IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 16 March 2023, accepted 3 April 2023, date of publication 12 April 2023, date of current version 18 May 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3266647

SURVEY

Smart Home Devices for Supporting Older Adults: A Systematic Review

MOOJAN GHAFURIAN[1], KANG WANG[2], ISHA DHODE[3], MANNAT KAPOOR[2], PLINIO P. MORITA[2,4,5,6], (Member, IEEE), AND KERSTIN DAUTENHAHN[1], (Fellow, IEEE)

[1]Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON N2L 3G1, Canada
[2]School of Public Health Sciences, University of Waterloo, Waterloo, ON N2L 3G1, Canada
[3]Department of Psychology, University of Waterloo, Waterloo, ON N2L 3G1, Canada
[4]Department of Systems Design Engineering, University of Waterloo, Waterloo, ON N2L 3G1, Canada
[5]Centre for Digital Therapeutics, Techna Institute, University Health Network, Toronto, ON M5G 2C4, Canada
[6]Institute of Health Policy, Management, and Evaluation, University of Toronto, Toronto, ON M5T 3M6, Canada

Corresponding author: Moojan Ghafurian (moojan@uwaterloo.ca)

ABSTRACT Smart home devices have great potential for supporting older adults' health, safety, and independent living. Past reviews have identified only a few studies on the use of smart home devices for older adults and reported low technology readiness levels for the devices. This article presents a systematic literature review to identify the devices that have been used in studies with older adults, the setting in which those devices have been tested, the evaluation methods of the existing user studies, and the limitations. [Method] ACM DL, Scopus, PubMed, and IEEE Xplore were searched for a set of different keywords that included smart home sensors and older adults. The search was limited to "past ten years" (from the search date). Articles written in English that included user studies evaluating smart home devices with older adults were included. PRISMA guidelines were followed. [Results] 3847 unique articles were identified, 48 of which were included in the review. The articles represented research from a large range of countries. The majority of the studies evaluated the devices in participants' homes, followed by research lab settings. A few articles used other settings such as care centres and hospitals. The studies mainly evaluated the performance of the systems, followed by users' evaluations, such as perceptions and acceptance. Many studies had long-term interactions (more than a month). [Conclusion] there are still limited studies on the impact and benefits of smart home devices on older adults' quality of life, health, or well-being. Future studies are needed to better understand these benefits.

INDEX TERMS Smart homes, older adults, smart home devices, systematic review, research gaps.

I. INTRODUCTION

The average age of the world's population is increasing steadily and the proportion of older adults in the world is expected to double by 2050 [1]. While many older adults can live independently, aging is associated with major challenges and disabilities, affecting people's independence and quality of life. Smart home devices and environments have a great potential to improve multiple aspects of older adults' lives (e.g., health and independence). However, the work on designing and evaluating smart homes that can successfully support older adults is still limited. A recent review of the literature found the technology readiness levels of smart homes to be low [2], which could be a key factor affecting their success. Due to this low level of readiness, it is reasonable to expect that studies that directly evaluated smart home devices' interactions with older adults are also relatively limited.

Smart home environments can have many benefits for older adults. Aside from the sense of control [3], security [4], and confidence [4], they can support older adults' physical and mental health, e.g., by detecting adverse events such as falls [4], supporting older adults in staying at home longer, helping older adults to stay connected with younger relatives,

The associate editor coordinating the review of this manuscript and approving it for publication was Liang-Bi Chen.

and notifying relatives about situations that may pose a threat to an older relative's health. Understanding how older adults perceive and interact with smart home environments is a necessity for the development of smart home environments that are desirable for and adopted by older adults. Because of the potential of smart homes in improving the lives of older adults, in this article, we review existing studies evaluating smart home devices with older adult participants to better understand (a) the existing findings of in-person user studies with older adults, (b) types of devices that have been used in studies with older adults, (c) limitations of the existing studies, and (d) research gaps.

Over the past decade, several review articles have addressed a variety of specific topics related to smart home sensors, smart environments, and remote health monitoring, with some focusing specifically on older adults [2], [4], [5], [6], [7], [8], [9]. Chung et al. reviewed ethical considerations and issues related to the use of smart home devices by older adults [7]. Based on the sixteen articles included in the review, it was concluded that privacy and obtrusiveness issues were the most important factors affecting the adoption of smart homes [7]. Pal et al. [8] presented a systematic review of how smart home devices were used for improving older adults' quality of life, in a home setting. Five categories were identified as the "purpose" of smart homes for older adults in the review: (1) health monitoring, (2) environmental monitoring, (3) providing companionship, (4) social communication, and (5) recreation and entertainment [8]. This review presented the themes of how the smart homes were implemented and what their purposes were, as opposed to studying their effects on older adults' quality of life. Security and privacy were found in five of the reviewed articles to be crucial for designing smart home solutions [8]. Choukou et al. presented a scoping review to study users' acceptance and intention to use, as well as perceptions of usefulness and ease of use of ambient assisted living technologies [9]. The review concluded that older adults have concerns about the adoption of the technologies while they find them to be useful [9]. A lack of standardization in the assessment of assisted living technologies was identified, and the use of mixed-method research was encouraged for research on the usability of these technologies [9]. Some of these barriers to acceptance of smart homes and smart home monitoring were also discussed in a review by Liu et al., which included privacy concerns and technical issues [2]. This systematic review investigated the evidence for using home health technologies for supporting aging, with a focus on the readiness levels of those technologies [2]. Monitoring daily activities, mental health, heart conditions, and cognitive decline were reported to be the most common applications of the reviewed home monitoring technologies for aging. However, the review argued that there was no evidence on how these technologies could help address these conditions [2]. The level of technology readiness was found to be low [2].

In this article, we review studies that directly used and evaluated smart home devices with older adult participants while not limiting the setting to any specific setting (e.g., research labs or participants' homes), and to further investigate smart home devices that were directly used by/evaluated with older adults. We also report on the application areas, settings, and the evaluation outcomes. We discuss the limitations of the existing studies, as well as research gaps that can be addressed in future work. To the best of our knowledge, this is the first systematic review that addresses user studies in a variety of settings where older adults used/interacted with smart home devices.

II. RESEARCH QUESTIONS

This review addresses the following research questions:

- **RQ1:** Which smart home devices have been evaluated in past user studies with older adults?
- **RQ2:** In which applications have smart home devices been used, and in which settings were they evaluated?
- **RQ3:** What were the foci of evaluations and what were the outcomes?
- **RQ4:** What are the limitations of the reviewed studies, which need to be taken into account as potential considerations for using and evaluating smart home devices for supporting older adults in the future?

III. SYSTEMATIC REVIEW PROTOCOL

PRISMA guidelines were followed for conducting this systematic review [10]. In the following, we will discuss our eligibility criteria, information resources, search strategy, and data screening and charting processes.

A. STUDY SELECTION AND ELIGIBILITY CRITERIA

Peer-reviewed articles published in journals or conferences were included. They had to (a) be written in English, and (b) had been published during the past 10 years (up to the time of data collection).

Since the focus of this review is on evaluations of smart home devices with older adults, we only included articles that involved user studies with older adult participants who interacted with a smart home device. In order to focus this review, and due to several existing review articles on the use of social robots or other robotic technologies with older adults (e.g., [11], [12], [13]), we only included studies with robots if the robot was also connected with another smart home device/sensor or was operating in a smart home environment. If additional cameras and microphones were only added to allow controlling the robot and monitoring the safety of robot navigation then we excluded the study. Similarly, we excluded articles that were solely focused on the evaluation of a mobile application, unless it was used to control smart devices. Below are more details about the study's inclusion and exclusion criteria:

Publication type: Studies published in conference proceedings or as a journal article.

TABLE 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
• Peer-reviewed articles published in journals and conference proceedings • Studies that evaluate different smart home devices with older adult users • Studies on smart home environments evaluated with older adults • Articles that have user studies with older adults who used, tested, or provided opinions on a smart home device or a smart environment • Articles published in the past 10 years.	• Articles written in languages other than English • Articles that propose a smart home device but do not include user studies with older adults • Articles that described a planned or an ongoing study without reporting the results. • Studies that only involved a robot without a connection with smart devices and sensors. • Articles that were published prior to the past 10-year period considered in this review.

Population: Older adults as participants. Note that the definition of age for older adults differs in different countries, therefore we relied on the authors' categorization.

Device Type: Studies needed to have smart home devices or sensors that were used by the participants.

Outcomes: Studied had to evaluate the system in studies with older adult participants.

Table 1 shows the inclusion and exclusion criteria of the study based on the above-mentioned eligibility criteria.

