SMART technologies in older adult care: a scoping review and guide for caregivers

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Abstract

Purpose – *A wide gap exists between the innovation and development of self-monitoring, analysis and reporting technology (SMART) technologies and the actual adoption by older adults or those caring for them. This paper aims to increase awareness of available technologies and describes their suitability for older adults with different needs. SMART technologies are intelligent devices and systems that enable autonomous monitoring of their status, data analysis or direct feedback provision.*

Design/methodology/approach – *This is a scoping review of SMART technologies used and marketed to older adults or for providing care.*

Findings – *Five categories of SMART technologies were identified: (1) wearable technologies and smart tools of daily living; (2) noninvasive/unobtrusive technology (i.e. passive technologies monitoring the environment, health and behavior); (3) complex SMART systems; (4) interactive technologies; (5) assistive and rehabilitation devices. Technologies were then linked with needs related to everyday practical tasks (mainly applications supporting autonomous, independent living), social and emotional support, health monitoring/managing and compensatory assistance rehabilitation.*

Research limitations/implications – *When developing, testing or implementing technologies for older adults, researchers should clearly identify concrete needs these technologies help meet to underscore their usefulness.*

Practical implications – *Older adults and caregivers should weigh the pros and cons of different technologies and consider the key needs of older adults before investing in any tech solution.*

Social implications – *SMART technologies meeting older adult needs help support both independent, autonomous life for as long as possible as well as aiding in the transition to assisted or institutionalized care.*

Originality/value – *This is the first review to explicitly link existing SMART technologies with the concrete needs of older adults, serving as a useful guide for both older adults and caregivers in terms of available technology solutions.*

Keywords *Care, Independent living, Technology, Older adults, mHealth, SMART*

Paper type *General review*

Introduction

New, now mainly digital technologies have permeated our daily lives. The digital boom has also sprung to life technological innovations in older adult care, creating a new dynamic market with an ever-increasing offering of numerous products and devices. Juxtaposed to that is the pervasive digital gap that is evident in most countries when it comes to older adults actively engaging in these technologies (Bert *et al.*, 2014; Hale *et al.*, 2014) as well as the slow adoption of these new technological innovations in practice, be it home or institution-based care (Liang, 2012). However, in the past two years, technology adoption especially in the healthcare sector has seen a sharp increase as a result of the COVID-19 pandemic (Clipper, 2020). This unprecedented event has led to the necessity to find new and efficient ways of delivering care, remote monitoring as well as communication.

(Information about the authors can be found at the end of this article.)

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Older adults, typically defined as persons aged 65 and over, exhibit physical, mental and social changes characteristic of older age (Zaidi, 2008), shaping their unique needs when it comes to engaging with technology. The physical changes associated with older age increase the risk of chronic diseases, functional limitations, and disability. Many of these negative effects are "preventable" or "reversible" with positive lifestyle changes (Dipietro *et al*., 2019), which can be facilitated with the use of new technologies (e.g. wearables). Technological innovations may also enable older adults to maintain their functioning and autonomy and so ensure a positive experience of older adult age (Gruss, 2009). For example, they can fulfill a compensatory function, by aiding in tasks of daily living or facilitating social contact and interactions. Several different literature reviews exist attesting to the feasibility and efficacy of different assistive or monitoring technologies for older adults. These reviews have focused on existing studies on the usability of (tele)health monitoring devices (Liu *et al*., 2022), smart homes and systems (Choi *et al*., 2019; Lee and Kim, 2020; Morris *et al*., 2013), exergames (i.e. gaming applications with exercise components) or fall prevention tools (Choi *et al*., 2017), assistive devices (Khosravi and Ghapanchi, 2016; Pedrozo Campos Antunes *et al*., 2018) or robotics (Allaban *et al*., 2020; Shishehgar *et al*., 2018).

There are also several reviews of technological innovations for special populations of older adults, such as individuals living with dementia (Brandt *et al*., 2020; Daly Lynn *et al*., 2019; Gagnon-Roy *et al*., 2017; Holthe *et al*., 2018; Ienca *et al*., 2017; Sriram *et al*., 2019).

Although these reviews provide robust evidence for the strong potential of technologies to help address issues of older age, there remains a wide gap between innovation development and its adoption, pointing at persistent barriers in adopting and using such technologies (Kampmeijer *et al*., 2016; Kruse *et al*., 2017). These barriers are not only on the side of the older adults themselves (e.g. low digital literacy) but involve external factors such as older adults not being involved in the design of technologies. In our interactions with care professionals, it has also become apparent that many of them had very low awareness about technologies that could aid in caring for older adults (Elavsky *et al*., in review). This lack of awareness can further increase the already substantial lag between rapid technology development and its transfer to real-life contexts and use in practice. Not uncommon are also misconceptions about technologies being available primarily for autonomous, independently living older adults. Without increasing awareness among professional public, institutions, nursing staff and caregivers about the availability and key features of existing technologies, it will not be possible to make full use of the potential that technology offers in reducing care burden and improving older adults' quality of life.

We believe that a source describing summatively various existing technologies in relation to the unique needs of the older adults would be useful to care providers and care professionals as they attempt to navigate the rapidly changing offering of technological innovations and products targeting older adults. The aim of this article was to provide a scoping review of (1) available SMART technologies focused on older adult care (in this regard, we include technologies worn on the person (sensor), with the person (e.g. medication dispenser – necessitating collaboration between the caregiver/pharmacist and the care recipient), or by the person (e.g. iPad)); and (2) the key functionalities of these technologies with respect to the needs of the older adults and the continuum of care, as the potential of each technology will vary according to the degree of self-efficacy/autonomy and specific needs of older adults.

Methods

Defining SMART technologies

What we can understand under the term "SMART" has evolved over the years along with the exponential increase in performance and innovation in new technologies. According to the Oxford Dictionary (Oxford's learners dictionaries, 2022), the word SMART itself refers to a computer-controlled device or a computer-controlled device that appears to act intelligently. SMART can also be used to describe a technology that is capable of monitoring, analyzing, and reporting. Nowadays, it is commonly applied to technologies that use artificial intelligence or machine

learning, or technologies that analyze big data to provide cognitive awareness to objects that are usually considered inanimate. Herein, we therefore apply the term SMART technology broadly and include technologies in several different categories:

Internet of Things (IoT or a term characterizing modern devices controlled remotely via the Internet) technology. Similar technologies may include various sensors, chips, automated, scalable devices, capable of operating autonomously to some extent. An example might be smart households.

Smart Connected Devices. Such technologies are usually controlled remotely and connected via the Internet or Bluetooth to other devices or cloud- or other mobile-based applications (e.g. smart cameras, light bulbs, wearables).

Smart Devices are devices that usually have limited automation without the need for an Internet connection. They are programmable and allow you to provide certain personalized services at a specific time. An example is an intelligent coffee machine.

Search strategy

In this review, we aimed to identify SMART technologies and products developed, marketed to, and targeting older adults or those that care for them. The emphasis was on available technologies and devices, although we also note some examples of technologies under development.

In order to provide a comprehensive and systematic overview of SMART technologies for older adults, we employed a scoping review methodology (Mak and Thomas, 2022) with a structured search strategy across multiple databases. Specifically, we searched Web of Science, PubMed, and EBSCO (includes PsycARTICLES, PsycINFO, Medline, JSTOR) databases using the following search terms:

Keywords: Elderly Middle aged or Aged or Aged, 80 and over or Age* or Aging or Elder* or "Older adult*" or "Older person" or "Older people*

AND.

