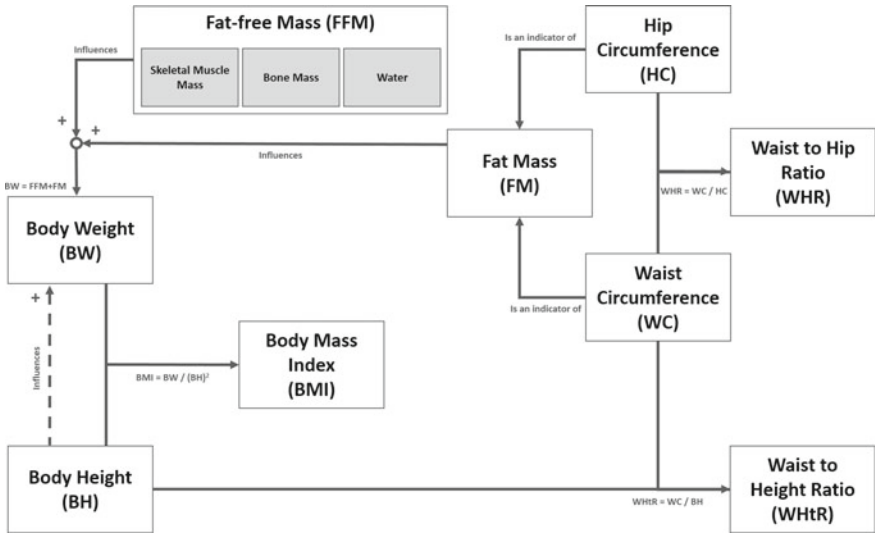

Fig. 1 Relationships among variables in the physical behaviour subdomain

Table 2 List of variables included in the anthropometric characteristics subdomain which is part of the nutrition domain

Subdomain	Anthropometric characteristics
Variables	Body height, body weight, body mass index, fat mass, fat-free mass, hip circumference, waist circumference, waist to hip ratio, waist to height ratio

4 Nutrition

Nutrition is an important element of health among older adults since it affects the whole process of ageing. The prevalence of malnutrition increases in older adults and it is associated with a decline in functional status, impaired muscle function, decreased bone mass, immune dysfunction, anaemia, reduced cognitive function and mortality [11]. Moreover, there are notable alterations related to ageing, such as body composition remodelling and metabolic dysregulation, which could be nutritionally managed.

In NESTORE, the nutrition domain was organized into four subdomains: (1) **Anthropometric Characteristics**, which is in common with the Physiological domain; (2) **Blood Parameters** which contain 3 crucial metabolic risk factors (glucose, cholesterol and triglycerides) for highly prevalent pathologies in aged adults like diabetes and cardiovascular disease; (3) **Energy Balance** which describes the components implicated in human energetic balance, a key factor for the regulation of body weight, mainly energy expenditure and energy intake; (4) **Nutrition Habits** which describes variables directly related to the study of a subject's dietary habits, including nutrient intakes.

An example of a list of variables, included in the Anthropometric Characteristics subdomain, is reported in Table 2, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 2.

5 Cognitive and Mental Status and Social Behaviour

Ageing is often associated with a decline in mental capabilities including biologically-driven cognitive domains such as memory, executive functions, processing speed and reasoning. These skills compose the so called fluid intelligence and are important for carrying out everyday activities and for retaining an independent life [12, 13].

At the same time, social and emotional experiences partly change and partly remain relatively intact with increasing age. In particular, social networks become smaller overall while remaining relatively stable in terms of the number of emotionally close others, the emotions experienced by the persons in day-to-day life tend to be more stable, and overall subjective well-being is well-maintained. In addition, social roles change quantitatively and qualitatively [14].

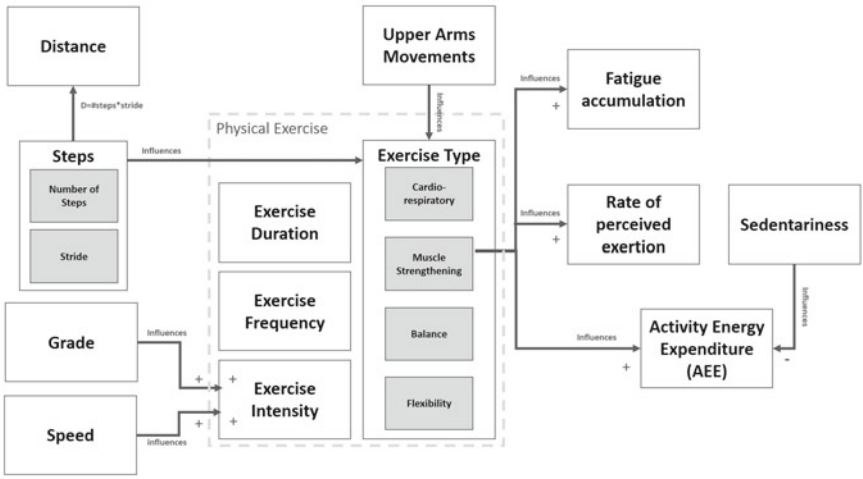

Fig. 2 Relationships among variables in the anthropometric characteristics subdomain