B. INFORMATION RESOURCES

To be comprehensive and due to the multi-disciplinary nature of the studies that we wanted to include in this review, we searched four different databases: Scopus, PubMed, IEEE Xplore, and ACM Digital Library. Google Scholar was not used because of its limitations, such as limitations in the search functionalities and its precision [14]. IEEE Xplore and ACM Digital Library were selected to cover the literature on smart home technologies. PubMed was selected to cover the related literature on health/well-being where smart home devices might have been used. Scopus was selected as it covers literature in both domains.

C. SEARCH STRATEGY

The search terms were defined according to the study's inclusion criteria and included terms that met the older adults and smart home criteria. These terms were informed based on previous reviews that involved older adults and/or smart home devices (e.g., see [15], [16]), and were cross-checked by the liaison librarian for computer science at the University of Waterloo who has extensive experience in conducting systematic reviews. The search terms were then modified based on each database. This resulted in the following search terms: (''smart home*'' OR ''home based technology'' OR ''home monitoring'' OR ''smart sensors'' OR ''domotics'' OR ''gerontechnology'' OR ''telesurveillance'' OR ''smart technolog*'' OR ''smart building*'' OR ''Smart environment*'' OR ''Ambient Assisted Living'') AND (''older adult*'' OR ''elder*'' OR ''senior*'').

The final search was run on May 31st, 2021, covering all articles that have been added to these databases until that date. All databases were searched for title, abstract, and keyword, modified for each database: title, abstract, and keywords were searched in ACM and Scopus. All metadata were searched in IEEE Xplore. Title, abstract, and MeSH terms (''Geriatrics, aging, aged, internet of things) were searched in PubMed. We also limited the search to include articles published in the past 10 years. The past 10 years filter was selected on databases that allowed it (e.g., PubMed), and January 1st, 2011 was selected on those that required a date (e.g., ACM DL). We also added a filter to only include articles in English. In Scopus, we added a filter to only include articles published in a journal or conference proceedings. Table 2 shows a detailed example of the search used in ACM DL.

D. DATA SCREENING PROCESS

Our search resulted in a total of 5469 articles, which included 1621 duplicates. After removing the duplicates, a total of 3847 articles were left for abstract screening. The abstract screening was performed in duplicates by two of the co-authors (i.e., each paper was checked by two team members), and in case of a conflict, it was either resolved through meetings with both reviewers, or by getting a third opinion from another co-author. A total of 3326 articles were removed during the abstract screening process, and the full text for three articles could not be retrieved. This left 518 articles. We then conducted full-text screening on those articles to check whether they met the inclusion/exclusion criteria. Each paper was screened by one of the team members (later checked by another member at the time of data extraction). In case of uncertainty, the decision was made in a meeting with 2 to 3 co-authors. This resulted in identifying a total of 48 articles as eligible articles that met our inclusion and exclusion criteria. Figure 1 visualizes this process.

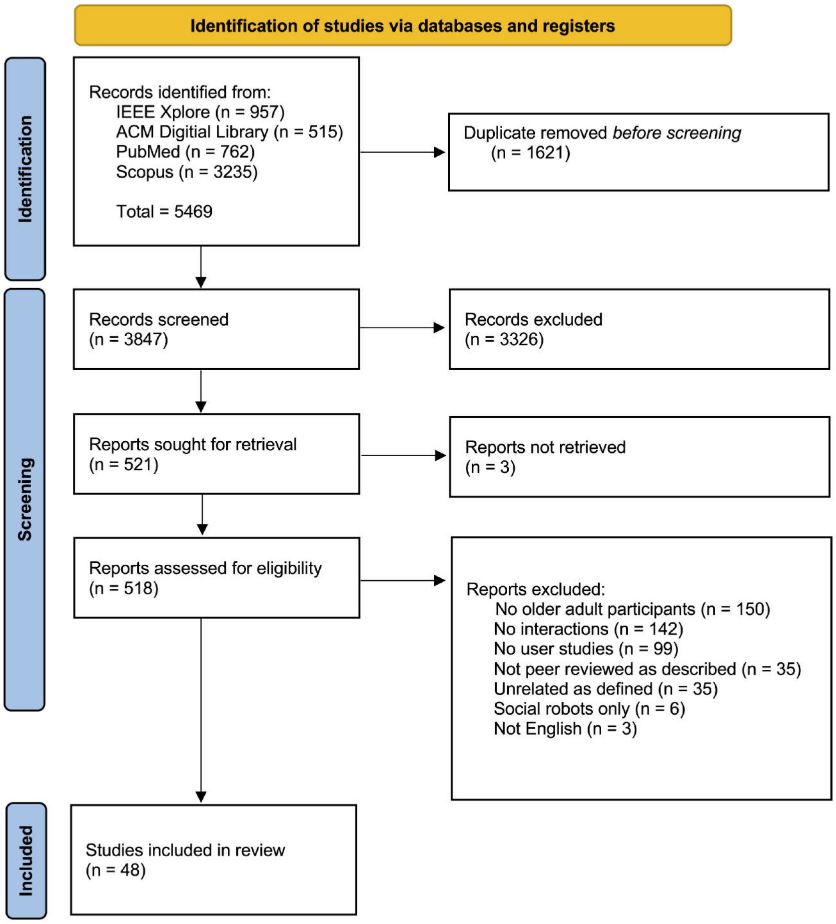


FIGURE 1. Data collection process visualized according to the PRISMA guidelines [10].

TABLE 2. Example of search queries - the query used in ACM DL.

[[Title: "smart home*"] OR [Title: "home based technology"] OR [Title: "home monitoring"] OR (Title: "smart sensors"] OR [Title: "domotics"] OR [Title: "gerontechnology"] OR [Title:"telesurveillance"] OR [Title: "smart technolog*"] OR [Title: "smart building*"] OR [Title: "smart environment*"] OR [Title: "ambient assisted living"] OR [Abstract: "smart home*"] OR [Abstract: "home based technology"] OR [Abstract: "home monitoring"] OR [Abstract: "smart sensors"] OR [Abstract: "domotics"] OR [Abstract: "gerontechnology"] OR [Abstract: "telesurveillance"] OR [Abstract: "smart technolog*"] OR [Abstract: "smart building*"] OR [Abstract: "smart environment*"] OR [Abstract: "ambient assisted living"] OR [Keywords: "smart home*"] OR [Keywords: "home based technology"] OR [Keywords: "home monitoring"] OR [Keywords: "smart sensors"] OR [Keywords: "domotics"] OR [Keywords: "gerontechnology"] OR [Keywords: "telesurveillance"] OR [Keywords: "smart technolog*"] OR [Keywords: "smart building*"] OR [Keywords: "smart environment*"] OR (Keywords: "ambient assisted living"]] AND [[Abstract: "older adults"] OR [Abstract: "older adult"] OR [Abstract: elder*] OR [Abstract: senior*] OR [Title: "older adults"] OR [Title: "older adult") OR [Title: elder*] OR [Title: senior*] OR [Keywords: "older adults"] OR [Keywords: "older adult"] OR [Keywords: elder*] OR (Keywords: senior*]] AND [Publication Date: (01/01/2011 TO 31/05/2021)]

E. DATA CHARTING PROCESS

Data charting was developed according to the research questions and through multiple iterations. Data charting was then tested by one of the team members and was finalized. Data from the papers were extracted based on this chart, and checked by another team member afterwards.

IV. RESULTS

The search identified a final set of 48 articles, 16 published in conference proceedings (including two peer-reviewed articles at a conference workshop and one extended abstract), and 32 journal articles. Figure 2 shows a word cloud created based on the titles of these articles. As expected, and in line with the scope of the search and search terms, "Home". "Monitoring", "Older adults", and "Evaluation" were the most frequently used words in the titles of the reviewed articles. Figure 3 shows the country of the authors of the reviewed articles (one added regardless of the number of authors. Note that in five cases the study was conducted by researchers in different countries, in which case we have added one count to the plot for each country. These articles were: [17], [18], [19], [20], and [21]). The majority of the articles were from researchers in France, Germany, and USA, followed by Italy. The number of articles published each

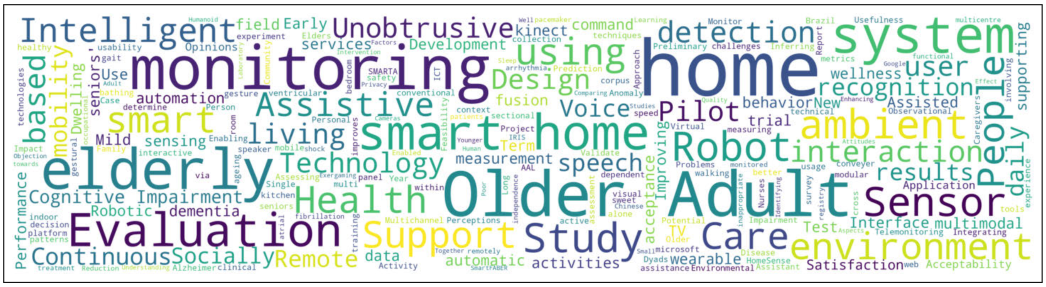


FIGURE 2. A word cloud presentation of the words used in the title of the reviewed articles.