Keywords: "Smart home*" or "ambient assisted living" or "ubiquitous home*" or "ubiquitous technology*" or "electronic assistive technology*" or "social alarm" or "telecare social alert platform*" or "environmental control system*" or "automated home environment*" or telehomecare or "Home Automation" or "smart device" or "smart monitor" or "wearable".

The search keyword string had to be adjusted for some databases due to their specificities (some do not allow *"wild card" designations).

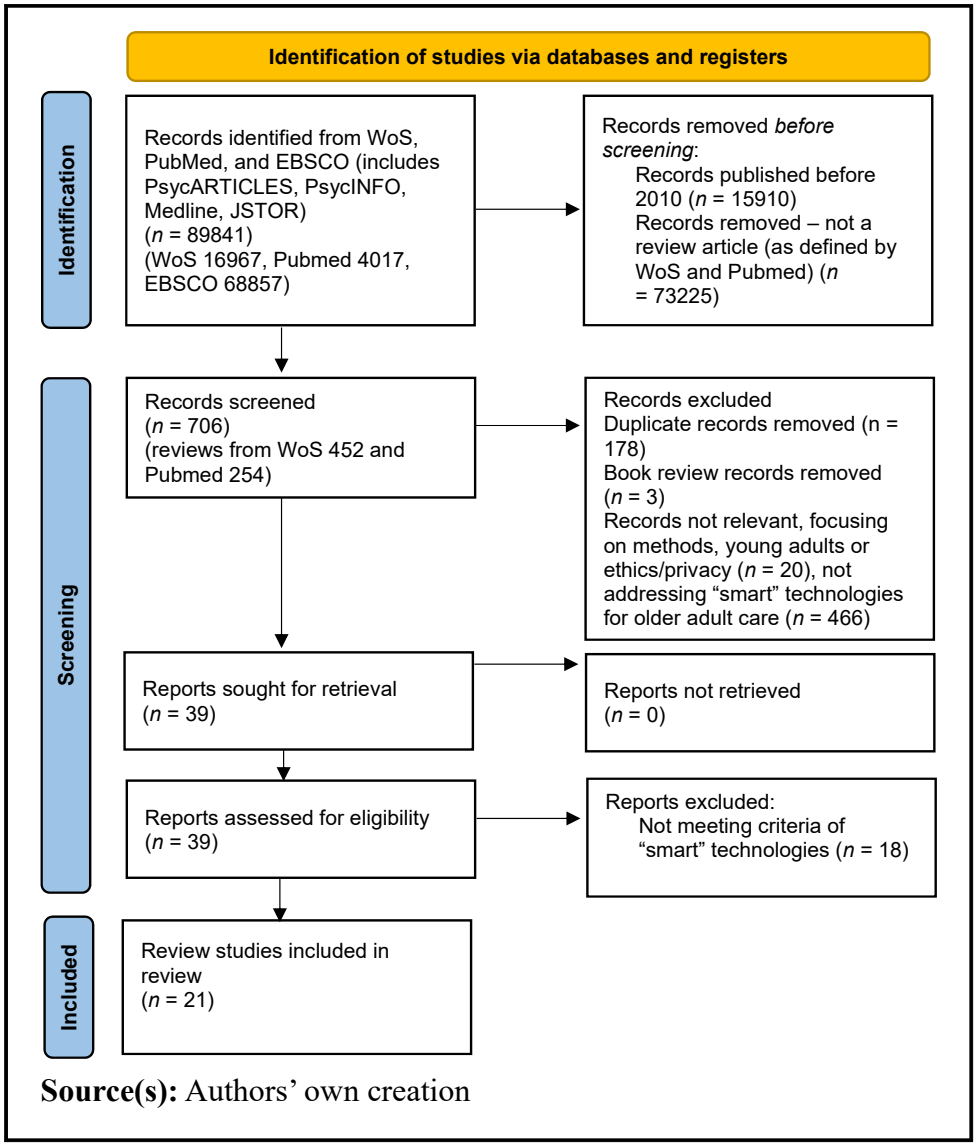
The initial search collectively yielded a total of 89,841 articles (WoS 16,967, Pubmed 4017, EBSCO 68857). We then narrowed our focus to articles published from 2010 onwards, in line with the rapid advancements in technology over the past decade. This refined search reduced the number of potentially relevant sources (WoS 11,037, Pubmed 3805, EBSCO 59089).

To ensure a thorough selection of the most relevant studies presenting technologies and to further narrow down the article volume, we focused on the selection of review studies on the topic. The specific inclusion criteria applied were: a review study, published in the English language, published in 2010 or later, and discussing the use of technology (as per the definition of SMART technology presented earlier) for older adults or in older adult care. The exclusion criteria were not a review study, not published in English, published before 2010, and not discussing the use of technology for older adults or in older adult care.

Since the selection of "review" was possible only in WoS 452 and Pubmed 254, we proceeded with searches for reviews within WoS and Pubmed only. The references were downloaded to excel and then to SPSS where duplicates were identified and removed (n = 178). The remaining 528 articles were screened based on their titles and abstracts, of which 3 were book reviews and an additional

20 were excluded due to either being irrelevant (i.e. not discussing the topic of interest) (9), focusing on statistical methods, modeling, or algorithm development (8), young adults (1), or more broadly on ethics and data privacy (2). On the remaining 505 reviews, we conducted a more detailed review of the full texts, which led to the selection of 39 most relevant reviews, of which 21 closely matched our study's focus on 'smart' technologies for older adults (see Figure 1). The process of data synthesis involved a detailed examination of these articles, focusing on the types of technologies reported and their 'smart' functions. This was complemented by iterative categorization and refinement of technology types, with the development of a list of examples, mainly featuring readily available technologies. This process continued until saturation was reached, as determined through group discussions among authors K.R., L.K., K.J., S.E., and co-authors who are also technology experts J.K., R.C. In this context, it is important to note that we interpret "saturation" as the point in qualitative research where no new themes or information emerged during data collection and analysis, indicating that further data gathering would not yield additional insights relevant to the primary research inquiry. Therefore, data collection was concluded with a sufficient

Figure 1 PRISMA flow chart depicting selection of review articles



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content of information that aided in deriving valid conclusions. Throughout this process, the search of academic papers was supplemented with online searches for commercial products marketed to older adults and/or their caregivers through commercial websites (market places such as Amazon, Alibaba, etc.), blogs and webs devoted to product development, product reviews and aging (e.g. Aging and Health Technology Watch, Senior Planet, Health for Older Adults Blog, AARP listing of tech trends for older adults and other „best of aging tech" blog posts, etc.). In each section of the results, we provide a brief description of a given technology category, list the advantages and disadvantages of the type of technology, and highlight the associated needs of older adults that such technologies can help meet.

