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ORIGINAL RESEARCH

Internet of things for remote elderly monitoring: a study from user-centered perspective

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Abstract Improvements in life expectancy achieved by technological advancements in the recent decades have increased the proportion of elderly people. Frailty of old age, susceptibility to diseases, and impairments are inevitable issues that these senior adults need to deal with in daily life. Recently, there has been an increasing demand on developing elderly care services utilizing novel technologies, with the aim of providing independent living. Internet of things (IoT), as an advanced paradigm to connect physical and virtual things for enhanced services, has been introduced that can provide significant improvements in remote elderly monitoring. Several efforts have been recently devoted to address elderly care requirements utilizing IoT-based systems. Nevertheless, there still exists a lack of user-centered study from an all-inclusive perspective for investigating the daily needs of senior adults. In this paper, we study the IoT-enabled systems tackling elderly monitoring to categorize the existing approaches from a new perspective and to introduce a hierarchical model for elderly-centered monitoring. We investigate the existing approaches by considering the elderly requirements at the center of the attention. In addition, we evaluate the main objectives and trends in IoT-based elderly monitoring systems in order to pave the way for future systems to improve the quality of elderly's life.

Keywords Internet of things · Elderly care · Remote elderly monitoring · Healthcare and well-being

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1 Introduction

Thanks to the developments in the medical science and related technologies, the world life expectancy index has been increased for the last decades, and has been projected to further increase in the future (WHO 2014). Subsequently, the number of elderly people will grow with a rapid rate (see Fig. 1). Senior adults require more attention and care as a minor accident or an insignificant disease may cause irreparable damages (WHO/Europe 2015). It should be also considered that many senior adults may live alone whereas it is necessary to be monitored or assisted by caregivers or medical experts. Therefore, there exists an increasing demand for developing novel technologies to provide efficient remote elderly monitoring services. To this end, various modern disciplines should be utilized to address the elderly requirements considering their limitations in daily life. Internet of things (IoT) as a promising paradigm can provide such essential services for elderly adults (Dohr et al. 2010; Huaxin et al. 2012).

IoT is an advanced technology exploiting various disciplines such as sensor development, data acquisition, communication and networking, data management and data processing, etc. where things (e.g., objects, people) with unique identities are able to connect to a remote server and also to form local networks (Atzori et al. 2010). The

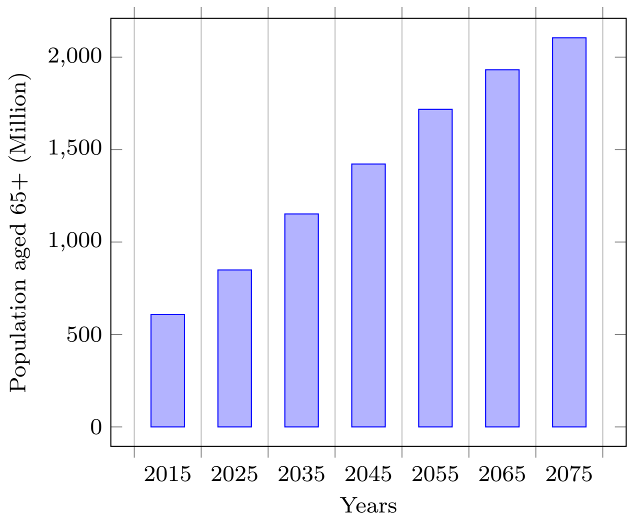

Fig. 1 Projection of world population of elderly (65+). Probabilistic population projections by United Nations (2015)

connectivity in IoT-based systems enables objects to exchange and fuse data to achieve a more comprehensive knowledge regarding their functionality as well as properties of the surrounding environments, thus, offering more enhanced, intelligent and efficient services. One of the main features of the IoT technologies is to facilitate improving the quality of life by enabling continuous (i.e., 24/7) remote monitoring systems (Niyato et al. 2009; Ray 2014).

There exist several efforts to utilize IoT-based system for elderly monitoring and care, most of which target only certain aspects of elderly requirements from a limited viewpoint (e.g, health monitoring, safety monitoring, etc.). Considering the significance of remote elderly monitoring and the variety of potential services that such systems can offer, there still exists a lack of a user-centered study. A user-centered design utilizes multiple sources to introduce a system focusing on the capabilities, requirements and abilities of the users (Ritter et al. 2014). Hence, it is essential to consider the existing monitoring systems for senior adults from a user-centered perspective, and discuss deployment challenges of monitoring applications from an all-inclusive top view.

In this paper, we study and classify the existing literature from an elderly-centered perspective to develop a comprehensive mindset on the area and evaluate the future trends. We discuss the current challenges from a different standpoint and present potential services offered by IoT technologies. Our study paves the way for future works in a new perspective to improve the quality of life of elderly people.

The rest of the paper is as follow: in Sect. 2, we present the significance and the motivation of this research. The methodology is described in Sect. 3. A common architecture of IoT-based systems is discussed in Sect. 4. In Sect. 5, we investigate the existing approaches in the context of remote elderly monitoring from a user-centered viewpoint. In Sect. 6, we classify the presented efforts, summarize their pros and cons, and illustrate the differences. In addition, we discuss the main objectives that IoT-based systems should seek in their implementation. Finally, Sect. 7 concludes the paper.

2 Significance and motivation

One of the profound applications of IoT-based remote monitoring systems is for addressing the requirements of elderly people. Frailty of old age, on one hand, makes elderly more susceptible to several diseases (both acute and chronic), impairments (e.g., visual, physical and speech), and weaknesses (e.g., forgetfulness), and on the other hand increases the likelihood of lacking awareness (e.g., computer illiteracy). Therefore, neglecting the importance of elderly care may result in a higher level of elderly's dependency or force them to live in a nursing home. In this context, IoT-based remote elderly monitoring can provide services to address the aforementioned issues, to mitigate the inevitable consequences, and to enable them to live independently.

Several related work in the literature have focused on IoT-based elderly care to provide a variety of monitoring services, however this field is still at infancy as many requirements and problems have not yet been tackled; E.g., the essentials of user-centered system design for elderly monitoring and development of multipurpose systems to monitor a large group of users in order to detect (or predict) patterns or situations that may happen to elderly people such as epidemic diseases. Considering the literature on remote monitoring systems, many shortcomings still exist. Some contributions are too focused in the sense that they only address a single requirement of elderly. For examples, a care system for dementia is presented by Lin et al. (2006), while in-home water sensor-based monitoring and home monitoring systems with Android phones are investigated by Tsukiyama (2015) and Lee et al. (2013), respectively. In addition, there are some studies which investigate the elderly monitoring systems based on a certain aspect (e.g., health-based, activity-based, location-based, etc.). For instance, Memon et al. (2014) provide a survey on healthcare frameworks and platforms of ambient assisted living. Similarly, smart house technologies for elderly and disabled people are investigated by Stefanov et al. (2004). Gokalp and Clarke (2013) study contributions on monitoring of daily living activities of elderly people, while Hamdi et al. (2014) classify elderly related monitoring according to use case (e.g., rehabilitation telemonitoring and chronic diseases telemonitoring). From a similar viewpoint, Lattanzio et al. (2014) investigates care systems for elderly health and well-being in Italy, which is geographically restricted.

In contrast to the aforementioned contributions, we consider a comprehensive monitoring framework for elderly people to satisfy their daily lives' requirements. The motivation behind our study is to investigate the existing IoT-based elderly monitoring systems from a wider viewpoint by considering the user at the center of the system, to identify the challenges in developing such systems, and to evaluate the current and future trends. The main contributions of this study is as follows:

- Investigating the existing literature from a different angle.
- Developing a comprehensive perspective on the area.
- Evaluating the future trends in IoT-enabled elderly monitoring systems.

3 Methodology

In order to fulfill the aims of this study, a systematic search process was conducted through the following sources.

I. *Digital Libraries* The digital libraries used in this research include IEEEXplore, SpringerLink, ACM DL, Scopus and Pubmed. In this manner, query syntaxes containing "elderly", "Internet of Things", "remote monitoring" and Boolean operators (i.e., "OR" and "AND") were utilized. Out of the obtained results, we selected the related work which: (1) address elderly problems, (2) target remote monitoring, and (3) include or relate to IoT technologies.

II. *Research Programs* We studied recent projects which have been funded from 2009 to 2015 by research programs and agencies including AAL,[1] FP7,[2] H2020,[3] NCI[4] and ECSEL.[5] The accomplished or ongoing IoT based elderly monitoring projects have been chosen. Then, their associated articles, technical reports, etc. have been studied in order to investigate their proposed procedures, features, and goals. The state-of-the-art projects proposed for elderly monitoring complement this study and can help indicating the current and future trends in this field.

4 IoT-based system architecture

IoT is a rapidly growing paradigm which has the potential to profoundly affect many aspects of human life by connecting objects and people. Based on the features and functionalists of IoT-based system (data collection, transmission, and analysis), the system architecture can be partitioned into 3 layers as proposed by Touati and Tabish (2013). However, architecture of an IoT-enabled system can be redefined with respect to its use cases. As shown in Fig. 2, in our case, to address the requirements of elderly monitoring, the system is defined as follows:

The first layer named as the *perception layer* is the closest tier to the person under monitoring. The main purpose of the perception layer is to collect required data from user and to interplay with the higher layers. As illustrated in Fig. 2, the perception layer can be divided into two categories: body area network (BAN) and fixed/mobile devices in the proximity. BAN which includes on-body and implantable devices can be a network of vital signs accessories (e.g., chest straps, pulse oximeters and blood pressure monitor) or smart wearable devices (e.g., smartwatch, fitness tracker and smart hat) which are in charge of obtaining user's status. Medical parameters including vital signs (e.g., heart rate and respiration rate), blood glucose level, galvanic skin response (GSR), etc. and activity specifications like position, activity level and sleep level are collected using such devices. Fixed context devices are in the second category which are often installed in the home or other public places (e.g., surveillance camera, Smart TV, etc.). Mobile context devices are also used to sense environmental parameters and to response based on the situation. Robots of different kinds can fit in this category.

Gateway layer is at the second tier. It receives sensory data from the perception layer via wired or wireless communication protocols (e.g., Bluetooth, 6LoWPAN and Zigbee) and then transmits the data to the Cloud layer for further analysis. In Fig. 2, the layer is divided into two types. The first one is dedicated to fixed access points which are installed in elderly home for indoor data transmission. The second type is mobile access point utilized for outdoor requirements. Smartphone is a typical example of a mobile access point which is capable of implementing data transmission and processing.