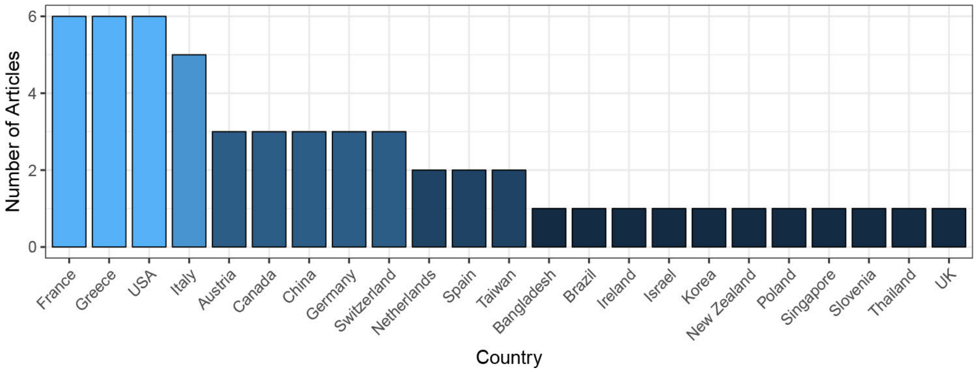


FIGURE 3. Number of articles by authors from each country. Note that if a paper had authors from different countries, it is counted for each of those countries in the figure.

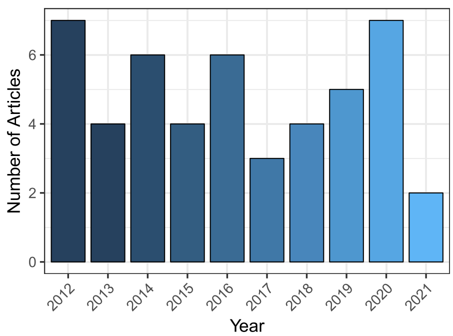


FIGURE 4. Number of articles per year up to the time of search in 2021 (May 31st).

year is shown in Figure 4 (up to the time of data collection, i.e., May 31st, 2021). Table A1 in the Appendix provides a summary of each reviewed article.

A. RQ1 - SMART DEVICES AND SENSORS

Table 4 shows how often each type of smart home device was used in the reviewed studies. In some cases, there was no clear description of the device type beyond its purpose, so we used the names and descriptions used in the reviewed articles. Overall, the results suggested that a large range of smart sensors and devices have been used in studies with older adults, with infrared and motion sensors, contact sensors, and smart lights being the most commonly used devices.

Table 3 shows more details about the devices that were clearly specified in the studies. When creating this list, based on the reviewed articles, we did not include microphones, cameras (except for depth cameras), screens, and PCs, as these devices are already extensively used in different types of studies that are not focused on smart home devices.

Table 3 also summarizes Technology Readiness Level (TRL) of each of these devices, which was determined by this review (i.e., was not reported in the reviewed articles). In the reviewed articles, TRL ranged from 6 (a level showing that a prototype of technology is ready to be demonstrated in an intended environment) to 9 (the highest possible TRL, where the actual system is ''flight proven''), with the majority being at TRL 9.[1] This range was indeed expected, as this review targeted user studies where the users actually used/interacted with the systems, therefore requiring a higher TRL for the devices.

Another information extracted and summarized in Table 3 is the purpose of each sensor. The purposes include, but were not limited to, data collection (different types of data such as electrocardiogram, pulse, blood pressure, etc.), detection of events around the home (e.g., motion, door open/close events, electric switch changes, fall detection, etc.), and providing a user interface for interactions with devices and virtual

[1]Technology Readiness Levels were assessed by one of the co-authors and confirmed by another co-author based on standard guidelines, e.g., https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level for guidelines and definitions.

TABLE 3. A summary of the sensors used in the reviewed articles. Note that TRL is measured based on the device used in the study (i.e., at the time that the study was run). Price range and a link to the product is provided in case it was available. TRL: Technology readiness level.

Sensor/ Device	Study	Purpose	TRL	Price Range	Company/Link to the Product
Domo Safety (a collection of ambient sensors such as motion, door, pressure, and smoke sensors)	[22], [23]	Monitoring activity (e.g., by detecting motion) and daily behaviour based on the sensor data.	9	NA	https://www.domo-safety.com
DomoCare ambient sensor system	[24]	Monitor activities	9	NA	NA
Microsoft Kinect	[25], [26]	Passive, In-home gait measurement	9	200-500	https://developer.microsoft.com/en-us/windows/kinect/
Electronic patch (self-developed)	[27]	Identifying people and detecting falls	6	NA	NA
Movement detector & usage detector (self developed)	[28]	Detecting active movements and electrical appliance usage	6	NA	NA
Nintendo Wiimote	[29]	As input device for mini-PC	9	50 - 100	NA
RFID reader (IPJ-REV-R420-GX11M)	[30]	Reading the data from triaxial accelerometer sensor to monitor people's activity	9	>1000	https://www.barcodesinc.com/impinj/part-ipj-rev-r420-gx11m1.htm
Triaxial accelerometer sensor (ADXL330)	[30]	Measuring the acceleration of motion	9	<50	https://www.analog.com/en/products/adxl330.html
AeonLabs	[31]	Magnitic contact sensor - Dectecting the door/window open/close	9	50-100	NA
Ecolink	[31]	PIR - Detecting motion	9	<50	https://discoverecolink.com/
Weight scale (UC-351PBT-Ci model)	[32]	Measuring weight	9	<50	https://www.aandd.jp/products/medical/bluetooth/uc351pbt_ci.html
PC-304 Spot-Check Monitor	[32]	Measuring heart rate, ear temperature, blood pressure, blood oxygen saturation, and glyce	9	>1000	CMI Health Inc
SMARTA patch (self-developed)	[32]	Recording single derivation electrocardiogram (ECG) and 3D accelerometry	7	NA	NA
KNX(Konex)	[32], [33]	A building management system that can monitor environment situation including contact sensors for doors, PIR sensors for movement, light switch sensors, electricity sensors, brightness sensors, and temperature sensors. Also for monitoring water tap, refrigerator, dishwasher doors, etc.	9	NA	www.knx.org
Arduino (Base AVR Easy-328 model)	[26]	Microcontroller. Used in the study to control the switching adapter	9	NA	NA
Xtion Pro - Ambient depth cameras	[34], [35]	Collecting image and depth data	9	200-500	http://xtionprolive.com/asus-3d-depth-camera
Plugwise sensor - Plug sensors	[34], [35]	Collects power consumption data	9	50-100	https://www.plugwise.nl/
Wireless Sensor Tag System - Tags	[34], [35]	Capturing motion data	9	<50	http://wirelesstag.net/
Withings Aura - sleep sensor	[34], [35]	Recording sleep durationand interruptions	9	100-200	https://www.withings.com/ca/en/sleep
Jawbone UP - wristwatch	[34], [35]	Measuring physical activity level	9	<50	https://jawbone.com/
SmartWalk	[32]	Fall detection	9	NA	H&S Quality in Software Srl
Voice assistant - Alexa	[36]	Virtual home assistant which has a wide range of voice-activated capabilities enabling assistance with the functions of independent living, communication, and entertainment.	9	NA	https://developer.amazon.com/en-US/alexa(also see Amazon.com for the hardware)
EMFIT QS bed sensor device	[23]	Recording heart rate, respiration rate, and sleep quality	9	NA	Emfit Ltd, https://emfit.com
Everion wearable sensor	[23]	Collecting vital signs and contextual data	9	500-1000	Biovotion
AX3 accelerometer	[23]	Records raw acceleration, temperature, and light	9	100-200	https://axivity.com/product/ax3
Philips 7000 Series Smart TV	[37]	Smart TV used for predicting health deterioration based on TV watching patterns	9	>1000	Philips, https://www.philips.ca/c-m-so/tv/p/7000series

TABLE 3. ***(Continued.)*** **A summary of the sensors used in the reviewed articles. Note that TRL is measured based on the device used in the study (i.e., at the time that the study was run). Price range and a link to the product is provided in case it was available. TRL: Technology readiness level.**