Defining elderly needs

Older adults have various unique needs (Abdi *et al*., 2019). Herein, we focus primarily on the needs related to everyday practical tasks, social and emotional support, health monitoring/managing, and compensatory assistance rehabilitation (Lim and Han, 2018). In terms of everyday practical tasks, older adults require support to enhance independent living and maintain autonomy in activities of daily living. They also need social and emotional support to maintain social activities and relationships, which is key to maintaining psychological health in later years. Health monitoring and managing are crucial for older adults, and applications that track and monitor vital signs, health indicators, and cognition can provide valuable support during the aging process (van het Bolscher-Niehuis *et al*., 2023). Additionally, older adults may require compensatory assistance rehabilitation to address functional limitations and maintain independence in performing basic, instrumental, and enhanced activities of daily living (Harrington *et al*., 2015). These needs highlight the importance of developing care models and support services, including useful and practical technological solutions, based on the specific needs of older adults (Upadhyaya *et al*., 2018). Corresponding tables and graphics are provided for a more explicit presentation of linking each type of technology to the needs of older adults and with respect to the level of autonomy/health status.

Results

All technologies are presented in five separate categories based on their features and main functionalities. The categories are also comprehensibly reported in Table 1 that also contains concrete examples of products available in each category (a detailed description of product examples and their use in practice is available as a supplementary file). Infographics (Figure 2–4) are also provided to demonstrate representative examples of smart technologies relevant for older adults depending on their functional status.

1. Wearable technologies and smart tools of daily living

Wearables, or wearable electronics, typically refer to miniaturized electronic devices designed to be routinely worn/used by humans. Although it is possible to carry such devices (e.g. a mobile phone in a hand or pocket), a natural part of wearable electronics is often an ergonomic design and some form of "wearing" the device (i.e. on the body, clothing or directly as part of clothing). Because there are many different types of wearables for many different uses, we narrowed our examples to highlight technologies that are not only wearable, but also of relevance to older adults, such as devices intended for monitoring and/or maintaining/improving the health of a person, their safety, wellbeing, or quality of life.

1.1. Wearable technologies. Wearable electronics can take the form of watches, bracelets, shoes, glasses, rings, or dresses. The devices are usually autonomous, however, for specific or extended functions and full control, it is often necessary to use them in combination with a mobile device (smartphone). Many wearables do not need to have a display or buttons and can be fully controlled via a mobile phone. Their purpose is then primarily to collect data on the user or the situation in which the object or user may be in. A most straightforward example is a smart watch, which usually

Table 1 Overview of SMART technology categories and specific examples of products for older adults and elderly care

Category	*Technology/Device*	*Specific examples**	*Needs fulfilled*	*Additional information*
1.1. Wearable Technologies	Smart Trackers and Watches	Fitbit, Garmin, Apple, Galaxy	1; 3; 4	Usually connected to a smartphone. Can track GPS when outdoors; can be connected to a HR chest belt or other sensors; can have an integrated SIM card
	Smart Rings	Oura Ring, Circular Ring, BodiMetrics CIRCUL Ring, Wellue O_2 Ring	3	Works connected to a smartphone for tracking results
	Chips; Pendants; Wrist Scanners; SOS Buttons	Localized brands with country-specific availability, custom hospital/home systems	1; 3	Used predominantly in hospitals and closed environments to monitor movement and report emergencies. Similar to "safe zone" monitors (section 2.3.). SOS buttons can be used in home care as well
	Smart Shoes; Smart Clothing/E-Textiles	Xiaomi, Nike, Under Armour	1; 3	Technology under development
	Smart Glasses	Google Glass, Microsoft HoloLens, NuEyes	1; 4	Incorporating augmented reality. Some can work as smart blind glasses, see section 5 for more examples
	Smart Contact Lenses	Mojo Vision, Sony, Google	1; 3; 4	Technology under development. Can incorporate augmented reality or measure sugar levels (through eye fluids)
1.2. Smart Tools of Daily Living	Smart Spoons	Liftware, GYENNO Spoon	1; 4	Especially suitable for reducing hand tremors (e.g. in Parkinson's disease)
	Smart Mug and Bottle	Moikit Cuptime 2, HidrateSpark, Equa	1; 3	Connected (wirelessly) to a smartphone for tracking results
	Automatic Drug Dispensers	Trisa Senior Care, MediPense	3	Can include remote adjustment and telemonitoring function
	Smart Thermometer and Thermometer Patch	iHealth, VAVA, TEMON, Motorola Care+	3	Connected (wirelessly) to a smartphone app for tracking results. Patches can monitor temperature continuously
	Smart Glucometer	iHealth, FreeStyle Libre, Dario, BeatO, Accu-Chek, One Touch Verio Flex	3	Connected (wirelessly) to a smartphone app for tracking results
	Smart Tonometer and Oximeter	Biobeat, iHealth, Omron Evolv, Tesla	3	Connected (wirelessly) to a smartphone app for tracking results
	Smart Scale	Tanita, Omron, Garmin, Fitbit, Xiaomi	3	Connected (wirelessly) to a smartphone for tracking results
	Smart Canes, Walkers	WeWALK Cane	1; 4	Can be connected to an app which can send, e.g. GPS location, heart rate, and temperature readings to caregivers

(*continued*)

Table 1 Continued

Category	*Technology/Device*	*Specific examples**	*Needs fulfilled*	*Additional information*
2.1. Passive Technologies Monitoring the Environment	Motion Sensors	Most of the 2.1. technologies are offered in localized brands and systems	1	Can be used to turn on lights, adjust heatingetc
	Remote Monitoring Systems, Video Cameras		1; 3	Most of the 2.1. technologies and devices can be used in combination with a central SMART hub/system described in section 3
	Door and Window Alert Sensors		1; 3; 4	
	Stove Sensors, Heat and Smoke Detectors, Air Quality Sensors		1; 4	
	Automatic Heating and Ventilation Sensors, Electricity Consumption Monitors		1; 4	
2.2. Passive technologies monitoring health	Smart Furniture	Early Sense, Anume System/Deeplab	3	Can monitor heart rate (incl. heart rate variability), respiratory rate, temperature, movement/ presence in bed
	Smart Toilet Bowls	Trueloo, Coprata, Casana	3	Able to detect dehydration, urinary tract infections; some also blood pressure, heart rate
2.3. Passive technologies monitoring behavior	Fall and Movement Detectors	EchoCare, Essence MDsense	3	Various systems using video, radio frequency, infrared or laser beams, pressure pads, etc. are available. Some advanced sensors can also detect stress or monitor sleep
	"Safe Zone" Monitors	Localized brands with country-specific availability, custom hospital/home systems	3	Various technological solutions (e.g. RFID chips, GPS positioning, light barriers) are available
3. Complex SMART systems	SMART Home Hub and Connected Sensor Systems	Essence Care@Home, HiveHome, Amazon ALexa, Apple HomeKit, Google Home, LifePod	1; 3	Automated control, regulation, and reminders. Can be accessed via a connected device (smartphone, laptop). Can usually be connected to various sensors from section 2. Some devices can send alerts to caregivers

(*continued*)