The *Cloud* is the third layer. This is a remote layer located in the data center. As depicted in Fig. 2, the Cloud layer consists of various sections. Heterogeneous incoming

[1] http://www.aal-europe.eu.
[2] http://cordis.europa.eu/fp7.
[3] https://ec.europa.eu/programmes/horizon2020.
[4] http://www.cancer.gov.
[5] http://www.ecsel-ju.eu.

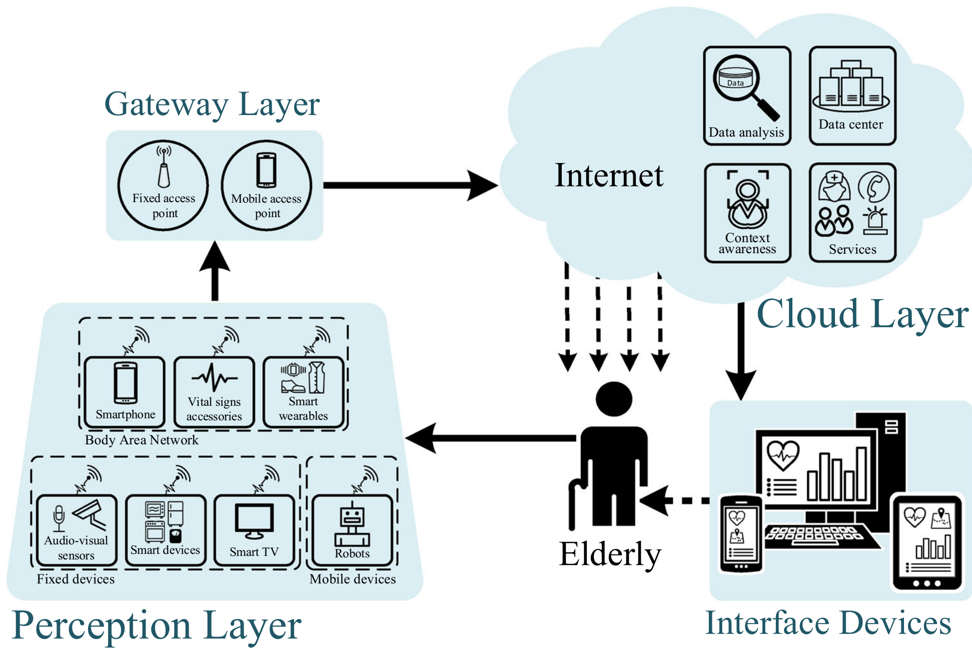

Fig. 2 A multi-layer IoT-based elderly monitoring system architecture

data is stored in data centers to be analysed by utilising high processing power at the Cloud. The data analysis includes reasoning (Russell and Norvig 2013), machine learning algorithms (Murphy 2012), pattern recognition methods (Bishop 2006), etc. Based on the obtained results, decisions and responses are made to efficiently react with respect to the elderly requirements. These back-end applications can provide behavioral changes detection such as Mild Cognitive Impairment (MCI) detection in elderly (Akl et al. 2015) as well as predicting chronic diseases, e.g. blood glucose concentration prediction for a person with diabetes (Zecchin et al. 2014) and acute diseases prediction including cardiac arrest prediction (Liu et al. 2012). Furthermore, various applications and services such as mobile user interface can be offered to transmit the results to end-users, e.g. monitored person, caregivers and medical experts.

System security plays also an important role in IoT based systems especially in the remote elderly monitoring systems where senior adults' privacy and trust should be preserved. According to the three tiers architecture of the system, the potential security issues can be considered in three parts (Yang et al. 2012). The first part includes the perception layer in which the sensor nodes without a security policy may be attacked. The second part is related to the Gateway layer which has a strategic bridging position of delivering the data to the cloud or sending commands to sensor nodes. Many adversaries target these Internet-connected gateways to attack. At the gateways, unauthorized access or damage to the data transmission causes critical security problems for the system. Finally, the third part targets the Cloud issues. The Cloud including data centers contains all of the history and collected data of the monitored people and their environments, so a data breach may cause irreversible damages for the individuals and the system. Therefore, satisfying security requirements such as data authenticity, data confidentiality and access control are essentials in IoT-based systems (Sicari et al. 2015). In this regard, various models or schemes have been introduced to ensure security in the IoT-based systems; e.g., Vucinic et al. (2015) propose a model (OSCAR) for end-to-end security in the IoT systems, Moosavi et al. (2016) also present an end-to-end security scheme for mobility enabled healthcare IoT systems and Neisse et al. (2015) offer a model to provide security for data protection in IoT systems.

5 Elderly-centered IoT-based remote monitoring

Taking into account the projected high rate of elderly population growth (see Fig. 1) in the near future, it is essential to dedicate significant efforts to exploit advanced concepts and technologies such as IoT in the elderly care. A variety of solutions have been provided to address the elderly needs by compensating the deficiency or mitigating the inevitable consequences. Figure 3 demonstrates some of these existing solutions and services. With this intention, many small, medium, and large projects have also been lunched to tackle the elderly requirements with different objectives.

We investigate major IoT-based applications and services that have been thus far introduced for remote elderly

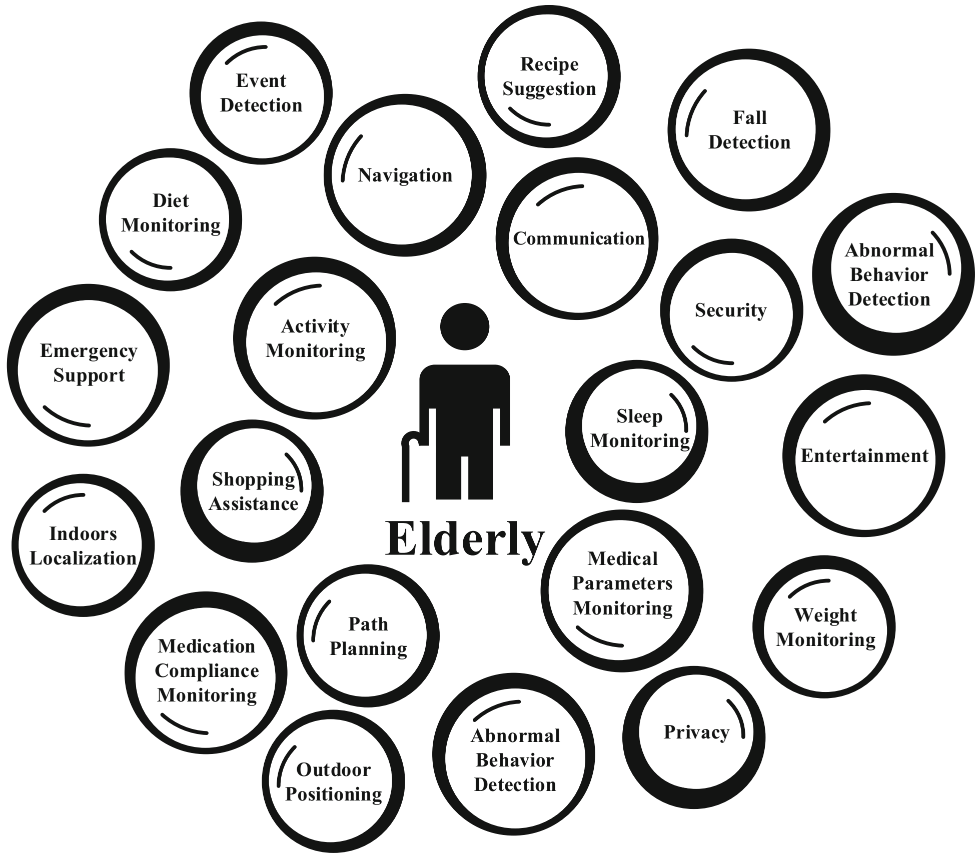

Fig. 3 Variety of applications and services proposed for remote elderly monitoring

monitoring. Due to the importance of monitoring in this context, we aim at studying such efforts from a different angle by considering elderly at the center of attention and classify different approaches with respect to their properties and benefits in daily life. In this manner, we categorise the applications and services of the approaches into five different sections: (1) health monitoring, (2) nutrition monitoring, (3) safety monitoring, (4) localization and navigation, and (5) social network, each of which is essential and includes some aspects of indoor and outdoor requirements.

Figure 4 demonstrates a general view of elderly daily life, IoT-based system architecture, and the advantages provided by the IoT technologies in different situations. The system offers remote monitoring applications as well as providing services such as reports (daily, monthly, etc.), suggestions and early alerts. It also shares the elderly information to the third party agents (i.e., caregivers, medical experts and emergency units), so they can intervene in case of emergency, suggest medical advices and provide supports. Moreover, the system is able to receive feedback from the third party agents in order to offer more personalization for the user and to improve the performance (e.g., system's sensitivity and specificity). In such systems, various issues such as data integrity, data authenticity and data confidentiality should be considered (Jara et al. 2013; Henze et al. 2016).

In the following, we study IoT related platforms and approaches by classifying them into five categories. It should be noted that some of these solutions lie in more than one category. This is also highlighted in Table 1. In addition, since various aspects of an approach may be introduced in different papers, a summary of which is provided in the related category and the associated papers are cited in the explanation. For instance, SAAPHO project along with its main associated publications (Rivero-Espinosa et al. 2013; Rafael-Palou et al. 2015; Ahmed et al. 2015) are introduced and explained in Sect. 5.1.