Sensor/ Device	Study	Purpose	TRL	Price Range	Company/Link to the Product
Hidea Solutions including activity sensors, door sensors, and flame and gas detector	[38]	Measuring activity, door opening/closing, fire/gas leak events	9	NA	http://www.hidea.kr/
Preventice BodyGuardian - ECG sensor	[24]	Measuring ECG signal, heart rate, heart rate variability, skin temperature, and respiration rate	9	NA	https://www.preventicesolutions.com/patients/body-guardian-heart.html
ICT-Supported Bath Robot including kinect sensor (self-developed)	[20]	Safely assists in various bathing tasks	7	NA	NA
EverspringHSP02 - PIR sensor	[39]	Motion detection	9	NA	NA
EverspringHSP02 - magnetic contact sensor	[39]	Detection of door open/close event	9	NA	NA
Aeotec ZW078 and ZW096 - smart electric switch	[39]	Detecting electric switch on/off events	9	100-200	http://www.aartech.ca/zw078/aeotec-zwave-heavy-duty-appliance-smart-switch.html
Implantable cardioverter defibrillator device	[40]	Collecting intracardiac electrogram data	9	NA	Medtronic St. Jude Biotronik
Robot-Era system (self-developed)	[41]	Provides six robotic services including shopping, garbage, communication, reminding, indoor walking support, and outdoor walking support	7	NA	NA
Robot Activity Support (RAS) system including a RGBD camera, LiDAR, and an Android tablet (self-developed)	[42]	Monitoring activity patterns, recognizing when an error is made in task execution and intervening to offer help in a multi-modal fashion.	7	NA	NA
Smart home cube remote control (self-developed)	[43]	Helping with controlling smart device in the home	6	NA	NA
Dem@Care solution including a wearable fitness tracker, a sleep monitor, motion sensors, audio, video and smart plugs. (self-developed)	[44]	Assist with multiple tasks for independent living	7	NA	NA
Wii Balance Board - pressure board	[45]	Used as an input device to track the movements of players during exergaming	9	200-500	NA
KSERA smart robot system including an interative robot, medical sensors, environmental sensors, IP sensors, and a camera (self-developed)	[17], [46], [47]	Monitors health and behavior; provides communication services; monitors the environment and notifies older adults or caregivers of dangerous situations	9	NA	http://www.aldebaran-robotics.co
EMCS (monitoring and care system) including 4 passive infrared motion sensors, one door contatct sensor(self-developed)	[48]	Measures movement patterns	7	NA	NA
Voice assistant - Google home	[49]	Voice control for smart home devices through google home	9	50-100	https://store.google.com/product/google_nest_mini?hl=en-GB
Hue lightbulbs - Phillips	[49]	Smart lights that can be controlled through an app or voice controlled system	9	50-100	https://www.philips-hue.com/en-us/products/smart-light-bulbs
WiFi Relay + Fan - Sonoff	[49]	Smart switch for power monitoring	9	<50	https://sonoff.tech/

assistants (e.g., Alexa[2]). The table also summarizes the price range for each device, as well as a reference to the product, if available. Note that this list only includes the devices in articles that clearly reported the type of the device, whereas many articles did not specify the device and only included the purpose of the sensor (e.g., "a sensor to detect falls").

[2]https://developer.amazon.com/en-US/alexa

TABLE 4. Devices included in the reviewed studies and how often each sensor/device was used in the studies.

Sensor/Device	Study	Num. of Studies
Infrared distance sensor/passive infrared sensor/passive infrared motion sensor/motion sensor	[21]–[23], [27], [28], [31], [33], [39], [41], [44], [48], [50]–[53]	15
Contact sensor/magnetic contact sensor/reed contact sensor/Dry contact sensor/door sensor	[19], [22], [31], [33], [38], [39], [41], [48], [51], [52], [54], [55]	12
Smart lights (light sensor/light switch sensor/lighting control/smart electric switch)	[33], [39], [41], [49]–[51], [55], [56]	8
Robots (ICT-Supported Bath Robots/Robot Era/Robot Activity Support system/mobile robot/KSERA robot/socially-assistive humanoid robot)	[17], [20], [41], [42], [46], [47], [57]	7
Wearables (wearable device/wearable fitness tracker/wristwatch/self-developed sensor wristband)	[23], [24], [32], [34], [35], [44], [51]	7
Energy monitor sensor/electricity sensor/electrical monitoring sensor/electricity meter/electrical usage sensor	[19], [28], [31], [33], [56], [58]	6
Microphones	[41], [58]–[62]	6
Temperature sensor	[33], [41], [50], [51], [56], [58]	6
Water monitor sensor/water meter/water leak sensor/water flow monitoring sensor	[19], [31], [33], [41], [56], [58]	6
Pressure sensor/pressure mat	[22], [31], [41], [45], [52], [56]	6
Camera/ambient depth cameras/Axis 215 PTZ Camera	[34], [35], [50], [53], [57]	5
Flat-screen TV/smart TV	[29], [37], [49], [51], [63]	5
Air quality sensor/environmental sensor	[31], [32], [51], [54]	4
Blood pressure monitor	[?], [32], [51], [64]	4
Humidity sensor	[41], [50], [56], [58]	4
RFID and other tages	[18], [29], [30], [34], [35]	4
Sleep sensor/sleep monitor/EMFIT QS bed sensor device	[23], [34], [35], [44]	4
Smart phone/care-phone	[18], [49], [51], [63]	4
Plug sensors/smart plugs	[34], [35], [44]	3
Presence sensor	[34], [35], [54]	3
Remotely controlled fan and heating control	[49], [55], [63]	3
Accelerometer	[30], [50]	2
Actuators	[18], [58]	2
Blood sugar sensor	[32], [64]	2
Blood pulse sensor/pulse oximeter	[32], [64]	2
Desktop/Asus EeeBox/EeeTop/laptop	[26], [29]	2
Fall detection device	[32], [55]	2
Fire/gas leak detector	[38], [41]	2
Implantable cardioverter defibrillator device/implanted device	[40], [65]	2
Microsoft Kinect/Kinect camera	[25], [26]	2
Tablet	[51], [55]	2
Voice assistant (Google home/Amazon Echo)	[36], [49]	2
Wireless weight scale	[32], [51]	2
Arduino board	[26]	1
Automatic switch/inactivity detector/all-off control	[55]	1
Brightness sensor/Lux sensor	[33]	1
Force sensor	[19]	1
Home emergency call	[55]	1
Mobility monitoring sensor/movement sensor	[38]	1
Nintendo Wiimote	[29]	1
Orientation light and led strips	[55]	1
Smoke sensor	[22]	1
Stove safety	[55]	1
Toilet flush sensor	[52]	1
Touch sensor	[50]	1
Visual doorbell	[55]	1
Wii Balance Board	[45]	1
Other devices (WIFI relay, audio/video recorders, self-developed electronic patch, switching adapter)	[26], [27], [44], [49]	1 each

B. RQ2 - APPLICATIONS AND SETTINGS

Figure 5 shows the study setting, as reported in the reviewed articles. The majority of the studies used the devices in a home setting, followed by a research lab. Note that some studies used more than one setting, so more than one data point represents them in Figure 5.

C. RQ3 - DATA TYPE, METHOD, AND OUTCOMES

The majority of the studies used and reported the results based on quantitative data (31 studies, see Figure 6). These studies used various methods for the evaluation of the systems (e.g., speaker recognition rate [61], command recognition rate [20], number of detected falls [27]), users' evaluations and ratings

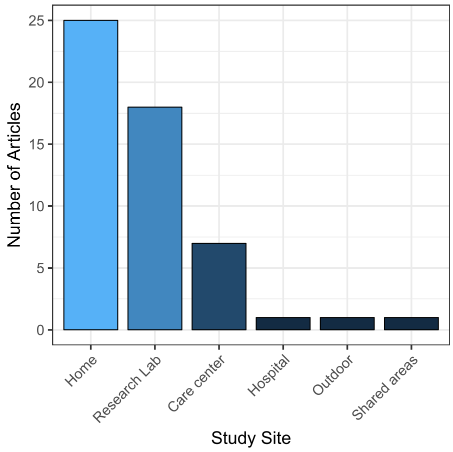


FIGURE 5. Location used for evaluating the devices. The Y axis shows the number of articles that used each location. Note that the research lab category included two instances of research labs that were similar to a real home.