Table 1 Continued

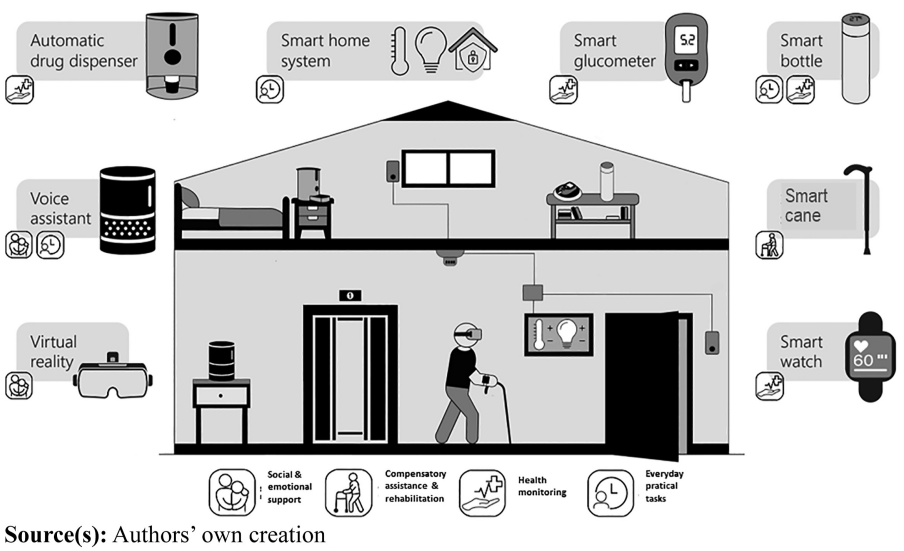
Category	*Technology/Device*	*Specific examples**	*Needs fulfilled*	*Additional information*
4. Interactive Technologies	Voice-Operated Virtual Assistants	Apple Siri, Google Assistant, Amazon ALexa, Microsoft Cortana, Samsung Bixby	1; 2; 4	Can be accessed via smartphone or additional device
	Interactive Tables	Interactive senTable, BRYM Table, GT Office Interactive Touch Table	2; 4	Developed specifically for seniors for neurocognitive rehabilitation and entertainment
	Virtual Reality	Oculus Quest, HTC Vive, PlayStation VR, Neuro Rehab VR	1; 2; 4	Connected to a PC or TV with a specific software for VR experience. Specific rehabilitation software and programs are available
	Companion Robots	Elliq, BUDDY, Pepper, Furhat	2; 4	Can be connected to a tablet and provide more applications and programs
5. Assistive and Rehabilitation Devices	Assistive Listening Devices, Alerting Devices	ReSound, Widex Evoke, Amplifon, Neosensory Buzz	1; 4	Some devices can be integrated into a SMART Home system to react to, e.g. doorbell, smoke alarm, microwave
	Smart Glasses for Vision Impairments	Ocram My Eye, NuEyes, Evision, AIRA, QD Laser Retissa	1; 4	Some devices allow the user to connect to a visual interpreter/ support online in real time
	Smart Wheelchairs	Various prototypes (e.g. MIT Intelligent Wheelchair)	1; 4	Mostly under development by research teams
	Telehealth Monitoring Devices	TytoPro, BioBeat	3; 4	Often with clinician's guidance. Results can be shared with clinicians

Note(s): *The list of specific examples is not exhaustive and provides several examples of such devices for the reader to look up and envision the technology
1 Everyday Practical Tasks
2 Social and Emotional Support/Entertainment
3 Health Monitoring/Managing
4 Compensatory Assistance/Rehabilitation
Source(s): Authors' own creation

allows you to monitor your heart rate, records physical activity, counts steps, or can monitor the quality of sleep. The data obtained in this way are sent to the mobile application, where the user's data are evaluated, and feedback may be provided back to the user through the mobile application or directly on the device. Often, for seamless access, the data are stored in a cloud, so that they are retained when the device is damaged or transferred when the user switches from one device to another.

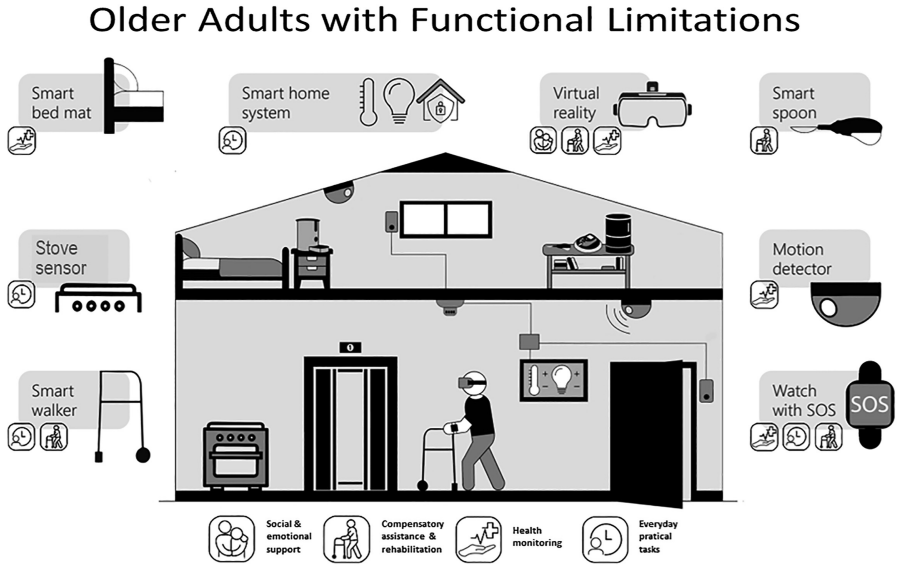
Among the advantages of wearable electronics are wearability and adaptability to the human body (ergonomics, material, weight, and adjustable size); continuous and relative ease of use (no need to turn off the device); safety; autonomy (setting up user preferences). The disadvantages are the need to charge the device (some even daily), the need to "wear" the device (may be inconvenient or unpleasant, e.g. wearing a watch while sleeping), price, language, or overall availability in some regions. For older adults with low technological or digital competency, learning how to use or operate the device may be challenging and require assistance of a third party in setting up the device or when troubleshooting is needed. Because they need to be "worn", some older adults

Figure 2 A graphic depiction of SMART technologies suitable for mobile, independently living older adults



Source(s): Authors' own creation

Figure 3 A graphic depiction of SMART technologies suitable for independently living older adults with functional limitations

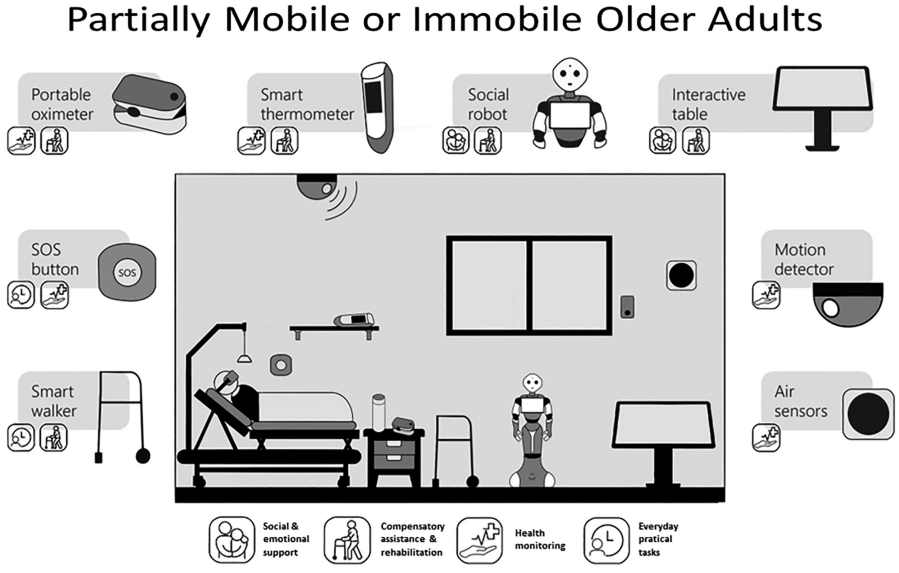


Source(s): Authors' own creation

may refuse to wear the device or simply not be capable of it (dementia patients or immobile, not lucid patients).