5.1 Health monitoring

According to the increased frailty and susceptibility to various diseases (e.g., acute and chronic diseases) in old age, health monitoring becomes the most important part of elderly remote monitoring. Remote health monitoring not only improves the quality of life of elderly people, and detects and notifies caregivers in the case of emergency, but also reduces nursing and hospital stays and subsequently healthcare costs. According to a report by the Agency for Healthcare Research and Quality

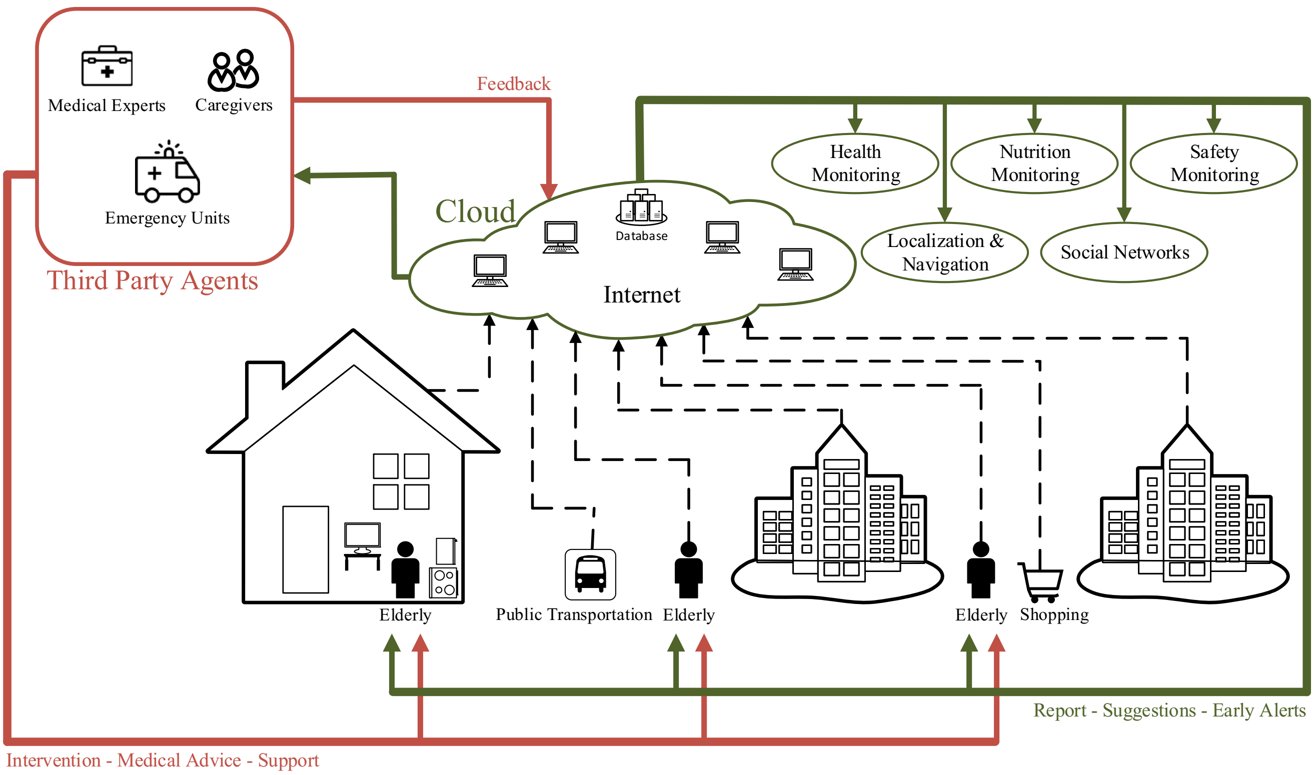

Fig. 4 An all-inclusive view of IoT-based remote elderly monitoring systems

(AHRQ) (Pfuntner et al. 2013), in 2011, more than one third of aggregate hospital costs and stays in the United States were spent for elderly people (see Fig. 5); Thus, it is essential to improve the care services and to reduce the hospital costs and stays of elderly people by providing remote health monitoring services at home. Furthermore, a significant number of senior citizens in the future may encounter with limited number of care and supportive services due to the reduction of potential supportive ratio $\left(\frac{Age25-64}{Age65+}\right)$ in the world (see Fig. 6) and the growing burden of aging associated diseases (and subsequently related costs) (WHO 2011).

We chose main health monitoring services with respect to requirements, diseases, and impairments of elderly people. As a significant part of a health monitoring system, the vital signs are collected and monitored in order to indicate a person's medical status. Early attempts on determining the medical status of a patient were implemented by obtaining four basic medical vital signs (i.e., temperature, pulse rate, respiratory rate and blood pressure) (Glaeser and Thomas Jr. 1975). Afterwards, more parameters were also added to the patient's condition evaluations. In 1997, a score system entitled Early Warning Score System (EWS) was introduced by Morgan et al. (1997). In the proposed EWS system, parameters such as respiration rate, heart rate, oxygen saturation and also level of consciousness are collected in order to predict patient deterioration in hospitals. In this regard, according to the possible serious medical condition that some elderly people might have, personalized EWS system is proposed to collect vital signs and to calculate the EWS scores in various conditions remotely (Anzanpour et al. 2015; Azimi et al. 2016). Moreover, in addition to vital signs, other medical parameters such as glucose and urine amount can be included to have a more comprehensive analysis.

In the same fashion, different approaches have been recently proposed to address remote health monitoring for elderly people. In SAAPHO project (Rivero-Espinosa et al. 2013), a system with an Android user-friendly platform is introduced to provide various aspects of elderly monitoring including health monitoring. It contains medical and activity monitoring parameters such as physical activity, blood pressure, glucose, medication compliance, pulse monitoring and weight. In this system, the data is transmitted via HTTPS and SOAP web services from the sensor layer to the Cloud. Then, after data analysis, the obtained results are transferred to the interface devices. Therefore, caregivers or medical experts can monitor the users by getting notified about emergency situations, historical summary (Rafael-Palou et al. 2015) and generated recommendations based on the recorded history data (Ahmed et al. 2015). Similarly, MOBISERV (Nani et al.

Table 1 A comparison among several approaches providing remote elderly monitoring

Project's name	Time period (years)	Health monitoring	Nutrition monitoring	Safety monitoring	Localization and Navigation	Social network	Other features
ALFRED	2013–2016	✓	–	–	–	✓	Physical and cognitive impairments prevention
ALICE	2010–2012	–	–	–	✓	–	Eligible for who are suffering from visual impairments
ASSAM	2012–2015	–	–	–	✓	–	Eligible for who are suffering from physical impairments
ASSISTANT	2012–2015	–	–	✓	✓	–	Mistake detection and classification Emergency situation notification
CaMeLi	2013–2015	–	–	✓	–	✓	Human-like virtual system Emergency situation notification Activity reminder
ChefMyself	2013–2015	✓	✓	–	–	✓	Includes a recipe library Shopping assistance
CONFIDENCE	2008–2011	–	–	✓	✓	–	Activities and postures recognition
DIET4Elders	2013–2016	✓	✓	–	–	✓	Daily activity monitoring and advice
EDLAH	2013–2015	–	✓	–	–	✓	Object location indicator Activity reminder
ELF@Home	2013–2016	✓	–	–	–	–	Elderly fitness monitoring
FEARLESS	2011–2014	–	–	✓	–	–	Emergency situation notification
GeTVivid	2013–2016	–	–	–	–	✓	A TV based system Public services (e.g. medical and shopping assistance, etc.) Activity reminder
HEREiAM	2013–2016	✓	–	✓	–	✓	A TV based system
Mobiserv	2009–2013	✓	✓	✓	–	✓	A personal robotic based system Nutrition habits monitoring
NITICS	2013–2015	✓	–	✓	✓	–	Emergency situation notification Object location indicator
SAAPHO	2011–2014	✓	–	✓	–	–	Generate advices w.r.t the recorded data Emergency situation notification
vAssist	2011–2014	✓	–	–	–	✓	Eligible for who are suffering from physical impairments Eligible for who have no computer literacy
WIISEL	2011–2015	✓	–	✓	–	–	Gait analysis Early identification of mobility

2010) as a multipurpose project, propose a system consists of a companion robot and wearable textiles (Faetti and Paradiso 2012). In this system, the elderly healthcare is addressed by monitoring medical parameters (e.g., ECG and vital signs) remotely.

Daily activity is another parameter representing the health status of elderly. The activities include physical activity level, the act of eating (i.e., number of meals per day and duration), sleeping, etc. For this purpose, several contributions have been proposed utilizing different methods and sensory data in order to offer activity monitoring for elderly people. Kasteren et al. (2010) present a system (within the CARE project) including wireless sensors and a recognition models to track and recognize activity level of elderly people. Moreover, Charlon et al. (2013) propose a telemetry system utilized in a combined trilateration method using a smart hat and smart shoes to accurately track indoor elderly activities. In the same category, a textile capacitive neckband is also proposed by Cheng et al. (2013) to detect daily activities such as eating and sleeping by monitoring head and neck movements. In addition, using vision sensors, Xiang et al.

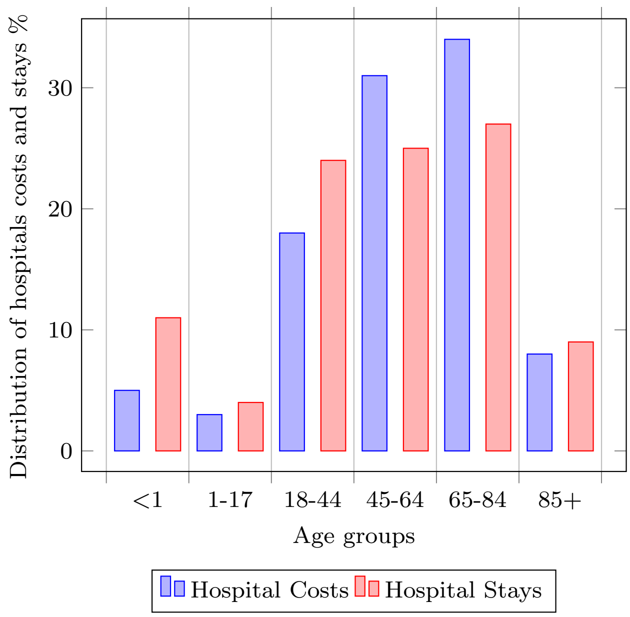

Fig. 5 Distribution of hospital costs and stays by age in the United States, 2011 provided by Agency for Healthcare Research and Quality (AHRQ) (Pfuntner et al. 2013)

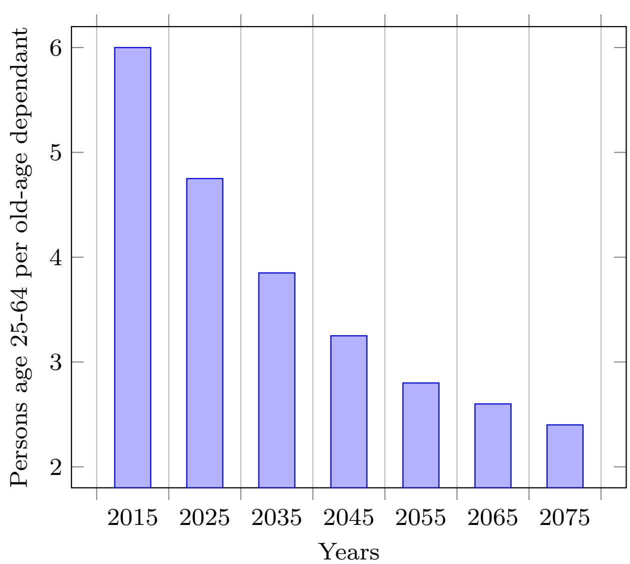

Fig. 6 Projection of World potential supportive ratio $\left(\frac{Age25-64}{Age65+}\right)$. Probabilistic population projections by United Nations (2015)

(2015) present an omni-directional vision sensor based system to track individuals, to recognize the posture, and to analyze the behavior.