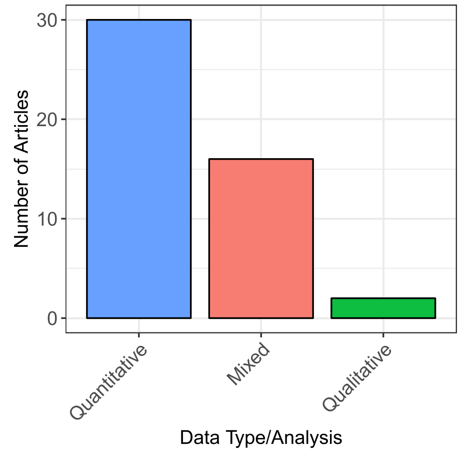


FIGURE 6. Type of data used in each study. Note that this shows the data type and, in some cases, statistical analysis or a proper qualitative analysis might not have been provided.

of the system (e.g., usability [55], user satisfaction [55], user acceptance [51], [63], or other impressions of the system, such as safety [41]), or the system's effect on users (e.g., impacts on independence, performance, and satisfaction [66]). Only two studies solely used qualitative data for evaluations, which evaluated users' opinions and perspectives through interviews [49], [62]. A mixed method was used in the remaining studies (17 studies), with similar measures used in the above-mentioned studies to measure different aspects of users' perceptions (e.g., acceptability and ease of use of the system [50]), systems' performances (e.g., identification of atypical patterns in users' activities [38]), and effect on users (e.g., improvement in sleeping times, reduction of anxiety and depressive symptoms [34] and changes in personal well-being [36]).

The studies measured and reported on three different general outcomes, described below and shown in Figure 7. We followed the guidelines provided in [67] for identification of these themes. Some studies had more than one evaluation type, so more than one entry is then shown in Figure 7.

Evaluation of the system: The majority of the articles evaluated a technical aspect of the system (28 studies), such as system performance, accuracy, or feasibility of using the system. This included using data collected through the system for training models predicting different aspects of users' health and well-being. Examples include correlations between TV usage and mental health [37], early detection of dementia [21], or assessing well-being based on users' daily activities [19]. Many studies evaluated accuracy, reliability (e.g., [26], [32], [48]), or feasibility (e.g., [23], [28], [56]) of using the smart home devices.

Users' evaluation of the system: 20 articles studied users' evaluations, including users' acceptance (e.g., [17], [50], [51]), opinions (e.g., [35]), preferences, perceived ease of use (e.g., [50]), and perceived effectiveness (e.g., [32]). These were measured through various methods such as questionnaires, interviews, and observations. Questionnaires included both self-designed and standard questionnaires. Examples of standard questionnaires were: Privacy Attitudes Questionnaire (PAQ) [68], Negative Attitudes towards Robots (NARS) questionnaire [69], system usability (SUS) [70], and Godspeed [71].[3]

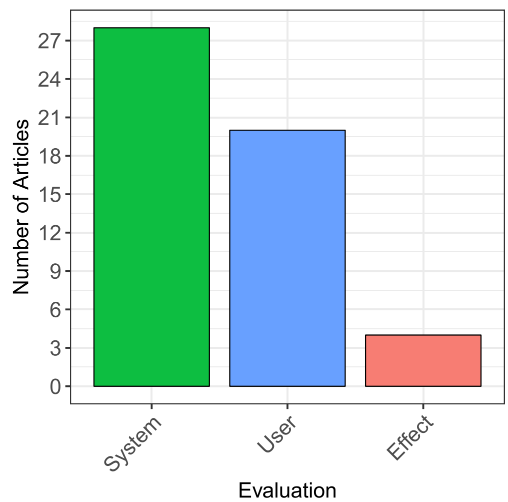


FIGURE 7. ***System*** **shows the number of articles that evaluated an aspect of the system's performance in the studies with older adults;** ***User*** **shows the number of articles where the system was evaluated by the users; and** ***Effect*** **shows articles that evaluated the effect of the system on users.**

Evaluation of the effect of the system on older adults: This category received significantly less attention in the

[3]http://www.bartneck.de/2008/03/11/the-godspeedquestionnaire-series/

past literature compared to the evaluation of the system or users' evaluation of the system ($p < .01$ based on binomial tests), with only four articles evaluating the effect of using the system on users [34], [35], [57], [66]. These studies suggested improvements in cognitive function [35], sleep quality [34], [35], daily activity [34], [35], personal hygiene [34], reduced TV usage [34], reduced anxiety and depressive symptoms [34], improved social life and interaction with the others [34], and increased functional independence [66]. One of the studies [57] reported both an increase and decrease in comfort when performing activities while being monitored [57], which was affected by the device type (e.g., camera vs. mobile robot) and the type of activity (e.g., intimate vs. dangerous). The findings also suggested privacy concerns of users and reported changes in older adults' behaviours for enhancing privacy (e.g., censoring speech in phone calls or hiding an image from the camera which was meant to be a surprise gift card for the caregivers) [57] (see associated systems used in each study in Table 3 and Table A1 in the Appendix).

D. RQ4 - LIMITATIONS OF PREVIOUS STUDIES

Reviewed articles emphasized a range of different limitations. The limited number of participants was one of the most commonly mentioned limitations in the studies [20], [24], [33], [35], [36], [37], [38], [40], [55], [56], [58], [63]. As many of the studies were conducted in participants' homes, and as our review only focused on studies with older adult participants, challenges with recruitment of larger groups of participants are, to some extent, expected.

Similarly, having samples/sample sizes that may not reflect or be sufficient for using the system in the actual context were reported as limitations by many studies [29], [49], [58], [58], [63]. These challenges included having technology-conscious older adults [49], being affected by a specific study region [36], [62], [63], or not having a random participant sample [29], [40]. These challenges are common in many user studies where technology is used and evaluated as participants self-select participation in studies (also pointed out by [36]). Involving the same participants in multiple sessions [41], lack of a control group [65], or before and after studies [56], and having participants that were not balanced in terms of gender [23], [41], [46], [63], or other demographic characteristics of the sample, were also identified as limitations of the reviewed studies.

Technical challenges occurring while running the studies were also among the most commonly mentioned limitations of the reviewed studies [20], [23], [26], [39], [42], [46], [59], [62]. These included challenges in the detection of participants [26], recognition of participants' speech [59], problems with connectivity [42], or challenges when multiple people were present at home (e.g., [23], [28], [39]; for identifying different individuals, recognizing their activities, etc.).

The short duration of the studies [38], [47], [55] was also emphasized in some of the reviewed articles as limitations, a challenge that is faced in many other studies when assessing technologies (e.g., social robots [72]), while other articles conducted long-term (months or years) evaluations of the systems. Similarly, not having a real-world setting was a limitation in some of the reviewed studies [61], [62], while many others evaluated the systems in an actual home environment (see Figures 5 and Table A1).

V. DISCUSSION, GAPS, AND FUTURE DIRECTIONS

We reviewed articles published in the past ten years where a smart home device was used and evaluated in studies with older adult participants. We presented an overview of the existing smart home devices used in the reviewed studies. The applications and settings of the existing studies, data types and outcomes of the studies, and limitations of the existing studies were discussed.

One major research gap that was identified in this review is evaluating the effect of smart home devices on older adults' quality of life, health, and well-being. The majority of the articles tested and evaluated the performance of the smart home devices, or studied users' acceptance and opinions. However, while improving quality of life and assisting older adults were common research goals in most of the studies, only a few investigated how smart home devices actually affected the quality of life of older adults. This suggests that despite the great potential of smart homes in improving older adults' lives, the research in this area might still be in its infancy, and many more studies on the influence of smart home devices on older adults' lives are needed to better understand the effects and benefits of these devices for supporting older adults, and to understand factors that can contribute to their effectiveness. This gap was raised in a 2008 review by Demiris et al. (2008) [15] (published 14 years before this review). Demiris et al. (2008)'s review included 20 articles, abstracts, and webpages, with most studies focusing on feasibility and technical solutions, and with a few tests in laboratory settings and with a limited number of participants. Since then, we have seen a larger number of user studies with older adult participants and in different settings being published, with many conducted at participants' homes. However, despite the increase in user studies and advancements in smart home devices, evaluating the effects of smart home devices on older adults' lives still remains a challenging gap that needs to be addressed in future work.

Aside from the limitations raised by the reviewed studies (e.g., limited participants, gender imbalances, participants with specific demographics, or limited data sample sizes), one of the common limitations we found in the studies was that they did not report the type of devices and only reported on the data that the devices collected. The device type is important information that should be reported, as it can affect the interpretation of the results (e.g., understanding the accuracy of data collection, participants' preferences of specific products, etc.) and allowing replicability of the studies. Another limitation was that in some cases the methodology and results were not described thoroughly, as was also pointed out in a 2013 review [27].

One of the common technical challenges, which was also identified in a review by Liu et al. [2] was to account for multiple residents, especially where users' activities were being monitored. This can limit the performance of the existing systems to homes with a single resident. Future studies on improving the performance of smart homes with multiple residents can be beneficial in expanding their potential for supporting older adults. This could also influence the study setting. Most of the reviewed studies evaluated smart homes in a home setting, followed by a research lab, while other types of technologies, such as social robots, have been more commonly tested at care centres. This could be in part due to challenges related to having multiple residents, as well as privacy and security issues that can affect the adoption of these technologies in care centres.