Meeting the needs of older adults. With respect to the needs of older adults, wearable smart technologies are used primarily to monitor health status, or to monitor unforeseen situations and

Figure 4 A graphic depiction of SMART technologies suitable for partially mobile or immobile older adults in assisted living or home care



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reduce possible consequences or risks (e.g. risk of falling). In the case of independently living (for self-sufficient older adults), the functions for monitoring health do not necessarily have to be associated only with disease management or prevention, but on the contrary, the goal can be improvement in specific health domain or even performance (e.g. increasing physical activity, fitness).

Wearables may also serve compensatory functions such as helping older adults compensate for sensory (e.g. sound detection) or cognitive (e.g. memory) deficits. Similarly, they can help with everyday routine tasks (e.g. contactless payment) and within the social/emotional sphere, wearables can serve an educational-entertaining function. Some older adults may use similar tools as part of "keeping up with the times" or use similar technologies because they want to learn something new or simply for entertainment.

1.2. SMART tools of daily living. Many tools have been redesigned as smart devices with the promise of easing tasks of daily living. These types of devices include an infinite variety of new technology products. Among key advantages for these devices are their practical utility, ease of use (many of these devices have been designed with older adult needs in mind) and providing a sense of autonomy. The disadvantages include the need to charge the device (some even daily), limited product warranty, affordability, and technical problems, failures with long-term use.
Meeting the needs of older adults. The described functions of the smart tools indicate that they are primarily aimed at facilitating the daily needs of older adults. By helping to satisfy/facilitate the accomplishment of "lower-order" needs (i.e. tasks of daily living), more time and effort can be afforded for the pursuit of "higher-order" needs, such as those associated with leisure activities and social and emotional wellbeing. By their nature, these smart devices also compensate for certain functional limitations of older adults. In some cases, technologies in this category can also serve as a suitable tool for life (or "life hack"). For example, smart mugs or thermoses can help individuals follow a drinking regime, which is suitable for any older adult, both for those active, independently living as well as those dependent on assistance or bed/wheelchair-bound. On the other hand, for some older adults, the availability of similar technologies may still be lower (depending on the

individual's location as some products are offered only regionally) or simply financially out of reach. Consequently, the motivation to use these tools may be lower in some individuals, depending on their perceived competence and awareness of availability of these tools.

2. Non-invasive/unobtrusive technology

This technological category includes a very diverse group of technologies and products such as environmental sensors, remote monitoring systems, or telemedicine applications. The common feature among these technologies is their unobtrusive nature and noninvasive data monitoring. Devices falling into this category collect information passively without or with minimal user input (user interaction is usually required for set-up or limited to adjustment to user preferences). Herein lies their main advantage. When set up and functioning correctly, these technologies operate without users even noticing them. On the other hand, there are some disadvantages. These can sometimes stem from the user experience (expert set-up, need for frequent charging, sometimes unnecessarily complicated user interface to control technology). Also, some devices may not be completely reliable or accurate in their measurement (especially if it is not a certified medical device). Some older adults may also associate technologies of this type and the "continuous surveillance" that they provide with lack of privacy or loss of autonomy and worry about data abuse or device breach.

2.1. Passive technologies monitoring the environment. Environmental sensors often function as integrated systems. They can measure multiple variables at once and it is possible to connect them to a complex control system. For example, "smart-home" applications are designed to enable opening doors or windows remotely, turning on the heating, light and much more. Various devices such as electronic or optical sensors, strain gauges, door monitors, pressure mats, heat and smoke detectors can collect data passively and noninvasively and so significantly improve the safety and ability of older adults to move around at home. As such, these technologies play an important role in assisting older adults in accomplishing everyday tasks/goals, and helping older adults "age in place". Among the disadvantages of these technologies are their price, need for expert set-up and setting of user preferences, assistance in resolving technical problems and sometimes the need for continuous technical support or add-on services.
Meeting the needs of older adults. Passive technologies monitoring the environment primarily compensate for the physical and mental limitations of older adults. They can also be viewed as "saving" the physical effort of an older adult, who can thus devote his limited physical (movement) abilities to other and/or "higher-order" needs. They also compensate for the loss of cognitive functions that could have fatal consequences without the systems being place (e.g. independently living older adults with cognitive impairment or dementia). Because these technologies can be controlled remotely (essentially from anywhere on Earth with Internet access), they help provide information about the "home" environment for caregivers or assistive services. The older adult is thus capable of partial (or fully compensated) autonomy of his life, which is key to their well-being and quality of life. Integrated smart systems in the house can thus serve older adults across the continuum of care and facilitate safe, dignified, and satisfied life at home for as long as possible.

2.2. Passive technologies monitoring health. Sensors detecting various environmental inputs are also used as part of remote monitoring of various health indicators of older adults. Devices incorporating electronic sensors or fall detectors, optical sensors, strain gauges, ultrasonic devices, bedside alerts, heart rate and breath sensors, pressure mats can collect data passively and noninvasively and so not only monitor an individual's health status but also significantly contribute to safety and the ability of older adults to move around at home. As such these technologies play an important role in monitoring a person's health and wellbeing by assisting older adults in accomplishing everyday tasks/goals, helping older adults manage their chronic conditions, and/or help older adults safely "age in place". The advantages and disadvantages of these technologies are very similar to passive technologies monitoring the environment.

Meeting the needs of older adults. Health is by far the highest value in the lives of most older adults. The "passive" monitoring of various health indicators that technology affords may help provide useful information both to the older adult or caregiver about the health status or safety of the older adult. The extent to which the full potential of such technologies is fulfilled however also depends on the feedback and data interpretation it provides beyond simply functioning as an "alert" system. The older adult and/or the caregiver must be able to understand the individual health data obtained so they can adjust their behavior or seek further evaluation or care. At the same time, the devices must provide such outputs that can be effectively used in follow-up clinical care (i.e. outputs that can be linked to clinically meaningful outcomes or at least provide data that are easy to interpret and inform about risk factors of clinical outcomes). From the standpoint of the older adults themselves, it is this type of functionality that would most likely meet the older adult needs (and potentially outweigh the concern of loss of privacy that is often cited by older adults with respect to this type of technology).

2.3. Passive technologies monitoring behavior. The third domain in which technologies placed in the environment and capable of passive sensing are used is monitoring different aspects of behavior. Among the most common applications with respect to older adult care are devices or technologies aimed at detection of falls and at monitoring of movement. The key advantages of these technologies lie in the unobtrusive "passive" nature of the monitoring that does not rely or require interaction with the user. Many of these systems are marketed along with telemonitoring and support services, are not available widely (or only in some countries) and remain pricey. Other limitations of these technologies are technical issues (e.g. the limited life of pressure sensors; need for expert installation/set-up; charging), and ethical or psychological issues related to the reluctance to be monitored constantly and with it associated privacy concerns or worry about misuse of such data.