Likewise, by considering the benefits of self-care, projects such as ELF@Home (Carus et al. 2014) introduce a system to monitor elderly fitness. In this project, the system offers real-time services to track daily activity level (by wearable physical activity sensor along with a computer vision system) and health status (using bio-sensors). A personalized fitness program is then proposed without needing a direct human supervision where the improvements are applied based on sensors' feedback.

Acceptance of a new technology is often a challenge, in particular when elderly are the target users of the system. This restricted some health monitoring approaches to use conventional devices (e.g., TV) for providing more user friendly services for the senior adults. In this regard, a digital TV based remote health monitoring service is proposed by Spinsante and Gambi (2012) using several wireless medical devices (e.g., oximeter, breathing tester and glycaemia meter). Similarly, HEREiAM project (Macis et al. 2014) demonstrates a TV based system in order to offer a wider assistance and support for elderly people. The project offers a variety of services using a TV set at home (HEREiAM 2015) to address remote healthcare technology acceptance along with other issues such as security and social communication.

5.2 Nutrition monitoring

Malnutrition due to deficiency (i.e., under-nutrition), excess (i.e., over-nutrition) or lack of proper nutrition is a common problem in aging which can be controlled. The prevalence rate of malnutrition is higher among elderly people (Stratton et al. 2003; Hickson 2006). Negligence of malnutrition in a time period can make elderly people susceptible to different diseases such as cardiovascular and cerebrovascular diseases, osteoporosis, and diabetes (WHO 2016a). Therefore, it is essential to consider nutrition monitoring, particularly weight and diet monitoring, along with health monitoring in IoT-based remote monitoring systems to enhance health and well-being of elderly people.

In this regard, different approaches and systems have been hitherto proposed. ChefMyself is a nutrition-related monitoring which introduces a system to support food related monitoring for elderly people (Lattanzio et al. 2014). Using a Cloud based connection, it offers remote nutrition monitoring that includes weight monitoring (by wireless scales), diet monitoring, recipe library, and shopping and cooking assistance for elderly people. It also provides social network accesses (see Sect. 5.5) to motivate elderly to have a better social life.

Similarly, to prevent malnutrition for old people, another approach called DIET4Elders (Sanchez et al. 2013) demonstrates a system (hardware and software) to monitor, advice and provide services for daily activities related to dining pattern of elderly people. Their proposed system consists of three layers (Sanchez et al. 2013): (1) Monitoring Layer to capture raw data from daily activities, (2) Analysis and Assessment Layer to extract information (Chifu et al., 2014) and to extract knowledge about the daily self-feeding, and (3) Support Service Layer to provide complementary knowledge (including communications) from medical experts and caregivers.

Another project entitled EDLAH (EDLAH 2015) also addresses elderly nutrition monitoring by introducing complementary system brought to users' tablets. In this manner, the application is connected to other devices (e.g., weighing scale) to have a more inclusive monitoring. Moreover, in the same package, other services are also offered (Borsella et al. 2015) such as medicine reminder, object location indicator (Ionescu et al. 2014), and social networks.

To achieve a multipurpose remote monitoring, a wearable IoT based device called eButton (Sun et al. 2014; Bai et al. 2012) has been designed for people with special needs such as elderly. The eButton device provides diet monitoring using a visual sensor installed on the user's chest. The food volume is also estimated from the images based on prior models of foods shapes. The obtained data coupled with supplementary data (e.g., food information) shows daily nutrition and calories of the user. Furthermore, the device also offers services for physical activity monitoring to estimate issues such as sedentary events and daily caloric expenditure.

Unlike the discussed application-oriented approaches, MOBISERV as also introduced in Sect. 5.1, proposes a personal robotic system along with wearable and environment sensors for remote monitoring. The system is designed to address nutrition and health services of elderly people by detecting elderly emotions and activities (Maronidis et al. 2010, 2011; Iosifidis et al. 2013). Monitoring consumed meals and water are instances of the nutrition habits monitoring proposed in this system (Zoidi et al. 2011; Marami et al. 2011; Iosifidis et al. 2012).

5.3 Safety monitoring

Security is one of the major issues in the daily life of elderly people. Ageing causes impairments, frailty and forgetfulness, so to live independently, safety monitoring becomes important. On the other hand, a real-time monitoring system capable of detecting harmful situations can provide a feeling of safety for the old users together with awareness of their status for their relatives who might not be in the vicinity. In this regard, several methods and projects have been proposed to address remote safety monitoring of elderly people. The major ones are discussed in the following to covering different aspects of elderly monitoring in daily activities.

As a result of diseases or limits caused by aging and visual and physical impairments, elderly people have a high risk to fall which might cause fatal injuries and even death, with a higher probability than younger adults (WHO 2016b). To alleviate such consequences, dedicated techniques have been proposed to perform fall detection. Based on the definitions given by Igual et al. (2013), fall detection methods can be divided into two categories: wearable sensors based and context-aware systems based. In the sensory level, wearable sensors separated into two groups as smartphones and miniature sensors mounted on a band or cloth. Wearable sensors provide more comfortable user experience for some users rather than being continuously recorded by cameras in the context-aware systems. Smartphone and sensor based fall detection methods utilize the sensors such as 3D accelerometer, gyroscope and magnetometer to determine the sudden position and orientation changes of a user's conditions, analyse the data and implement further processes (e.g., send notifications) when a fall is detected. Some attempts to propose smartphone based methods can be found in Fang et al. (2012), Sposaro and Tyson (2009) and Mellone et al. (2012) while Pierleoni et al. (2015), Cheng (2014) and Odunmbaku et al. (2015) are efforts to present wearable sensors based methods. In the same fashion, CONFIDENCE project (Kaluza et al. 2014) introduces several methods for fall detection, activities recognition and postures recognition (Gjoreski et al. 2011; Lustrek and Kaluza 2009; Kozina et al. 2011) using wearable sensors placed on wrists, chest and ankle of the user. However, another approach entitled as WIISEL (WIISEL 2015) offers a similar system for detecting falls in addition to gait analysing using a wireless insole sensor (Rosa et al. 2015).

On the other hand, context-aware systems are developed to detect falls utilizing visual sensors. Compared with wearable sensors, there are limitations using context-aware systems such as spatial coverage of installed cameras or uncomfortability for some senior adults when they feel being watched all the time. However, context-aware systems also provide certain advantages for the monitored person, such as eliminating the need for wearing the sensor all the time and avoiding the anxiety for forgetting to carry the sensors. In this regard, two main fall detection projects Bian et al. (2015) and Juang and Wu (2015) have been proposed to accomplish the fall detection using a depth camera and a robot vision system, respectively. Furthermore, as an comprehensive elderly monitoring approach using visual sensors, FEARLESS project aims at monitoring elderly people without any wearable sensors (Planinc et al. 2011). In their system, elderly people are monitored continuously by collecting captured data from 3D depth sensor (e.g., Kinect), cameras and microphones, and transferring the data to a computing system (Planinc and Kampel 2012a). In addition, a robust fall detection is proposed to detect the individuals, and their motions, using a combination of different techniques (Planinc and Kampel 2011, 2012b). In this system, when an emergency accident (e.g., fall) happens, the system transmits the data to the server, and after analysing the data, proper notifications and results are provided via interface devices (e.g., caregivers/medical experts smartphones) (Berndt et al. 2012).

FEARLESS project also introduces a system to investigate behavior changes of patients for detecting unusual activities (e.g., mobility decrease, depression, etc.). Activities in certain places in user's home are monitored to detect the changes in their frequency and duration (Berndt et al. 2012). Subsequently, a comparison on the activity histograms of the collected data is provided by which the system detects abnormal behaviors (Planinc and Kampel 2014). Similarly, NITICS approach (NITICS 2015) presents a localization based system to track the location (Badawika and Kolakowski 2014) and daily activities of the user using portable body sensors along with cameras. The system is designed to distinguish abnormal behaviour (i.e., lack of activities and erratic behavior) and to inform caregivers in case of emergency (Rusu et al. 2015).

The aforementioned approaches (i.e., FEARLESS and SAAPHO) also offer some other services such as environmental accident detection presented in Berndt et al. (2012) and Domenech et al. (2013). Supplementary services are specified to focus on distinguishing the incidence of accidents such as fire, smoke, CO presence and gas leakage.

5.4 Localization and navigation

Mazeophobia (fear of being lost) in unfamiliar environments, reduction of physical and cognitive capabilities, and the risk of confronting odd places without any aid from other people force elderly people to spend most of the time at home. Staying at home for a long time makes elderly people susceptible to be inactive, to lose social life, and to get depressed. Therefore, the significance of remote localization and navigation has motivated the researchers in both academia and industry to provide services for elderly people to feel safe in different environments, and to enable them to have their outdoor activities (e.g., shopping, traveling, etc.). In this regard, various IoT-based approaches have been proposed to address the aforementioned real-life issues and to mitigate their associated inevitable difficulties.

In order to provide assistance for elderly people in outdoor environments, ASSAM project proposes a system to be installed on different mobility platforms (e.g., walker, wheelchair, and tricycle). The assistance system features obstacle recognition, navigational and cognitive assistance and alerts to call center (caregiver) in case of emergency (Krieg-Br++ckner et al. 2012). The platform provides old adults suffering physical impairments with an automated driving service to a certain location without any obstacle collision (Mandel and Birbach 2013). An emergency situation system is also demonstrated in this project to notify others along with on-line monitoring services using an on-board camera and an on-line navigational assistance.

Additionally, based on sensory data and maps, the ASSISTANT system is introduced for individuals (particularly senior adults) to navigate and to apply remedial approaches whether an error or mistake occurs. To provide the solution, an application for smartphones was designed (Carmien and Obach 2013; Barham 2013). The application uses the sensory data obtained from phone sensors (e.g., accelerometer and gyroscope) and server data (e.g., routing information from the local public transportation or Open Government Data) via Internet to perform the related analysis (e.g., error detection and classification) locally (i.e., in the smartphone) or remotely (i.e., in the server) (-Kalian and Kainz 2013). Besides, the sensitivity and response of the application in case of errors are defined with respect to the user capabilities and requirements (Carmien and Obach 2013).