Therefore, aside from the need to have more studies on the impact of smart home devices on older adults, it would be beneficial to study how each of the devices can benefit individuals in different settings (e.g., individuals' homes, a room in a care centre, or a common/shared area), and how they need to be adjusted for different settings. Similarly, privacy considerations may also be different according to the setting and context. For example, [57] discussed a situation where constant monitoring could reveal some information that the user does not wish to share with caregivers (i.e., planning a surprise for the caregiver in this case [57]). While in most of the existing studies researchers specified the type and frequency of data collection, future studies can consider empowering users themselves to control and make decisions on the type and frequency of data collected by the system (even if this means limiting the system's functionalities), which could lead to better acceptance and adoption.

The reliability of smart home devices in user studies is another important factor to consider, as also emphasized in [7]. Many studies reported different types of technical issues, which can affect the performance and acceptance of the devices. Unlike the review by Liu et al., which found the common readiness levels to be at TRL 6 [2], we found high technology readiness levels for the devices used in the reviewed studies, with the majority being at TRL 9, followed by 7. This can be because the current review focused on user studies with smart home devices, many of which were conducted over a longer period such as weeks or months, which requires a higher technology readiness level for the devices used.

VI. CONCLUSION

This article presented a systematic review of user studies on smart home environments and devices for supporting older adults, which used or evaluated smart home devices in studies with older adult participants. Results showed (1) a range of devices that have been used in the studies with older adults, along with information about the devices, (2) different settings where the smart home devices were used/tested in studies with older adult participants, (3) data types, evaluations, and outcomes, and (4) limitations of the studies. Based on these results we discussed research gaps and directions for future work, such as limited user studies on the impact of smart home devices on older adults' lives, health, and well-being, as well as limitations in participants groups, technical challenges, challenges with supporting multiple occupants, and limitations in reporting the methodology. Overall, it appears that smart home environments have great potential in supporting older adults, but significant future work is needed to better understand their potential impacts.

VII. LIMITATIONS

Our review had several limitations. While we attempted to be comprehensive with our search queries and modified them based on meetings with the Librarian for Computer Science at the University of Waterloo, it is always possible that some articles might not have been found. For example, they were not identified if they did not contain any of the search keywords. Although our review only included studies with the devices being used by actual participants, to increase comprehensiveness, we did not add any keywords for user studies and manually screened the papers for including those that had user studies. This resulted in a significantly larger number of papers for the screening stage, prolonging the time of review. Further, as the included reviewed articles were all written in English, studies published in a language other than English were not considered.

Different databases may apply a 10-year condition differently. For example, some allowed us to clearly define the dates for the past 10 years (e.g., ACM DL), while others did this automatically (e.g., PubMed). Also, as expected with review articles, the past 10 years refers to the time that the search was conducted (January 1, 2011 to March 31, 2021). Further, we did not verify the validity of the methodology and results presented in the reviewed articles and relied on the authors' reports. As there was missing information in some cases, our results on the data type may only reflect the type of data collected and not a proper data analysis on that data.

APPENDIX

Table A1 provides a detailed summary of the reviewed articles.

TABLE A1. Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
					System Evaluation						
2020	[39]	SE	Passive infrared (PIR) sensors, magnetic contact sensors, smart electric switches	Examining the concurrent validity of AAL monitoring reports and information gathered by care professionals using triangulation.	ADL with sensor firing	Home	One participant (female; 90yrs) with Alzheimer's disease	490 days	sleep habits, outings, cooking activities, hygiene, low mobility	Quant.	Most trends detected by the system were consistent with the clinical information gathered by the nurse, and some highlight information was not yet identified by the nurse, suggesting potential of the system for supporting health care services.
2020	[23]	SE	Passive infrared motion sensor, EMFIT QS bed sensor device, wearable sensor	Delivering a proof-of-concept for the use of multimodal sensor systems with pervasive computing technology for the detection of clinically relevant health problems over longer time periods.	Physical activity in the apartment, toilet visits, refrigerator use, and entrance door openings; Heart rate, respiration rate, and sleep quality; Vital signs and contextual data	Home	24 participants(mean age 88.9, 79% female)	1 to 2 years	Correlation between sensor data and health-related data collected from the weekly visits of the seniors by health professionals, including information about physical, psychological, cognitive, and behavior status, health problems, diseases, medication, and medical diagnoses	Quant.	Monitoring of seniors with a multimodal sensor and pervasive computing system over longer time periods is feasible and well-accepted, with a great potential for detection of health deterioration.
2020	[31]	SE	Magnetic contact sensors, passive infrared motion sensors, energy sensors, pressure sensors, water sensors and environmental sensors	Expending the knowledge about ambient-assisted smart homes for older adults by describing a novel and comprehensive ambient home-sensing platform, HomeSense.	room entry/exit, electrical consumption, luminance, humidity, temperature, toilet usage, location of occupant, and behavior	Home	21 participants (15 female and 6 male; mean age 75.6) with 3 or more comorbidities	3 years	summary time and frequency of various daily living activities	Quant.	The proposed HomeSense platform is able to support healthy living for older adults through 1) daily activity visualization and summary visualization of activity trends over time; 2) periodic reporting for case management; 3) custom real-time notifications of behaviors that may signal adverse events; and 4) advanced analytics that allow examining long-term health and behaviour trends that may signal system deficits, changes in habits, and/or risk or resilience over time.
2019	[20]	SE	ICT-Supported Bath Robots	Evaluating the effects of a user training on gesture-based human-robot interaction (HRI) between an assistive bathing robot and potential elderly robot	NA	Care center	25 participants (mean age 77.9) with bathing disability	Two testing sessions and a training phase	gestural performance command recognition rate	Quant.	Gestural performance and CRR significantly improved over training (p< .001). Improvements in gestural performance and CRR were highly associated with each other ($r = 0.80$˘$0.81, p < .001$). Participants with lower initial gestural performance and higher gerontechnology anxiety benefited most from the training.
2019	[38]	SE	Mobility monitoring sensor, door opening sensor, fire/gas detector	Testing the feasibility of a home mobility monitoring system as a supportive tool for monitoring daily activities in community-dwelling older adult.	activity amount, door open/close event, fire/gas break out event	home	8 participants (7 female and one male; mean age 80.38) with multiple chronic diseases	15 months	identification of daily activities patterns including sleep period, indoor activity level, and going out	Mixed	A typical patterns were identified with reference to baseline activity. Daily indoor activities were clearly differentiated by sensor outputs and discriminated atypical activity patterns.
2019	[56]	SE	Temperature and humidity sensor, switch, pressure, water meter, electricity meter	Reporting on a pilot study of a smart home for elders designed to continuously monitor senior adults' daily behaviors and the living environment of their residential homes using the application of unobtrusive sensors.	Indoor temperature, humidity; temperature of gas stoves; doors and windows event; occupancy of different rooms; water, electricity, and refrigerator usage; medicine consumption; sleeping and resting	Home	One participant (female, 72yrs)	3 months	thermal comfort by predicted mean value of temperature and humidity; quality of sleep; medicine compliance behavior; water usage; use of electrical appliances	Quant	The results indicated that the smart home for elders is a feasible way to analyze the behaviors (e.g., sleeping, cooking, water usage) of the elder and monitor the built environment (e.g., temperature, windows, and doors).