Meeting the needs of older adults. Safety represents an important need in the lives of older adults, which is determined to a great extent by the environment in which they live and interact. Passive technologies monitoring behavior can on one hand give the older adult support and a sense of safety in the event of an unexpected situation (by providing help when needed), on the other hand, they may be perceived as a significant invasion of privacy (not only in the home environment, but also in residential facilities). In some instances, such as when an older adult has compromised cognitive functions, they may not be aware of being monitored and thus also not perceive that their needs are being met. Essential for the practical use of the above technologies is therefore how care providers utilize them. The fear of being under constant surveillance (someone watching us) clearly limits the satisfaction of higher-order needs. From this perspective, it is important to utilize these technologies in accordance with what they were originally intended to do, which is to monitor behavior and subsequently adapt the environment so that it is as safe as possible, and thus satisfy the need for safety. The concerns over invasion of privacy may also be alleviated by educating the older adults and caregivers by explaining how the device works, where it is, what data it collects, how it is shared and why. When older adults understand how the use of a particular technology can meet their personal needs (such as keeping them safe), they would be expected to become more open to using such technology.

3. Complex SMART systems

Nowadays, systems are emerging that offer complex automated control of different components (e.g. within a home). While these tools can be viewed as universally useful, their features offer functions that may be increasingly useful with age. These complex systems include elements of the previously discussed passive sensing technologies with the addition of operating as an interconnected system with advanced automated control of different components. The advantages and disadvantages of these technologies are thus like those of passive monitoring technologies. The perceived utility of complex SMART systems for older adult care may increase with a generational shift when those living with such technologies through adulthood may find them irreplaceable and essential in later life as they age.

Meeting the needs of older adults. In addition to monitoring vital signs, the above can help meet the need to compensate for functional limitations and naturally occurring daily activities. Again, several limiting variables in relation to older adults can be considered problematic. Besides the concern over the invasion of privacy, older adults accustomed to using these technologies already in pre-older adult age, may reduce the time they spent on various activities of daily living, which may be counterproductive as these activities are considered especially important in older adulthood. Concretely, for example, smart technologies can be used to control or replace "work" in the garden, care for some pets, by a few clicks on a mobile phone. While such advances should help, facilitate, compensate the older adults´ limitations, they should not comprehensively deprive the older adult of the activities that he/she can perform autonomously. They should therefore help to meet the needs of the older adult, which are disrupted due to his functional limitations but not deprive them of opportunities to actively engage in their care or preferred leisure activities and practice their cognitive and physical skills. If technologies are however sensitively chosen, they can benefit older adults by learning from the older adults´ behavior and providing them with reminders of certain tasks (taking medication, waking them up), locking the front door if evening is approaching and the older adult no longer leaves home at that time.

4. Interactive technologies

Most devices require some aspect of the interaction between the user and the device (at least in the installation/set-up phase), however, some technologies have been devised with the main purpose of interactive engagement with the user or to offer companionship. These devices range from systems serving as sources of information (such as voice-operated virtual assistants), therapeutic/mental training devices, virtual reality to companion/care robots or similar robotic devices that simulate/substitute companionship. The benefits and advantages of these technologies lie in their specific applications/functions. Once set up for use, older adults can benefit from their interaction with these technologies with minimal effort (systems do not require much additional control, they can operate, monitor and can alert older adults as needed). The disadvantages may include the price, the need for at least a basic knowledge of the technology going hand in hand with the need to control it, even if only in the basics. And also, some devices may not be comfortable for everyone to wear (e.g. virtual reality goggles). Some users may be distrustful of the new (unknown) technology from the beginning. Finally, the need for regular recharging of the device or its basic management.

Meeting the needs of older adults. One of the serious negative consequences of old age and concerns about old age is the social isolation of older adults and thus the failure to meet their social and emotional needs, which negatively impacts on their overall health and quality of life. Interactive technologies (software and/devices based on such technologies) make it possible to satisfy these needs. For the older adult population, voice assistants, interactive robots, and other technologies with elements of artificial intelligence capable of interaction however remain marginal technologies. The use of virtual reality, which can serve not only for rehabilitation purposes, but also compensatory in relation to certain leisure activities, which the older adult cannot implement for objective or subjective reasons, seems to be promising. Older adults can also satisfy their social, emotional, and educational needs through the use virtual reality tools by reducing or overcoming common barriers to participation such as fear of injury or fear of falling.

5. Assistive and rehabilitation devices

The area of SMART technologies is a rapidly and dynamically evolving field with new devices and technologies springing into life at an incredible speed. This constant innovation brings many new examples of technologies and devices in each of the reviewed categories. One technological category that is characterized by fast pace of innovation is the domain of assistive devices. This is an area of relevance not only to older adults but broadly to individuals suffering from various types of impairments, herein lie their main advantages and utility. The disadvantages can be high cost (when their use is not covered by health insurance), limited life or repair capability of the devices or

availability only in certain regions or selected languages. Many technologies are set primarily in English. If they are not used by English-speaking individuals, the language barrier may become the reason not to use the technology.

Meeting the needs of older adults. This category of technology fulfills dominant compensatory functions and satisfies the needs of older adults that are limited by functional limitations. By aiding and facilitating the execution of tasks of daily living, they help promote autonomous functioning and independent life for as long as possible. Despite this, older adults sometimes remain reluctant to adopt assistive devices, because it is difficult for them to accept, they require assistance. This reluctance combined with the apprehension to use digital or other technologies because of the generally low level of digital literacy or perceived competence, creates important barriers to use of such technologies. It is important to educate older adults about how these devices can help them compensate for the inevitable changes with aging (i.e. decline in function) and emphasize how their adoption can help older adults stay independent, achieve their goals and maximize their participation in social life. Gradual inclusion of these technologies/devices already in the productive age, would support their successful adoption in older adulthood.

Discussion

We attempted to create an intuitive and succinct categorization of available technologies for older adult care and pointed out their key advantages and disadvantages. We are aware that a universally valid categorization of smart technologies may be unattainable since some of these technologies meet the characteristics of several categories, or their classification depends on the way they are used by older adults. This can lead to other subcategories of smart technologies. However, we would consider such a complex classification to be counterproductive in relation to the implementation of smart technologies into the lives of older adults. Thus, we aimed to provide a digestible, yet research-supported and systematic overview of current technologies for older adults and older adult care.

An important addition of the presented overview of SMART technologies is the focus on the needs of older adults that can be fulfilled by using a specific technology. Linking the examples of technologies to the needs and evaluating them in the context of their actual use and function is often neglected. However, to increase the adoption of technologies in the reluctant groups/segments, it might prove highly beneficial to show what specifically given technologies aid with and which needs of older adults they could support or fulfill.

The review of available technologies showed that wearable technologies are increasingly being used to monitor health status. They can record and monitor real-time data such as physical activity, sleep metrics, and heart rate variables, which can directly impact care provided to older adults as well as clinical decision-making (Deng *et al*., 2023). They can also serve compensatory functions, helping to compensate for sensory or cognitive deficits (Toh *et al*., 2023). Additionally, wearable technologies can assist with everyday routine tasks and provide educational-entertaining functions (Wu *et al*., 2022).

Smart tools of daily living aim to facilitate the daily needs of older adults and can help maintain independence, improve quality of life, and reduce care costs for older adults (Facchinetti *et al*., 2023). However, the availability of these tools may vary for older adults depending on their perceived competence, awareness of their availability, technological features, cost, and privacy (Harris *et al*., 2022).