Providing assistance for elderly people who are suffering from visual impairments is of high importance. For this purpose, a wireless system connected to a local or remote computing unit is proposed in ALICE project. Utilizing a smartphone mounted on the chest of users, the system provides a data fusion of sensory data (i.e., image, sound, positioning, orientation and inclination) for planning and anticipating events (Tapu et al. 2014). The system can robustly detect and classify static and dynamic obstacles without needing prior information (Tapu et al. 2013). Moreover, the project has been extended by introducing methods for object recognition (e.g., crossings, traffic light, etc.) and urban building recognition (Boujelbane et al. 2014; Said et al. 2014).

In addition to the outdoor localization and navigation, some solutions have been proposed to remotely detect indoor location of elderly people. Such techniques enables monitoring activity level of elderly people, recognizing their daily habits, and analyzing their life style and well-being. As an example of indoor localization methods, CONFIDENCE project proposes localization approaches for detecting abnormal activities (Brugger et al. 2010; Zamora-Cadenas et al. 2010). Furthermore, as a supplementary service, some projects present methods for object localization for lost items (e.g., key, eye-glass, cell phone) due to forgetfulness of elderly people. For instance, EDLAH project demonstrate a Bluetooth based method to track and find objects within a house perimeter (Ionescu et al. 2014). Similarly, NITICS project presents an assertive service to locate an object with an appropriate accuracy for indoors measurements (Badawika and Kolakowski 2014).

5.5 Social networks

Promoting social life for senior citizens who may live alone is essential. Living alone might lead elderly people to become isolated and having inadequate interaction with other people (e.g., family members, friends, etc.). This subsequently may cause mental problems such as depression and social anxiety. Therefore, preparing social networks to improve the social life for elderly people is as vital as other discussed services. In this regard, a number of social networks utilizing different methods and interaction devices have been proposed for elderly people under different scenarios.

Specific home care and communication services are offered by vAssist project (Caon et al. 2011) for old people who have either movement restrictions or computer illiteracy. They have developed a simplified interface using multilingual natural speech interactions provided by wearable and fixed devices (e.g., smartphones, fall detection systems) for communication applications along with remote medical monitoring (Sansen et al. 2014). The proposed integrated system of natural speech interaction consists of speech recognition, natural language understanding and output generation (i.e., text or audio) (Milhorat et al. 2013, 2014). Thanks to these features, the system can also be utilized for disabled people suffering from physical or visual impairments. Moreover, taking into account the care of solitude elderly people, a virtual assistive companion was suggested by CaMeLi Project (Tsiourti et al. 2014). The proposed platform acquires user behaviour and environment data, analyses them and responses properly with respect to the conditions, thus trying to provide an intelligent system capable of simulating human interactions and conversations. It also offers notifications (e.g., take medicine, do exercises, and eat meals) and safety (e.g., by detecting emergency situation and informing caregivers).

Similarly, ALFRED project (ALFRED 2015) introduces the idea of interactive assistant to enable elderly people to live independently and be active in social life. Using a voice-driven interaction, elderly people are enabled to communicate by asking questions or receiving suggestions based on their requirements and interests (OpenPR 2015). As a complementary service, the system also offers health monitoring (see Sect. 5.1) by tracking users' vital signs with the aim of enhancing physical and cognitive conditions. This is realized by utilizing games and quests provided via a physical and cognitive impairments prevention unit (Hardy et al. 2015).

GeTVivid is another project (GeTVivid 2015) which introduces in a platform of connected TV devices based on the HbbTV standard to provide supports for elderly people suffering from impairments. The system, which includes a connected TV (TVX2015-Workshop 2015) and applications in smartphones/tablets, offers a social network for communications and social networking (e.g., with caregivers and other old adults) as well as a number of public services such as medical assistance, shopping assistance, and Meals on Wheels. It also includes a reminder for daily activities (e.g., take medicine) (Moser et al. 2015).

6 Discussion

As discussed, many accomplished or ongoing elderly monitoring projects have been introduced so far, using various IoT related platforms and methods to implement the services for elderly care. They target several demands of elderly people over their daily life. To classify these efforts, summarize their pros and cons, and illustrate the differences, a comprehensive comparison on the specifications of the discussed projects is given in Table 1.

As can be observed from the table, some of these projects have provided software applications along with embedded devices to deeply tackle a narrow set of elderly requirements. Two proper examples are (1) a user-friendly social network for elderly suffering from impairments by GeTVivid project, and (2) fitness monitoring for improving elderly health by ELF@Home project. Moreover, some projects tackle a single issue using different methods. For instance, as mentioned in Sect. 5.3, fall detection is considered in both FEARLESS and WIISEL projects; However, FEARLESS utilizes camera based methods, while WIISEL is based on wireless wearable sensors. On the other hand, some projects target wider systems and services to address more than one aspect of elderly demands, however they are still at early stages. ChefMyself approach includes health monitoring, nutrition monitoring as well as providing social networks for elderly people. Correspondingly, Mobiserv project covers indoor services (e.g., health monitoring, nutrition monitoring, safety monitoring and social network) utilizing a smart robot.

In addition to the discussed ongoing or recently developed services and products, there exist various IoT-based products which are already available in the market. For instance, various Internet- and Cloud-connected fitness trackers (e.g., Jawbone UP,[6] FitBit,[7] etc.) are in the market which can be utilized for elderly people to track their daily activities and vital signs. There are also available tracking devices for senior adults (e.g, Mindme,[8] SafeLink,[9] etc.) as well as emergency response systems (e.g., MobileHelp[10])

[6] https://jawbone.com/up.

[7] https://www.fitbit.com.

[8] http://www.mindme.care.

[9] http://safelinkgps.com.

[10] https://www.mobilehelp.com.

in the market. Medication management systems (e.g., TabSafe[11]) can be also added to this list which help managing medications 24/7. On the other hand, the current existing solutions in the market have still many shortcomings. Some of these devices are not miniaturized, lightweight, low-power, user-friendly, and convenient enough for elderly to wear 24/7. Inaccurate results and false alarms are also issues diminishing the trust of users and caregivers.

In this section, we investigate the issues in IoT-based remote elderly monitoring in a deeper level to pave the way for more efficient systems in future. Nowadays amalgamation of IoT-based systems and big data (Laney 2001; Beyer 2015) analytics enables systems to offer deeper and wider range of services and applications. Therefore, the essential demands of elderly people in their life can be more efficiently addressed in a comprehensive remote monitoring system. With this in mind, we represent a hierarchical model of the elderly-centered monitoring system in 4 tiers in Fig 7. Starting from the lowest level, the first tier entitled as *Application Layer* includes the final applications proposed to tackle the elderly requirements (e.g., activity level monitoring, fall detection, etc.). This layer is discussed in Sect. 5 in details. The second tier is *Domain Layer* including five major monitoring service categories. The applications indicated in the first tier are subsets of these 5 domains. The third tier is defined as *Objective Layer* in order to present and classify high-level challenges/objectives in remote elderly monitoring. Finally, the fourth tier is the *System Layer* which points to a comprehensive elderly-centered monitoring system covering all the divisions and aspects.

In the following, we discuss the objective layer, related challenges and viable solutions for elderly-centered monitoring. As illustrated in Fig. 7, the objective layer is divided into 4 different classes, each of which may partially cover and overlap the domains represented in the previous tier. The first objective is defined to consider an extensive system for addressing the main requirements of elderly. More precisely, it reflects the demand for full-fledged systems in terms of number and type of utilized sensors to monitor vital signs along with environmental and activity related signals. The second objective indicates the issues related to the long-term monitoring of elderly people. Taking into account the back-up systems in case of emergencies is specified in the third class. Last but not least, the fourth class addresses the personalization issues in elderly monitoring systems. Consequently, considering these objectives enables development of a comprehensive elderly-centered monitoring system shown as system layer in Fig 7.

6.1 Extensive monitoring

As discussed, all the existing or under-development elderly monitoring systems focus on a subset of aspects of elderly requirements in their everyday life. However, from a user point of view, an extensive monitoring is required to support different applications and services comprehensively. In other words, there is a demand for an all-inclusive monitoring in order to improve the quality of elderly people's life considering a variety of aspects (e.g., addressing the health and well-being requirements, improving the independent living, and enhancing the security). Such a system needs to monitor indoor and outdoor activities of elderly people and to suggest related services in real-time. Thanks to advanced technologies such as IoT-based systems and big data analytics, developing such a system is nowadays feasible.

An extensive IoT-based elderly monitoring system can potentially integrate many objects related to elderly to obtain a comprehensive knowledge of elderly conditions. Considering the issues such as scalability and availability (Mukherjee et al. 2012), it is possible to implement big data analytics to handle a huge volume of incoming heterogeneous data (e.g., health data) and extract useful information (Andreu-Perez et al. 2015). Furthermore, the analysis can be carried out not only using incoming sensory data, but also utilizing history data (e.g., medical records), and complementary data (e.g., maps, public transportation data, shopping info, and weather forecast) to provide more comprehensive services.

The proposed system also needs to be convenient and user-friendly. Elderly people may have different kind of impairments or be forgetful in many situations, therefore, the design process should take these aspects into account. Moreover, attaching a large number of sensors to the body of a user is not appropriate in practical long-term cases if they are not convenient to be deployed. On the other hand, as proposed by some of the discussed approaches, required data can sometimes be collected non-invasively using other devices installed at home or other places. As an example, the elderly status recognition (e.g., detecting fall, unconsciousness, low physical activity, etc.) can be performed using surveillance cameras and computer vision techniques. In addition, several in-home services can be offered via smart home applications and devices (e.g., smart TV, smart stove, etc.).

6.2 Long-term monitoring

Long-term monitoring is another challenge of remote elderly monitoring systems. The system should potentially provide long-term services for many years. Impairments and chronic diseases can be properly addressed only by long-term monitoring. As an example, types of diabetes

[11] http://www.tabsafe.com.