TABLE A1. *(Continued.)* **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
						System Evaluation					
2018	[53]	SE	Motion sensors, electromagnetic contact sensors, cameras	Exploring whether simple and wireless technology used in two different smart environments could add value to performance and rater-based measures of IADL when it comes to predicting mild cognitive impairment in older adults.	sensor firing, video	Research lab	48 participants (over 65 yrs); 26 cognitively healthy 22 mild cognitive impairment	45 minutes	Instrumental activities of daily living performance using memory and executive function z-score; Predictive relationship between IADL performance-based composite scores, cognitive performance composite scores, and MCI clinical diagnosis	Quant.	Sensor-based observations showed that participants with mild cognitive impairment spent more time in the kitchen and looking into the fridge and kitchen cabinets than cognitively healthy participants. Moreover, these measures were negatively associated with memory and executive performances of participants and significantly contributed to the prediction of mild cognitive impairment.
2018	[48]	SE	Passive infrared motion sensors, door contact sensor	Identifying older adults with poor sleep quality based on the movement patterns detected by motion sensors installed in different parts of the house	sensor firing	Home	39 participants(over 60 years old)	one year	sleep quality	Quant	The identification model achieved 84% classification accuracy and holds promise for improved accuracy with additional data points.
2017	[21]	SE	Passive infrared motion sensors	Early detection of dementia	Sensor firing	Home	68 participants (7 males, 61 females) with cognitively healthy	At least 3 years	Weekly online questionnaires, annual assessments (MMSE and CDR)	Quant	Detected mild cognitive impairment with an average area of 0.716 and 0.706 under ROC curve and precision-recall curve.
2017	[52]	SE	Passive infrared motion sensors, reed contact sensors, pressure mat and toilet flush sensors	Measuring gait velocity (as a predictor of fall risk and functional health)	Motion, pressure, door state	Home	3 participants (1 male, 2 female; mean age 84)	50 random weeks	KATZ, Assessment of Motor and Processing Skills assessments, Gait velocity both from sensor data and occupational therapist	Quant	Results showed that gait velocities can be measured with low variance. Compared with the walking speed values measured by the therapist, the estimated velocity is slightly lower.
2016	[54]	SE	environmental, presence, and contact sensors	Design of innovative methods and tools for continuously monitoring the functional abilities of the seniors at risk and reporting the behavioral anomalies to the clinicians	raw sensed events data	research lab and home	21 participants in lab environment (14 of them have early symptoms of MCI); one participant in real-home environment (female, 74yrs, mild cognitive impairment and medical comorbidities)	one day in lab environment; 55 days in real home environment	Abnormal behavior recognition performance using true positive, false positive, false negative, precision, recall, and f1-score.	Quant.	Experimental results, including comparisons with other activity recognition techniques, show the effectiveness of SmartFABER in terms of recognition rates.
2016	[44]	SE	motion sensor, wearable fitness tracker, sleep monitor, audio, video record devices, smart plugs	Presenting a comprehensive multi-sensor monitoring and feedback system to support independent living for elderly people with dementia or other conditions, and provide decision support for their formal and informal caregivers.	environmental data, health status of the individual	hospital and home	98 participants in Study 1 (aged 60-90; 27 with Alzheimer's Disease, 38 with Mild Cognitive Impairment, and 33 Healthy); 4 participants in study 2 (Mild Cognitive Impairment and mild dementia)	Study 1: 20 minutes; Study 2: 2 months	sleeping, eating, sociability, levels of activity, mood	Quant	In the hospital setting: a significant difference was observed between people with Alzheimer's disease and healthy individuals in their duration and number of attempts. People with Mild Cognitive Impairment (MCI) also performed better than those with AD. In the home setting: The system identified difficulties in daily living activities (e.g., sleep interruptions). Individuals were encouraged by caregivers to walk more, etc., which was monitored using their wristband trackers. Participants showed improvement in physical activity, as well as sleep and mood.
2016	[37]	SE	Smart TV	Predicting health deterioration based on TV watching patterns.	Daily TV usage	Home	Four female participants living alone	11 months	clinical tests (e.g., cognitive function, Montreal cognitive assessment, Friendship scale, physical tests, quality of life, etc.)	Quant	Significant correlation between TV usage time and mental health. Monitoring TV usage can help predict early signs of health deterioration.

TABLE A1. *(Continued.)* **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
System Evaluation											
2016	[22]	SE	Motion, door, pressure, and smoke sensors	Detecting anomalies in behaviour of older adults	Sensor firing	Home	40 participants (27 female, 13 male)	Four months	Questionnaires, daily activity journals	Quant	Proposed an approach capable of detecting significant behavioural changes, specially with an hourly detection method.
2015	[61]	SE	Microphones	Presenting an approach to provide voice commands in a multi-room smart home for seniors and people with visual impairments.	audio signal	research lab	11 participants (8 female, 3 male; mean age 71.71), 5 of them with visually impaired	20-40 minutes	Word Error Rate, Domotic Error Rate, Speaker Recognition Rate	Quant	The voice command recognition error rate was 3.2% in off-line condition and of 13.2% in online condition. For speaker identification, the average recognition rate is 70% for all speakers. However, it shows a high correlation between performance and training size.
2015	[60]	SE	Microphone	Developing an automatic speech recognition system to detect the call of elderly for an emergency when in a distress case.	voice signal (corpus)	research lab and home	24 participants in group 1 (age range 68-98); 95 participants in group 2 (52 non-aged people and 43 elderly people); 17 participants in group 3 (13 young adults and 4 elderly people)	Group 1: 48 minutes; Group 2: 6 hours; Group 3: 1 hour	Word Error Rate, Detection Error Rate	Quant	Only 67% of calls were detected when participants falling as they called for the help.
2014	[33]	SE	Passive infrared sensors, contact sensors, light switch sensors, water and electricity sensors, brightness sensors and temperature sensors	Investigating the relationship between the data collected from the ambient sensors in smart homes and the health status of residents	movement, door or window open/close, light, water, electricity usage, brightness/lux, temperature	care center	13 participants (6 female, 7 male age between 60 and 88)	28 days	standardized health questionnaires including anxiety, sleep quality, depression, loneliness, cognition, quality of life and independent living skills	Quant	Significant associations were found between the scores for each of the standardized health questionnaires and the ambient sensor data (absolute p-value between 0.343 and 0.788).
2014	[26]	SE	Kinect camera, laptop, Arduino board, switching adapter	Facilitating daily activities in a bedroom with the help control devices such as TV, fan, lights through remote control. Detecting and warn falling out of bed. Monitoring signs of abnormality.	Motion	Care centers and homes	10 participants (included younger adults)	Not mentioned	Accuracy	Quant	High accuracy was achieved for controlling devices, bed falling alerts, help signal, and unusual wake0up alerts.
2014	[58]	SE	Microphones, energy monitor sensor, water monitor sensor, temperature sensor, humidity sensor, actuators	Presenting a corpus made of 4 subsets acquired in daily living conditions in a fully equipped and complete smart home.	audio signal, temperature, humidity, energy and water consumption	research lab	21 participants in subset 1 (7 female, 14 male, age 22-63); 23 participants in subset 2 (9 female, 14 male, age 19-64); 16 participants in subset 3 (7 female, 9 male, age 19-62); 11 participants in subset 4 (8 female, 3 male, 50-91); 5 participants are visually impaired	Between 23 minutes and 48 minutes	Signal to Noise Ratio; speech duration"	Quant	This corpus was used in studies related to ADL recognition, context-aware interaction and distant speech recognition applied to home automation controlled through voice.
2014	[59]	SE	Microphones	Presenting an approach to improve voice command recognition at the decoding level by using multiple sources and model adaptation	Audio signal	research lab	11 participants (9 female, 2 male, 5 people with visual impairment)	20-40 minutes	Word Error Rate, Domotic Error Rate	Quant	The results show a recognition error rate of 3.2% in off-line condition and of 13.% in on-line condition.
2013	[65]	SE	Implanted device	Evaluating trends in atrial fibrillation (AF) burden following early AF detection in patients treated with pacemakers equipped with automatic, daily Home Monitoring function.	Atrial rate	Home	701 participants(278 female, 423 male, average 72.1 yrs for dual-chamber pacemaker group, 63 yrs for biventricular pacemaker group)	180 days	atrial fibrillation burden	Quant	At least one episode of AF was observed in 22.9% of patients with dual-chamber pacemakers and in 28.8% of patients with biventricular pacemakers. In both pacemaker groups, mean AF burden decreased significantly (P<0.05) over 180 days following the first AF detection. The number of patients with an AF burden >10% per month was significantly reduced over 6 months of implantation in both dual chamber and biventricular pacemaker recipients.