Noninvasive/unobtrusive technology can passively monitor both health indicators and the environment, providing valuable information for older adults or caregivers regarding their health status or safety. These technologies rely on feedback and data interpretation to unlock their full potential, enabling older adults to adjust their behavior or seek further evaluation or care. Additionally, these devices should ideally in the future provide outputs that can be effectively utilized

not only in follow-up clinical care, but also in the context of providing personalized care or as early warning signals (Baker and Xiang, 2023).

Complex SMART systems can enhance the capabilities of older adults in daily activities while preserving their autonomy. These systems should learn from the behavior of older adults and provide support, for example, in the form of reminders for tasks such as medication management or securing the front door in the evening. Smart home technology has emerged as a critical development that supports the wellbeing of older adults by providing tools and services for health, safety, and independent living (Turjamaa *et al*., 2020) These technologies not only improve the lives of older adults but also increase security, reduce costs, and free up time for other activities (Facchinetti *et al*., 2023).

Interactive technologies, such as voice assistants, interactive robots, and artificial intelligence-based interaction tools, have been shown to effectively meet the social and emotional needs of older adults (Sidner, 2015; Ostrowski, 2019). These tools can also be used for rehabilitation purposes and compensatory activities that older adults may struggle with (Rizzo, 2011). Furthermore, they can enhance mental health, particularly through cognitive-behavioral therapy for depression and anxiety, and assistive technology for individuals with dementia (Cangelosi and Sorrell, 2014).

Finally, assistive and rehabilitation devices for older adults are indispensable for older adults with functional limitations to maintain functionality and promote independence (Agree, 2014; Leite *et al*., 2016). In spite of this, these technologies are often underutilized and lack in user-centered design (Lancioni *et al*., 2019). To support successful adoption of assistive and rehabilitation technologies and enhance aging, independence, and social participation, it is important to educate older adults about the benefits of these devices, integrate them gradually into their daily routines as well as to reflect specific needs and cultural differences in populations of older adult (Begde *et al.*, 2024; Orellano-Colón *et al*., 2017).

Smart technologies will undoubtedly gain their place in the care of older adults as they hold the promise of supporting both independent, autonomous life for as long as possible, as well as aiding in the transition to assisted or institutionalized care. Indeed, the majority of older adults prefer to age and end their life in the comfort of their homes, and from an economic perspective, aging and dying in institutionalized care accrues higher costs (Miskelly, 2001). The development of new assistive technologies can make a significant contribution in the "aging in place" efforts by enabling older adults to safely live independently for as long as possible, and they could help with easing the caregiving burden as part of assisted or institutionalized care.

To discuss the various barriers in adoption of technologies by older adults and for older adult care is beyond the scope of this article and is extensively discussed elsewhere (e.g. Kampmeijer *et al*., 2016; Kruse *et al*., 2017; Elavsky *et al*., in review). There will undoubtedly be a natural, more significant penetration into the field of care for older adults because people for whom smart technologies are more natural will reach older adult age. The negative demographic development in the developed countries in connection with the aging of the population will place higher and higher personnel demands on medical and nursing staff in the relevant facilities, or time demands on the family in connection with deinstitutionalization trends. It will therefore be necessary to compensate for these claims using smart technologies. Such a trend can be observed in Japan, which is not only one of the most technologically advanced countries, but also the country with the most significant problems caused by population aging (Marukawa, 2022). By introducing smart technologies into the care of older adults, it seeks to alleviate the growing demands on medical care, care and family members caring for older adults. The categorization proposed by us, which is also intended and suited for persons who are usually authorities for older adults – physicians and other medical staff, nursing and professional care staff and other professionals in the field of social services, should also help to achieve this goal.

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Supplementary file

1. Wearable Technologies and Smart Tools of Daily Living

1.1. Wearable technologies

Examples. Examples of specific wearable technologies of relevance to the needs of the elderly are devices for monitoring different aspects of physical condition or different physiological indicators such as chest belts, rings, or various sports sensors can be used separately or in combination with a smartwatch or mobile application. Similarly to smartwatches, smart shoes can contain accelerometers, gyroscopes, magnetometers, atmospheric pressure sensors, ambient environmental sensors, and other sensors to provide feedback on movement, activity, or gait through a mobile app. Interestingly, although highly relevant from a disease prevention standpoint, fitness and sports oriented wearables are typically not targeting older adults as the target customer population and are not being developed with specific elderly needs in mind (e.g. display is too small, not bright enough, or interface is too complicated).

Further, chips, pendants, wrist scanners, or other similar devices using infrared or other technology are used in care facilities or hospitals to identify or track clients. E-textiles and smart clothing enable

the implementation of electronic functions in clothing, or the incorporation of microelectronic devices, including temperature sensors, batteries, gas analyzers, photovoltaic components, LEDs, and the like. At present, these garments are already in the so-called third generation, when the garment itself has the function of a sensor. Many companies offer pressure, temperature, and deformation sensors for this purpose. They can be used wherever there is a need to monitor vital signs (not only in patient populations), scan ECG, collect data such as sports activities, monitor users when handling hazardous materials, and in many other places, including the fashion industry. Smart glasses or wearable computer glasses can change their optical properties and come with augmented reality (AR) overlays that have been used to assist older adults with cognitive impairment with tasks of daily living (e.g. such as help navigate them in the preparation of tea) (Rohrbach *et al*., 2019). The same technology has been used in training healthcare workers in terms of dementia care (Jones *et al*., 2021).

Alternative technology, still under development, are smart contact lenses which should provide users not only with the correction of common eye defects, but also, for example, the ability to measure sugar levels (through the analysis of eye fluids), present a head-up display (with AR functions) or with an integrated camera and zoom features (Altman, 2022; Zhu *et al*., 2022).

1.2. SMART tools of daily living

Examples. Smart spoons were created for people with nerve disorders that cause uncontrollable hand shaking (e.g. Parkinson's disease) and sensitive sensors and algorithms to absorb up to 85% of stress, allowing the spoon to stabilize, allowing the user to eat independently (Abbasi *et al*., 2018). Monitoring food or fluid intake can be made easier with the use of products such as smart mug or bottle. These products monitor the temperature of the beverage, can warn if temperature is too high for consumption, can maintain desired temperature and more importantly also monitor intake. Smart (automatic) drug dispensers can remind drug use and report to authorized users whether and when drugs have been dispensed. They usually have a timer to protect against overdose or unauthorized access. Smart thermometers allow you to quickly measure body temperature from the forehead or temporal lobe area. They monitor all measured values and allow one to connect to a smartphone where the temperature readings of one or more people can be monitored and stored. Smart weighing devices work closely with the connected smartphone application to compare current and historical body values. They automatically send information to the phone and monitor different parameters such as weight, body water content, fat ratio and muscle mass. Smart canes offer a potential solution not only for seniors but also the visually impaired. For example, some devices allow you to connect to a mobile phone, pair with Google Maps and communicate with the user via touchpad or voice. The cane emits ultrasound in the area around the user and when it detects an obstacle, it vibrates, and it can also provide voice information about the exact location, the nearest shops or bus stops, etc. Some smartphones often allow you to send GPS location over the Internet along with heart rate or user temperature information. In case of suspicion of a health problem or accident, the stick is able to send an emergency signal even with the current position where it is located.