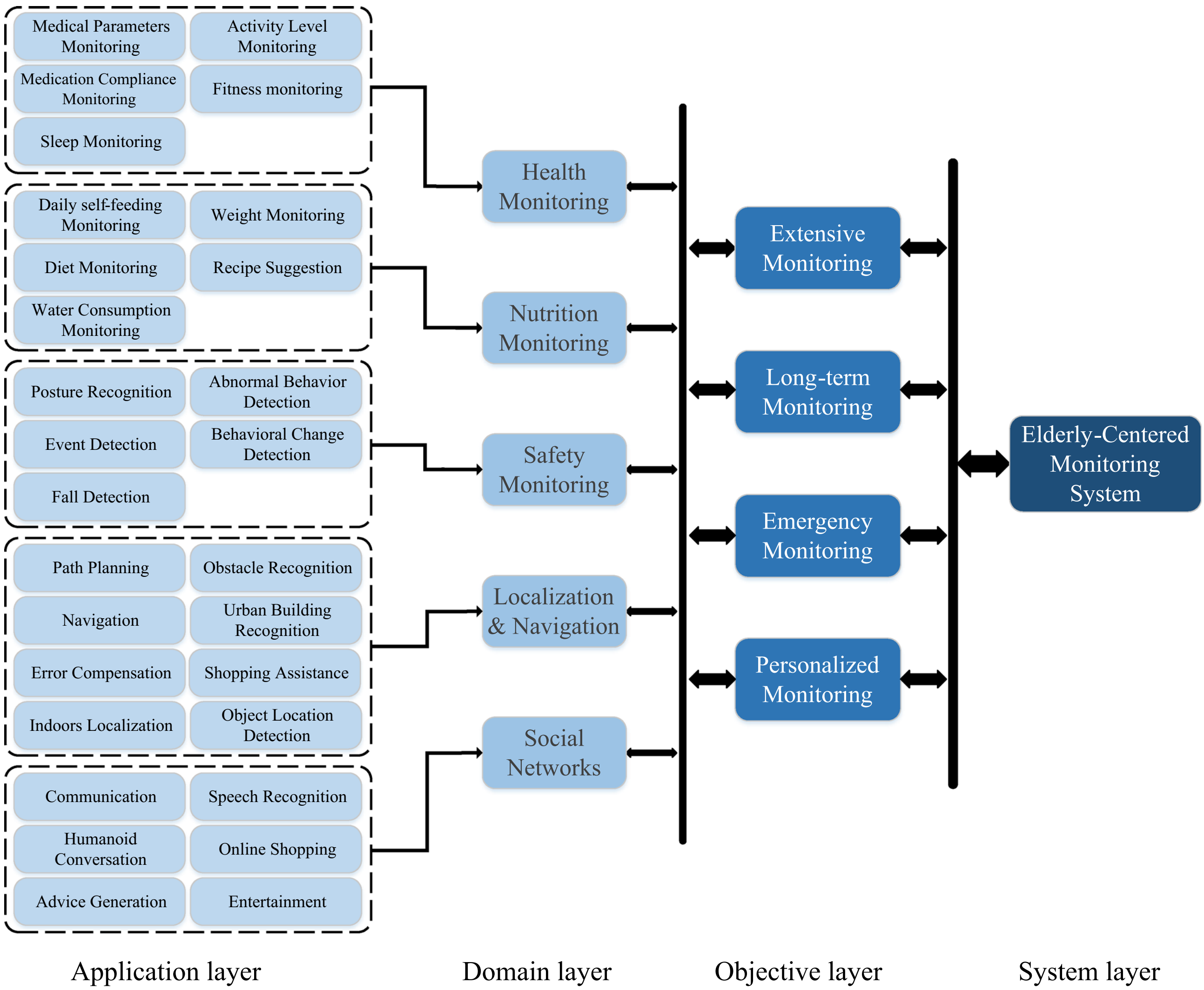

Fig. 7 Hierarchical model of the elderly-centered monitoring system

should be monitored for the whole life span. Thus, life-time, minimally-invasiveness, and battery-life of sensor devices for a long-term service should be considered. Using compact and limited number of wearable sensors in daily activities as well as utilizing smart devices in the environment can be a proper solutions for IoT-based system in long-term monitoring.

Using long-term monitoring for elderly, the system can analyze the daily habits of the users for a long period in a deeper level. Many physical and mental diseases manifest only via long-term monitoring of habits and behavior of the user. Collecting and analyzing incoming big data in a long period from a user's daily life including physical activity, eating, sleeping and social life can assist the system to extract valuable knowledge. This knowledge provides a reliable understanding of user's life style to mitigate improper activities (e.g. low physical activity, insufficient sleep and malnutrition) and enables the medical experts to perform collective analysis (e.g., analysing prevalent behavior and epidemic diseases). Furthermore, such long-term knowledge may contain changes in habits that can be considered for medical analysis. Various mental illnesses (e.g., depression and anxiety) might be detected or even predicted by monitoring changes in habit in long-time.

6.3 Emergency monitoring

Another challenge in elderly monitoring systems is the emergency detection with a low latency and rapid back up supports. The likelihood of accidents such as medical accidents (e.g., stroke and heart attack) and environmental accident (e.g., fall detection, being lost) are higher for elderly adults. Therefore, a comprehensive remote elderly monitoring need to detect emergency situations and react accordingly (i.e., notifying caregivers or medical experts to mitigate the consequences).

In this regard, new concepts such as smart gateways (Rahmani et al. 2015) can be utilized to address the emergency detection issues. The concept of extending the Cloud computing paradigm named as Fog computing closer to the user location has been proposed by Bonomi et al. (2014). In this manner, due to the additional (local) computational power, networking, and online data analysis of the streaming sensory data, the latency of the system is reduced. Moreover, it improves the system reliability in case of unavailability of Internet connection.

6.4 Personalized monitoring

Personalized monitoring is one of the essential objective which IoT-based elderly monitoring systems should consider in a comprehensive monitoring process. In general-purpose elderly monitoring systems, several presumptions are specified for the system based on the general requirements and conditions of users. These presumptions result in inefficiencies in long-term elderly monitoring. Therefore, techniques to provide adaptivity and customization (i.e., personalization) are of utmost significance.

Self-awareness concept (Agarwal et al. 2009) and big data analytics can be integrated to the IoT-based systems in order to provide a personalized monitoring. On one hand, big data analytics extract useful information from incoming heterogeneous big data to make the system aware of the patient and surrounding environment states, and on the other hand, self-aware approaches enable the system to refine its behaviour with respect to the situation (i.e., patient state and environmental state) and adjust *attention* to critical parameters in the system over time (Preden et al. 2015). As an example, in the context of health monitoring, the system defines several priorities for different medical parameters based on the elderly diseases. The priorities indicate the importance level of the parameters. In other words, they specify the data collecting rates from the sensors, the execution time and the order of the data analysis for each parameter. In this way, for instance, the system is more sensitive to heart-related parameters of the user suffering from cardiovascular diseases compared with other parameters. Such adaptivity can be extended to other services (e.g., safety monitoring, etc.) to mitigate impacts of accidents and in general to implement a robust remote elderly monitoring system.

7 Conclusions

Several approaches have been recently proposed to address the daily life requirements of elderly people. However, there exists a lack of comprehensive user-centered study in the literature. In this paper, we studied state-of-the-art IoT-based elderly monitoring approaches to investigate their advantages and shortcomings from a different viewpoint by considering the elderly requirements at the center of attention. In addition, we introduced a modernized classification and proposed a hierarchical model for elderly-centered monitoring to investigate the current approaches, objectives and challenges in a top-down fashion. Consequently, our study develops a comprehensive perspective on the area, discusses the existing solutions and presents the main objectives and trends that IoT-based systems can provide for future remote elderly care.

References

Agarwal A, Miller J, Eastep J, Wentziaff D, Kasture H (2009) Self-aware computing. Technical report, MIT

Ahmed MU, Banaee H, Rafael-Palou X, Loutfi A (2015) Intelligent healthcare services to support health monitoring of elderly. In: Internet of things. user-centric IoT, volume 150 of lecture notes of the institute for computer sciences, social informatics and telecommunications engineering. Springer International Publishing, pp 178–186

Akl A, Taati B, Mihailidis A (2015) Autonomous unobtrusive detection of mild cognitive impairment in older adults. IEEE Trans Biomed Eng 62(5):1383–1394

ALFRED (2015) ALFRED | personal interactive assistant for independent living and active ageing. Retrieved on December 2015. http://alfred.eu/

Andreu-Perez J, Poon CCY, Merrifield RD, Wong STC, Yang G-Z (2015) Big data for health. IEEE J Biomed Health Inform 19(4):1193–1208

Anzanpour A, Rahmani AM, Liljeberg P, Tenhunen H (2015) Internet of things enabled in-home health monitoring system using early warning score. In: Proceedings of ACM international conference on wireless mobile communication and healthcare, 2015

Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. Comput Netw 54(15):2787–2805

Azimi I, Anzanpour A, Rahmani AM, Liljeberg P, Tenhunen H (2016) Self-aware early warning score system for iot-based personalized healthcare. In: Proceedings of international conference on IoT and big data technologies for healthCare, 2016

Badawika A, Kolakowski J (2014) UWB positioning system architecture based on paired anchor nodes. In: Proceedings of 20th international conference on microwaves, radar, and wireless communications, pp 1–4, 2014

Bai Y, Li C, Yue Y, Jia W, Li J, Mao Z-H, Sun M (2012) Designing a wearable computer for lifestyle evaluation. In: 38th annual northeast bioengineering conference, pp 93–94, 2012

Barham P (2013) ASSISTANT—creating a smartphone app to assist older people when travelling. In: de Waard D, Brookhuis K, Wiczorek R, di Nocera F, Brouwer R, Barham P, Weikert C, Kluge A, Gerbino W, Toffetti A (eds) (2014) Proceedings of the human factors and ergonomics society Europe chapter 2013 annual conference, 2013

Berndt RD, Takenga MC, Kuehn S, Preik P, Berndt S, Brandstoetter M, Planinc R, Kampel M (2012) An assisted living system for the elderly FEARLESS concept. In: Proceedings of the IADIS multi conference on computer science and information systems, pp 131–138, 2012