In NESTORE, this complex domain was composed of four subdomains: (1) **Cognitive Status** which describes a range of intelligence domains that describe biologically- and experience-/knowledge-driven facets of cognition and intelligence, (2) **Mental Status**, including traits of psychological functioning in the area of subjective well-being, self and personality and social integration/feelings of loneliness. The two domains of status or trait variables will allow describing a dispositional profile of a person's general resources in the cognitive and mental domain. These will be complemented by (3) **Mental Behaviour and States**, which capture the within-person processes mainly in emotional functioning that are observable in daily life on the basis of self-reported experiences and as information extracted from text bodies and speech, and (4) **Social Behaviour** which analyses the social context of the users involved in the studies and in using the NESTORE system. The social behaviour analysis aims at measuring both qualitatively and quantitatively some core variables describing the social behaviour of users in terms of (a) existence of social interactions through self-reported diaries and with sensing devices, (b) the number and duration of such interactions, and (c) possibly, the location of the interactions.

An example of a list of variables, included in the Cognitive and Mental Status and Social Behaviour subdomain, is reported in Table 3, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 3.

Table 3 List of variables included in the mental status subdomain which is part of the cognitive and mental status and social behaviour domain

Subdomain	Mental status (psychological functioning)
Variables	Personality (extraversion, agreeableness, openness to experience, conscientiousness, neuroticism, control beliefs, self-efficacy), social network/integration (quantity, quality, loneliness, support), subjective well-being (life satisfaction, positive affective states, negative affective states)

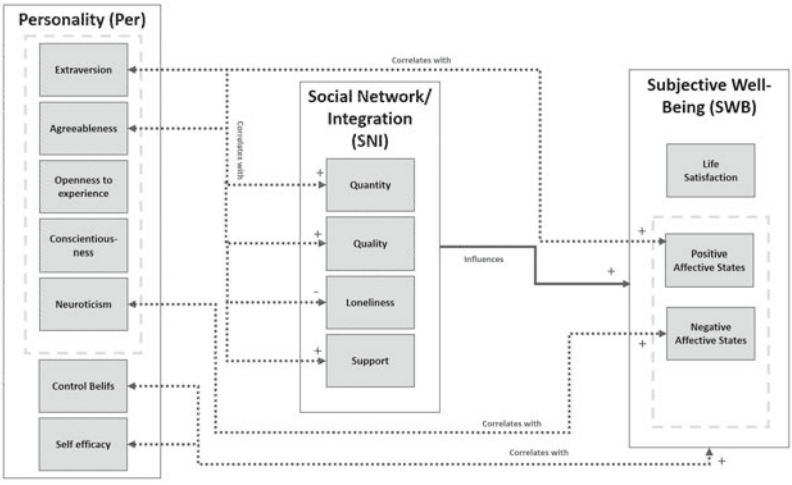

Fig. 3 Relationships among variables in the mental status (psychological functioning) subdomain

6 NESTORE Healthy Ageing Model Outcomes

The knowledge integration model presented in this paper is mainly intended as a necessary **preliminary step** to provide a wide-ranging semantic representation of the ageing subject profiles. In this context, this model will be useful **to support specific inference within a comprehensive ontology model** of the healthy ageing-related knowledge that will be implemented in NESTORE.

The NESTORE model of healthy ageing provides the list of variables, their relationships (intra- and inter-domain), the range of normality of each variable and the measurement scenarios that represent the basic foundation of the NESTORE technological implementation and of the system intelligence.

In particular, the proposed approach has a direct effect on:

- **System Requirements**. Wearable and environmental sensors and devices, composing the monitoring system, will be selected according to the variables included in the model.
- **System Intelligence**. The decision support system will be developed according to the variables relationships and ranges reported within the model.

- **Coaching Plans Definition**. The coaching activities in physical, nutrition, cognitive and social domains are designed and tailored to the subjects profiles taking into account the information provided by the integrated knowledge.
- **Pilot Studies**. The efficacy of the system will also be evaluated in each one of the well-being domains included in NESTORE: validated clinical measurements in each health domain will be definitely defined according to the model.

7 Conclusions

The NESTORE model of Healthy Ageing is the outcome of a prolific multidisciplinary cooperation and convergence among experts belonging to different scientific fields. The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: (i) the characterization of the older adults, (ii) the personalization of the coaching plans and (iii) the implementation of an effective ICT system.

Acknowledgements NESTORE is co-funded by the European Commission under the H2020 program, GA769643. The authors wish to thank all partners involved in the WP2 activities of NESTORE. In particular, the authors desire to thank Antoni Salvà (Fundació Salut i Envelliment, Universitat Autònoma de Barcelona), Filippo Palumbo (Consiglio Nazionale delle Ricerche), Michele Girolami (Consiglio Nazionale delle Ricerche) and Martin Sykora (University of Loughborough, Centre for Information Management).

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