2. Noninvasive/unobtrusive technology

2.1. Passive technologies monitoring the environment

Examples. Technologies that can be included in this category are, for example, video cameras and remote monitoring systems. They can also be connected to motion sensors and/or integrated with heat/smoke detectors (usually within a smart home) to trigger a fire alarm, notify a person, or trigger a call to a relative (or emergency services) who can evaluate the situation and, if necessary, send

help. The most often used technology for motion detectors is infrared light technology, which can also be used to map whether a senior is moving around in a location where they could potentially be injured. Electromechanical sensors can also be used as part of door alerts that can trigger an alarm if the senior is sleepwalking or leaves the room or apartment at night or at other times. Automatic lights reacting to the surrounding environment can adjust the intensity of light, smoke alarms (optical or ionization alarms), fire detectors all play a role in maintaining a safe environment for seniors. Stove sensors/cooker controls (often part of smart homes) monitor whether there is a reason to have the stove on or how high the temperature is. Other devices (automatic heating, ventilation, humidity, air, dust detectors, electricity consumption monitors) may be additional components in smart-home systems.

2.2. Passive technologies monitoring health

Examples. Concrete examples include sensors in the furniture that can be used to monitor a person's activity, movement and/or presence (e.g. in bed), heart rate and respiratory rate, temperature. During sleep, heart rate can be measured using sensors with such accuracy that heart rate variability (HRV) can be reliably evaluated. HRV parameters have been linked to a number of health indicators including hypertension, apnea, Parkinson's disease, and progression of Alzheimer's dementia. Although the interpretation of HRV has not yet become a standard clinical tool in elderly care, it shows potential in practical applications given the technical competency with which it can be easily, unobtrusively measured in the home environment (Hickey *et al*., 2021; Liu *et al*., 2022; Manser *et al*., 2021).

Other applications of passive technologies in the environment can include sensors in bed capable of monitoring sleep phases (apnea, hypopnea, snoring or sleep quality) with similar accuracy as wearable fitness bracelets, camera-equipped toilet bowls capable of detecting dehydration, urinary tract infections and diseases caused by *Clostridium difficile* and noroviruses (which are among leading causes of hospitalization of the elderly).

2.3. Passive technologies monitoring behavior

Examples. For fall detection a range of devices are available including camera systems, radio frequency sensors (mounted to ceiling or walls), electromagnetic or other pressure sensors (in pads, furniture) that detect falls and can send automated alerts to emergency systems or a predefined group of caregivers. Similarly, for movement detection there is a range of technologies capable of monitoring movement, lack of movement, or one's location. These include closed-circuit television (CCTV) camera systems that represent the simplest and cheapest solution. Image analysis is already so advanced that it can take place directly in a microcomputer connected to the camera without the need for a central server. Movement can also be monitored through floor pressure sensors, either using very precise (and rather expensive) solutions or more affordable basic solutions capable of detection of basic positioning. These sensors are placed on the floor, dividing the room into areas (pixels) of one meter, for example. Even in this case, it is possible to find out whether the person is standing, sitting on a chair or lying on a bed. Passive infrared sensors or PIR detectors (known from security systems) record the person's movement, not the position, and can be used, for example, to turn on ambient lighting under the bed when the client gets out of bed (color can adjust to time of day). Finally, radar, infrared (NIR, FIR) or laser (LIDAR) detectors can maintain a three-dimensional image of a room in which moving objects can be traced.

A specialized application related to monitoring movement of the elderly has to do with systems for detection of a person leaving an area or "safe" zone. These applications are suitable primarily for institutions caring for older adults with special needs (e.g. those with dementia) but can be useful also in home-care when care is not available 24 h a day. Light barriers can be used, for example, in doors and alert caregivers or the nurse's station when a client leaves a "safe" area. This solution is the cheapest of all variants and the simplest in construction. However, it provides no additional

information about the client or their whereabouts. These limitations can be overcome with devices utilizing global positioning system (GPS) or Bluetooth devices, but GPS devices do not work well (or with high precision) in buildings, whereas Bluetooth is limited outside of buildings. Radio-frequency identification (RFID) chips use electromagnetic fields to automatically identify and track tags attached to objects. In some care facilities, all laundry is equipped with passive RFID chips. The outgoing client then triggers an alarm when passing through the security frame (similar to how tagged goods are detected in a supermarket). Face recognition technology can also be used for purposes of detection of movement or leaving a "safe" zone (in some countries this is applied at airports in combination with measuring the temperature of the arrivals, for example). These approaches may not be practical and feasible to use in elderly care, plus they again encounter problems with privacy policies (such as GDPR – although solutions can be found such as signing a consent, short-term storage of features to recognize the face of incoming people and deleting them after passing in front of the camera when leaving the object, etc.).

3. Complex SMART systems

Examples

A typical example of complex SMART system is a smart home system that controls a certain area of the smart home (e.g. blinds on windows) and can provide zone and regulation of heating and cooling or ventilation. Similar systems can detect, for example, water leakage and then immediately stop the main supply, detect fire, monitor the condition of doors and windows (closed/open), detect the movement of people, use electronic door locks, indoor and outdoor cameras, regulate heating, control air conditioning, monitor through temperature, humidity and CO_2 sensors, ventilate, control lights, blinds, shutters, irrigate, control electrical appliances, thermostat, measure electricity consumption, manage water and much more. When securing a smart home, it is then possible to control individual tools with a smartphone, either separately (each device separately, for example via specific software) or through a central unit (hub).

4. Interactive technologies

Examples

For example, companion robots in nursing homes can converse with clients, play games with individuals, interpret jokes or lead a mobility program for seniors (Pedersen *et al*., 2018). An interactive table can be used for cognitive training, entertainment, or activation for seniors in different settings (home, community center, hospital, nursing home). Virtual reality (or augmented virtual reality) can be used for activation and entertainment as well as for therapy/rehabilitation (Jones *et al*., 2021; Putrino, 2014). Clients in nursing homes can, for example, "visit" places and virtually travel. Mostly in the phase of research development are virtual reality systems that offer fall prevention training (Dermody *et al*., 2020) or facilitate activities of daily living in individuals with cognitive impairment (more in the next section).

5. Assistive and rehabilitation devices

Examples

Assistive devices allow older adults to compensate for problems with impaired vision, hearing or movement. Assistive listening devices allow you to amplify the phone, add subtitles or connect due to mutual compatibility with certain types of hearing aids. Furthermore, digital (smart) hearing aids, which are not primarily intended for seniors but can improve listening quality, are almost unnoticeable and allow one to adapt to listening through a smartphone in various situations.

Similarly, smart glasses can be a substitute for vision (smart blind glasses). The camera in the glasses can read text, recognize faces, products, banknotes and much more. It can convert a visual image into text that it reads to the user. Smart wheelchairs also fall into this category and beyond enabling movement (as other typical wheelchairs), they can be equipped with sensors, alarm and touch screen control, for automatic obstacle detection, and can have even more sophisticated built-in tools that also use aspects of artificial intelligence (AI). Various telehealth monitoring devices and systems also fall in this category, enabling older adults to monitor key health indicators with a clinician's guidance from the comfort of their home or delivering rehabilitation services into their home.

Source(s): authors' own creation.

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