Beyer M (2015) Gartner says solving 'Big Data' challenge involves more than just managing volumes of data. Retrieved on December 2015. http://www.gartner.com/newsroom/id/1731916
Bian ZP, Hou J, Chau LP, Magnenat-Thalmann N (2015) Fall detection based on body part tracking using a depth camera. IEEE J Biomed Health Inform 19(2):430–439
Bishop CM (2006) Pattern recognition and machine learning. Springer-Verlag New York Inc, New York
Bonomi F, Milito R, Natarajan P, Zhu J (2014) Fog computing: a platform for internet of things and analytics. In: Big data and internet of things: a roadmap for smart environments, pp 169–186, 2014
Borsella E, Mantovani E, Porcari A (2015) Information and communication technologies for health, demographic change and wellbeing: a survey of the technological scenario. Technical report, Italian Association for Industrial Research (AIRI, Italy)
Boujelbane I, Said SH, Zaharia T (2014) Multi-object recognition and tracking with feature points matching and spatial layout consistency. In: Proceedings of IEEE fourth international conference on consumer electronics, Berlin, pp 355–359, 2014
Brugger M, Christ T, Kemeth F, Nagy S, Schaefer M, Pietrzyk M (2010) The FMCW technology-based indoor localization system. In: Proceedings of ubiquitous positioning indoor navigation and location based service, pp 1–6, 2010
Caon DRS, Simonnet T, Sendorek P, Boudy J, Chollet G (2011) vAssist: the virtual interactive assistant for daily home-care. In: Proceedings of 8th international conference on wearable nano and macro technologies for personalized health, 2011
Carmien S, Obach M (2013) Back on track: lost and found on public transportation. In: Proceedings of the 7th international conference on universal access in human–computer interaction: user and context diversity, vol 2, pp 575–584, 2013
Carus JL, Garcia S, Garcia R, Waterworth J, Erdt S (2014) The ELF@Home project: elderly sELF-care based on sELF-check of health conditions and sELF-fitness at home. Stud Health Technol Inform 200(16):164–166
Charlon Y, Fourty N, Campo E (2013) A telemetry system embedded in clothes for indoor localization and elderly health monitoring. Sensors (Basel, Switzerland) 13(9):11728–11749
Cheng J, Zhou B, Kunze K, Rheinländer CC, Wille S, Wehn N, Weppner J, Lukowicz P (2013) Activity recognition and nutrition monitoring in every day situations with a textile capacitive neckband. In: Proceedings of the 2013 ACM conference on pervasive and ubiquitous computing adjunct publication, pp 155–158, 2013
Cheng SH (2014) An intelligent fall detection system using triaxial accelerometer integrated by active RFID. In: Prodeedings of 13th international conference on machine learning and cybernetics, pp 517–522, 2014
Chifu VR, Salomie I, Chifu ES, Izabella B, Pop CB, Antal M (2014) Cuckoo search algorithm for clustering food offers. In: Proceedings of 2014 IEEE international conference on intelligent computer communication and processing, pp 17–22, 2014
Dohr A, Modre-Opsrian R, Drobics M, Hayn D, Schreier G (2010) The internet of things for ambient assisted living. In: Proceedings of seventh international conference on information technology: new generations, pp 804–809, 2010
Domenech S, Rivero J, Coll-Planas L, Sainz FJ, Reissner A, Miralles F (2013) Involving older people in the design of an innovative technological system promoting active aging: the SAAPHO project. J Access Des All 3(1):13–27
EDLAH (2015) Retrieved on December 2015. http://www.edlah.eu/presentation.html
Faetti T, Paradiso R (2012) A novel wearable system for elderly monitoring. Adv Sci Technol 85:17–22
Fang SH, Liang YC, Chiu KM (2012) Developing a mobile phone-based fall detection system on android platform. In: Proceedings of computing, communications and applications conference, pp 143–146, 2012
GeTVivid (2015) Retrieved on December 2015. http://getvivid.eu/
Gjoreski H, Lutrek M, Gams M (2011) Accelerometer placement for posture recognition and fall detection. In: Proceedings of 7th international conference on intelligent environments, pp 47–54, 2011
Glaeser DH, Thomas LJ Jr (1975) Computer monitoring in patient care. Annu Rev Biophys Bioeng 4:449–476
Gokalp H, Clarke M (2013) Monitoring activities of daily living of the elderly and the potential for its use in telecare and telehealth: a review. Telemed J E Health 19(12):910–923
Hamdi O, Chalouf MA, Ouattara D, Krief F (2014) eHealth: survey on research projects, comparative study of telemonitoring architectures and main issues. J Netw Comput Appl 46:100–112
Hardy S, Feldwieser F, Dutz SGT, Steinmetz, Steinhagen-Thiessen E (2015) ALFRED back trainer: conceptualization of a serious game-based training system for low back pain rehabilitation exercises. In: Göbel S et al (eds) Serious games, volume 9090 of lecture notes in computer science. Springer International Publishing, New York, pp 36–47
Henze M, Hermerschmidt L, Kerpen D, Haußling R, Rumpe B, Wehrle K (2016) A comprehensive approach to privacy in the cloud-based internet of things. Future Gener Comput Syst 56:701–718
HEREiAM (2015) Retrieved on December 2015. http://www.hereiamproject.org/
Hickson M (2006) Malnutrition and ageing. Postgrad Med J 82(963):2–8
Huaxin S, Qi X, Xiaodong L, Baoyan L, Shusong M, Xuezhong Z (2012) Constructing ideas of health service platform for the elderly. In: Proceedings of 14th international conference on e-health networking, applications and services, pp 526–529, 2012
Igual R, Medrano C, Plaza I (2013) Challenges, issues and trends in fall detection systems. BioMed Eng OnLine 12(1):1–24
Ionescu G, de la Osa CM, Deriaz M (2014) Improving distance estimation in object localisation with bluetooth low energy. In: Proceedings of the eighth international conference on sensor technologies and applications, 2014
Iosifidis A, Marami E, Tefas A, Pitas I (2012) Eating and drinking activity recognition based on discriminant analysis of fuzzy distances and activity volumes. In: Proceedings of IEEE international conference on acoustics, speech and signal processing, pp 2201–2204, 2012
Iosifidis A, Tefas A, Pitas I (2013) Minimum class variance extreme learning machine for human action recognition. IEEE Trans Circuits Syst Video Technol 23(11):1968–1979
Jara AJ, Zamora-Izquierdo MA, Skarmeta AF (2013) Interconnection framework for mhealth and remote monitoring based on the internet of things. IEEE J Sel Areas Commun 31(9):47–65
Juang LH, Wu MN (2015) Fall down detection under smart home system. J Med Syst 39(10):1–12
Kalian K, Kainz W (2013) ASSISTANT—aiding sustainable independent senior travellers to navigate in towns. In: Proceedings of the European navigation conference, 2013
Kaluza B, Cvetkovic B, Dovgan E, Gjoreski H, Gams M, Lustrek M (2014) A multi-agent care system to support independent living. Int J Artif Intell Tools 23(1):1440001
Kasteren TL, Englebienne G, Krose BJ (2010) An activity monitoring system for elderly care using generative and discriminative models. Pers Ubiquit Comput 14(6):489–498
Kozina S, Lustrek M, Gams M (2011) Dynamic signal segmentation for activity recognition. In: Proceedings of international joint conference on artificial intelligence, 2011

Krieg-Brckner B, Bothmer H, Budelmann C, Crombie D, Guern A, Heindorf A, Lifante J, Martnez AB, Millet S, Velleman E (2012) Assistance for safe mobility: the ASSAM project. AAL-Forum, 2012

Laney D (2001) 3D data management: controlling data volume, velocity, and variety. Application Delivery Strategies by META Group Inc., Technical report

Lattanzio F, Abbatecola AM, Bevilacqua R, Chiatti C, Corsonello A, Rossi L, Bustacchini S, Bernabei R (2014) Advanced technology care innovation for older people in Italy: necessity and opportunity to promote health and wellbeing. J Am Med Dir Assoc 15(7):457–466

Lee JV, Chuah YD, Chieng KTH (2013) Smart elderly home monitoring system with an android phone. Int J Smart Home 7(3):17–32

Lin CC, Chiu MJ, Hsiao CC, Lee RG, Tsai YS (2006) Wireless health care service system for elderly with dementia. IEEE Trans Inform Technol Biomed 10(4):696–704

Liu N, Lin Z, Cao J, Koh Z, Zhang T, Huang G-B, Ser W, Ong MEH (2012) An intelligent scoring system and its application to cardiac arrest prediction. IEEE Trans Inf Technol Biomed 16(6):1324–1331

Lustrek M, Kaluza B (2009) Fall detection and activity recognition with machine learning. Informatica 33:205–212

Macis S, Loi D, Angius G, Pani D, Raffo L, Rijnen W, Nap H (2014) Towards an integrated tv-based system for active ageing and tele-care. Poster presented by Silvia Macis (UniCa) at the 4th National Congress of Italian Group of Bioengineering (GNB), 2014

Mandel C, Birbach O (2013) Localization in urban environments by matching sensor data to map information. In: Proceedings of the 6th European conference on mobile robots, 2013

Marami E, Tefas A, Pitas I (2011) Nutrition assistance based on skin color segmentation and support vector machines. In: Czachórski T et al (eds) Man–machine interactions 2., volume 103 of advances in intelligent and soft computing. Springer, Berlin, pp 179–187

Maronidis A, Tefas A, Pitas I (2010) Frontal view recognition using spectral clustering and subspace learning methods. In: Diamantaras K et al (eds) Artificial neural networks ICANN 2010, volume 6352 of lecture notes in computer science. Springer, Berlin, pp 460–469

Maronidis A, Bolis D, Tefas A, Pitas I (2011) Improving subspace learning for facial expression recognition using person dependent and geometrically enriched training sets. Neural Netw 24(8):814–823

Mellone S, Tacconi C, Schwickert L, Klenk J, Becker C, Chiari L (2012) Smartphone-based solutions for fall detection and prevention: the FARSEEING approach. Zeitschrift für Gerontologie und Geriatrie 45(8):722–727

Memon M, Wagner SR, Pedersen CF, Beevi FHA, Hansen FO (2014) Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes. Sensors 14(3):4312–4341

Milhorat P, Schlgl S, Chollet G, Boudy J (2013) What if everyone could do it?: a framework for easier spoken dialog system design. In: Proceedings of the 5th ACM SIGCHI symposium on engineering interactive computing systems, pp 217–222, 2013

Milhorat P, Schlgl S, Chollet G, Boudy J, Espisoto A, Pelosi G (2014) Building the next generation of personal digital assistant. In: Proceeding of 1st international conference on advanced technologies for signal and image processing, pp 458–463, 2014

Moosavi SR, Gia TN, Nigussie E, Rahmani AM, Virtanen S, Tenhunen H, Isoaho J (2016) End-to-end security scheme for mobility enabled healthcare internet of things. Future Gener Comput Syst

Morgan RJM, Williams F, Wright MM (1997) An early warning scoring system for detecting developing critical illness. Clin Intens Care 8(2):100

Moser C, Kargl T, Tscheligi M, Feldbacher B, Collini-Nocker B, Harutunian M, Schiller F, Eitelberg M, Altaani N, Eisele M, Osl P (2015) A TV platform for P2P support exchange. In: TVX2015, 2015

Mukherjee A, Pal A, Misra P (2012) Data analytics in ubiquitous sensor-based health information systems. In: Proceedings of sixth international conference on next generation mobile applications, services and technologies, pp 193–198, 2012

Murphy KP (2012) Machine learning: a probabilistic perspective. The MIT Press, Cambridge

Nani M, Caleb-Solly P, Dogramadzi S, Fear T, van den Heuvel H (2010) MOBISERV: an integrated intelligent home environment for the provision of health, nutrition and mobility services to the elderly. In: 4th companion robotics workshop in Brussels, 2010

Neisse R, Steri G, Fovino IN, Baldini G (2015) SecKit: a model-based security toolkit for the internet of things. Comput Secur 54:60–76

NITICS (2015) Retrieved on December 2015. http://nitics.eclexys.com/

Niyato D, Hossain E, Camorlinga S (2009) Remote patient monitoring service using heterogeneous wireless access networks: architecture and optimization. IEEE J Sel Areas Commun 27(4):412–423

Odunmbaku A, Rahmani AM, Liljeberg P, Tenhunen H (2015) Elderly monitoring system with sleep and fall detector. In: International conference on IoT technologies for healthcare, 2015

OpenPR (2015) openPR.com—Press release—Ascora GmbH—Project ALFRED: personal interactive assistant for independent living and active ageing, Retrieved on December 2015. http://www.openpr.com/news/275440/Project-ALFRED-Personal-Interactive-Assistant-for-Independent-Living-and-Active-Ageing.html?SID=64de8ec1e1c924e6428973b78bf9a1a

Pfuntner A, Wier L, Steiner C, (2013) Costs for hospital stays in the united states, 2011. HCUP Statistical Brief # 168. Agency for Healthcare Research and Quality, Rockville

Pierleoni P, Belli A, Palma L, Pellegrini M, Pernini L, Valenti S (2015) A high reliability wearable device for elderly fall detection. IEEE Sens J 15(8):4544–4553

Planinc R, Kampel M (2011) Emergency system for elderly—a computer vision based approach. In: Bravo J et al (eds) Ambient assisted living, volume 6693 of lecture notes in computer science. Springer, Berlin, pp 79–83

Planinc R, Kampel M (2012a) Introducing the use of depth data for fall detection. Pers Ubiquit Comput 17(6):1063–1072

Planinc R, Kampel M (2012b) Robust fall detection by combining 3d data and fuzzy logic. In: Park J et al (eds) Computer vision—ACCV 2012 workshops, volume 7729 of lecture notes in computer science. Springer, Berlin, pp 121–132

Planinc R, Kampel M (2014) Detecting unusual inactivity by introducing activity histogram comparisons. In: Proceedings of the international conference on computer vision theory and applications, pp 313–320, 2014

Planinc R, Kampel M, Zambanini S (2011) Audiovisual Assistance for the elderly—an overview of the fearless project. In: Abdulrazak B et al (eds) Toward useful services for elderly and people with disabilities, volume 6719 of lecture notes in computer science. Springer, Berlin, pp 225–229

Preden JS, Tammemae K, Jantsch A, Leier M, Riid A, Calis E (2015) The benefits of self-awareness and attention in fog and mist computing. Computer 48(7):37–45

Rafael-Palou X, Vargiu E, Miralles F (2015) Monitoring people that need assistance through a sensor-based system: evaluation and

first results. In: 4th international workshop on artificial intelligence and assistive medicine, 2015
Rahmani AM, Thanigaivelan NK, Gia TN, Granados J, Negash B, Liljeberg P, Tenhunen H (2015) Smart e-Health gateway: bringing intelligence to internet-of-things based ubiquitous healthcare systems. In: Proceedings of annual IEEE consumer communications and networking conference, pp 826–834, 2015
Ray P (2014) Home health hub internet of things (H3IoT): an architectural framework for monitoring health of elderly people. In: Proceedings of international conference on science engineering and management research, pp 1–3, 2014
Ritter FE, Baxter GD, Churchill EF (2014) Foundations for designing user-centered systems: what system designers need to know about people. Springer Publishing Company, Incorporated, New York
Rivero-Espinosa J, Iglesias-Prez A, Gutirrez-Dueas JA, Rafael-Palou X (2013) SAAPHO: an AAL architecture to provide accessible and usable active aging services for the elderly. ACM SIGACCESS Access Comput 8(107):17–24
Rosa MD, Stara V, Rossi L, Breuil F, Reixach E, Paredes JG (2015) Burkard S (2015) A wireless sensor insole to collect and analyse gait data in real environment: the WIISEL project. In: Andò B et al (eds) Ambient assisted living, volume 11 of biosystems and biorobotics. Springer International Publishing, New York, pp 71–80
Russell S, Norvig P (2013) Artificial intelligence: a modern approach, 3rd edn. Pearson, London
Rusu L, Cramariuc B, Benta D, Mailat M (2015) Implementing BPMN 2.0 scenarios for AAL@Home solution. Int J Comput Commun Control 10(2):230–237
Said SH, Boujelbane I, Zaharia T (2014) Recognition of urban buildings with spatial consistency and a small-sized vocabulary tree. In: Proceedings of IEEE international conference on consumer electronics Berlin, pp 350–354, 2014
Sanchez J, Sanchez V, Salomie I, Taweel A, Charvill J, Araujo M (2013) Dynamic nutrition behaviour awareness system for the elders. In: Proceedings of the 5th AAL forum norrkoping, impacting individuals, society and economic growth, 2013
Sansen H, Baldinger J-L, Boudy J, Chollet G, Milhorat P, Schlgl S (2014) vAssist. Building the personal assistant for dependent people—helping dependent people to cope with technology through speech. In: Proceedings of international conference on health informatics, 2014
Sicari S, Rizzardi A, Grieco LA, Coen-Porisini A (2015) Security, privacy and trust in internet of things: the road ahead. Comput Netw 76:146–164
Spinsante S, Gambi E (2012) Remote health monitoring for elderly through interactive television. BioMed Eng OnLine 11:54
Sposaro F, Tyson G (2009) iFall: an android application for fall monitoring and response. In: Proceedings of 31st annual international conference of the IEEE engineering in medicine and biology society, pp 6119–6122, 2009
Stefanov DH, Bien Z, Bang W-C (2004) The smart house for older persons and persons with physical disabilities: structure, technology arrangements, and perspectives. IEEE Trans Neural Syst Rehabil Eng 12(2):228–250
Stratton R, Green C, Elia M (2003) Disease-related malnutrition: an evidence-based approach to treatment. CABI Publishing Series, CABI Pub., Cambridge
Sun M, Burke LE, Mao Z-H, Chen Y, Chen H-C, Bai Y, Li Y, Li C, Jia W (2014) ebutton: a wearable computer for health monitoring and personal assistance. In: Proceedings design automation conference, pp 1–6, 2014
Tapu R, Mocanu B, Bursuc A, Zaharia T (2013) A smartphone-based obstacle detection and classification system for assisting visually impaired people. In: Proceeding of IEEE international conference on computer vision, workshop on wearable computer vision systems, pp 444–451, 2013
Tapu R, Vizintin M, Zaharia T (2014) An efficient and affordable device to improve cognition and navigation of visually impaired people. AAL solutions for Europe—AAL forum 2014
Tsiourti C, Joly E, Wings C, Moussa MB, Wac K (2014) Virtual assistive companion for older adults: field study and design implications. In: Proceedings of 8th international conference on pervasive computing technologies for healthcare (PervasiveHealth), 2014
Touati F, Tabish R (2013) U-healthcare system: state-of-the-art review and challenges. J Med Syst 37:9949
Tsukiyama T (2015) In-home health monitoring system for solitary elderly. Procedia computer science. 5th international conference on current and future trends of information and communication technologies in healthcare, vol 63, pp 229–235, 2015
TVX2015-Workshop (2015) A workshop on "People, Context, and Devices: Defining the New Landscape of TV Experiences". Retrieved on December 2015. https://projects.icts.sbg.ac.at/tvx2015/
United Nations (2015) Probabilistic population projections based on the world population prospects: the 2015 revision. Population division, DESA., 2015. http://esa.un.org/unpd/ppp/
Vucinic M, Tourancheau B, Rousseau F, Duda A, Damon L, Guizzetti R (2015) OSCAR: object security architecture for the internet of things. Ad Hoc Netw 32:3–16
WHO (2011) Global health and ageing. WHO, Technical report
WHO (2014) World health statistics 2014: a wealth of information on global public health. WHO, Technical report
WHO (2016a) Nutrition for older persons. Retrieved on April 2016a. http://www.who.int/nutrition/topics/ageing/en/
WHO (2016b) Falls. Retrieved on April 2016b. http://www.who.int/mediacentre/factsheets/fs344/en/
WHO/Europe (2015) Healthy ageing—risk factors of ill health among older people. Retrieved on December 2015. http://www.euro.who.int/en/health-topics/Life-stages/healthy-ageing/data-and-statistics/risk-factors-of-ill-health-among-older-people
WIISEL (2015) Retrieved on December 2015. http://www.wiisel.eu/
Xiang Y, Ping Tang Y, Qing Ma B, Chen Yan H, Jiang J, Yuan Tia X (2015) Remote safety monitoring for elderly persons based on omni-vision analysis. PLoS One 10(5):e0124068
Yang X, Li Z, Geng Z, Zhang H (2012) A multi-layer security model for internet of things. In: Wang Y et al (eds) Internet of things, volume 312 of communications in computer and information science. Springer, Berlin, pp 388–393
Zamora-Cadenas L, Arrue N, Jimenez-Irastorza A, Velez I (2010) Design of an IR-UWB indoor localization system based on a novel RTT ranging estimator. In: Proceedings of first international conference on sensor device technologies and applications, pp 52–57, 2010
Zecchin C, Facchinetti A, Sparacino G, Cobelli C (2014) Jump neural network for online short-time prediction of blood glucose from continuous monitoring sensors and meal information. Comput Methods Programs Biomed 113(1):144–152
Zoidi O, Tefas A, Pitas I (2011) Object tracking based on local steering kernels for drinking activity recognition. In: Proceeding of 33rd international conference on information technology interfaces, pp 237–242, 2011