TABLE A1. *(Continued.)* **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type** ***gathered by the smart home devices*** **for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
System Evaluation											
2013	[25]	SE	Microsoft Kinect	Presenting a system for capturing habitual, in-home gait measurements using an environmentally mounted depth camera, the Microsoft Kinect.	Video data	home	15 participants(6 female, range 67-97 yrs)	2-6 weeks	Gait parameters	Quant	Kinect-based gait analysis systems deployed in the apartments of elderly residents in an independent living facility were able to continuously, unobtrusively identify walks and automatically generate in-home gait parameter estimates for the residents.
2012	[40]	SE	Implantable cardioverter defibrillator device	Investigating the impact of home monitoring system on the early detection of ventricular arrhythmia and inappropriate shock in daily clinical practice.	Intracardiac electrogram data	care center	69 aprticipants (mean 68.4 yrs, 25 female, 44 female) with ventricular arrhythmia	16 months	appropriate detection rate of ventricular arrhythmia, detection rate for inappropriate shock	Quant	The home monitoring group showed a higher appropriate detection rate of ventricular tachycardia (P <0.01) and ventricular fibrillation (P=0.02). The proportion of inappropriate shock was comparable in the two groups (6/11 in the non-home monitoring group vs. 1/7 in the home monitoring group; P=0.08).
2012	[19]	SE	Electrical monitoring sensor, Force sensor, Water flow monitoring sensor, Contact sensor	Presenting a novel mechanism to foresee the well-being of the elderly through monitoring and functional assessment of the daily activities with the help of sensor data fusion.	use of electrical appliances; daily usage of bed, couch, toilet and dining chair; open and close of the door operations	home	four households	6 days	wellness of older adults which is defined by two wellness functions	Quant	Results of wellness functions are able to determine how well (regular) the elderly are performing their daily activities in using their household appliances and encouraging to be applied in real-time monitoring for predicting the irregular behaviour of the elderly.
2012	[28]	SE	Movement detectors, electrical usage detectors	Presenting the remote monitoring and assessment of daily activities of older adults living alone at home, assuming that comprehensive profiles of daily activities at home can be captured by using simple and low-cost sensors in a less diverse.	active movements, television use	home	one female participant (75 yrs)	over 6 months	A set of activity features that measure the intensity, regularity and abnormalities of activity patterns is defined and demonstrated to quantify the characteristics and rhythms of daily activities of the subject.	Quant	Different rhythms of daily activities can be estimated from different locations at home, and distinct behaviors were shown between weekdays and holidays. Unusual activities have been detected by the system.
2012	[27]	SE	Infrared motion sensors, electronic patch	Designing and experimenting a complete monitoring system on a real site. The system consists in a motion sensors network deployed on the ceiling to monitor activities and an electronic patch worn by the subject to identify him and detect falls.	sensor occupancy, detection of fall	care center and shared areas	2 participants with Alzheimer's disease	several months	number of falls detected, average motion speed, distance covered, level activity	Quant	The monitoring system allowed to monitor the subjects 24/7. The preliminary results of fall detection function were promising: 7 falls on 8 were detected. The number of false alarms was reasonable with an average of one false alarm every week. The localization function permitted locating subjects in some areas of the hospital and in the garden. In case of alert message, the medical staff could immediately locate the subjects. The activities monitoring allowed medical staff to tailor a treatment for one subject followed."
2021	[55]	UE	Tablet, stove safety, orientation light, lighting control, led strip, visual doorbell, door detector, automatic switch, inactivity detector, fall detection in bath and toilet, all-off control, home emergency call, and heating control.	Studying usability, user satisfaction, and costs and benefits of different built-in smart home solutions	NA	Home	98 participants (76 female, 22 male; ages 65-95+; 35 in intervention and 63 in control group). Condition: physical disorders, impaired mobility, chronic pain, urinary incontinence	One month	Participants opinions about satisfaction about the installed smart home devices	Quant.	Usability, satisfaction, and price: performance was mostly positively evaluated. Smart home solution was rated to be better than the conventional mobility supporting tools (e.g., handholds).

TABLE A1. ***(Continued.)*** **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
Users' Evaluation											
2021	[36]	UE	Amazon Echo	Describe virtual home assistant use and usefulness from the perspective of older adults and their support persons	Initial virtual home assistant commands	Home	10 older adults (mean age: 75 yrs) and 9 support persons (mean age: 53 yrs). 13 female and 6 male. Condition: obesity, hypertension, type 2 diabetes, depression, atrial fibrillation, fibromyalgia, and history of stroke	60 days	Patient Reported Outcomes Measurement Information System (PROMIS), questionnaire on health and well-being, Personal Well-being Index (PWI), World Health Organization-5 (WHO-5) Well-Being Index, Macera Caregiver Burden Scale, interviews about how the devices was used and its usefulness	Mixed	Participant dyads had positive perceptions, including the potential for promoting aging in place. Challenges of learning the technology and replacing old habits with new ones, and recommendations for future functionalities and potential trainings were discussed.
2020	[24]	UE	Ambient sensor system wearable sensors (ECG, activity tracker)	Evaluating a new in-home monitoring system among home-dwelling older adults, family caregivers, and nurses for home care support	Daily activities and health-related events (e.g., sleep habits, fridge visits, mobility, door events)	Home	21 older adults (11 male, 10 female; mean age 85 yrs, range: 72-96), 13 family caregivers and 20 nurses. 16 with cardiovascular disease, 4 with diabetes mellitus, 15 with, and 8 with Dyslipidaemia	One year	Opinions of older adults, family caregivers, and nurses towards in-home monitoring system	Quant.	Majority considered in-home sensors to help with staying at home, improving home care and quality of life, preventing domestic accidents, and reducing family stress. More frequently favourable opinions toward ambient sensors than wearable sensors. Older adults and family caregivers were more enthusiastic than nurses. Barriers reported by nurses: fear of weakening the relationship with older adults and lack of time.
2020	[29]	UE	Asus TV, Asus EeeBox, wide touchscreen, Nintendo Wiimote, RFID, EeeTop	Providing social e-services: public care e-services, health suggestions, games and mind training activities, independent living voice communication, appointment management, task list, reservation management, tele-presence.	NA	Care center	14 participants (10 female, 4 male) over 70 yrs. Majority with a low education level. Low to no familiarity with smartphones, game consoles, etc. Not very familiar with computers/internet. Living alone at home, with a relative, or in a care center	Two sessions (2-hour session plus 15 minutes of training), one session for each setup	Two Questionnaires (familiarity with technology, etc., and evaluation of the system), observations while using the system, interviews	Mixed	Proposed system may reduce older adults' reluctance of using ICT by providing a familiar interface. Touch screen was preferred over the Wiimote for selecting buttons to browse, and both were preferred over speech commands.
2020	[63]	UE	Smartphone, TV, lamp, fan	To design and implement a mobile smart home control system	NA	Research lab	10 participants (7 female, 10 male), mean age 73.1 yrs	12 major tasks (5 minutes each)	Difficulty ratings, usability, satisfactory, and acceptance of the proposed mobile web application using System Usability Scale (SUS), Reactions and perceptions of the evaluation participant using Self-Assessment Manikin (SAM)	Quant.	The proposed application had a satisfactory acceptance level by the participants

TABLE A1. ***(Continued.)*** **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
						Users' Evaluation					
2020	[42]	UE	Robot Activity Support (RAS) system	Evaluate opinions of younger and older adults about design/performance of the RAS	NA	Research lab	26 younger adults (ages 18–29 yrs) and 26 older adults (ages 52–87 yrs). 34.62% of older adults had mild cognitive impairment	2 hours	comfort with technology, evaluation of robot characteristics, self-reported satisfaction, system usability	Mixed	No differences between younger and older adults' perceptions across a variety of factors (e.g., likability, cognitive demand). Both age groups expressed generally neutral opinions and rated full Video prompts as least helpful, effective, and liked. Robot's response accuracy, movement speed, alerting style, and system flexibility were suggested to be improved. Younger adults overestimated how much older adults would want a robot.
2019	[49]	UE	Google home, smart phone, TV, fan, lights, WIFI relay	To examine the potential of voice assistants for older adults in the context of Smart Home Technology	NA	research lab	7 participants (3 female, 4 male; mean age: 73.15 yrs)	NA	Interviews about opinions	Qual.	Observations suggested that participants were impressed by the range of possibilities and convenience of Voice Assistants (VA). Participants could naturally identify various already available applications of VAs and found them generally useful and empowering.
2018	[41]	UE	Robot Era, passive infrared sensors, pressure sensors under a chair/bed, switches on doors/drawers; gas, water leak, temperature, humidity, and light sensors; wearable microphone.	Supporting older adults to increase their independence	Voice, GUI inputs, environmental alerts (e.g., gas leak)	Home and Outdoor	45 participants. Session 1: 35 participants (22 female, 13 male; mean age: 74.97 yrs). Session 2: 33 participants (22 female, 11 male; mean age: 73.45 yrs). Criteria: positive evaluation of mental status, some required autonomy, and normal mental functioning	About 3 hours	Questionnaires, video recordings	Quant.	Rated impressions were positive about the use of the robot, especially when used outside the domestic environment (at a condominium or an urban area). Better scores by men. Colored lights in the eyes of the robot were found to be useful for communication. Participants reported to feel safer when using the robot because of its notifications about the dangerous situations such as gas leak, door being opened, etc.
2018	[64]	UE	Devices for detecting blood pressure, pulse, and blood sugar levels	To present a conceptual solution of modular panel for measuring health parameters	Physiological parameter	Research lab	Group 1: 5 participants over 60 yrs; Group 2: 12 participants younger than 60 yrs	Two sessions	Questionnaire on perspectives regarding the designed interface	Mixed	The simplicity of the interface was perceived well. Older participants may need more time to conduct certain commands, but most fully understood the interface.
2016	[45]	UE	ExerGames, Wii Balance Board (pressure sensors)	Developing an application that monitors body posture and balance of older adults during exercise games to improve body balance	Standing balance and movements	Personal space chosen by participants	10 healthy participants (3 male 7 female; mean age 72 yrs)	5 days	Exercise completion time, and questionnaire to evaluate the content and accessibility of the application and participants' satisfaction and exercise enjoyment	Mixed	Using application was rated high in enjoyment and participants expressed experiencing improved balance and willingness to play Exergames again in the future.
2016	[51]	UE	Tablet, smartphone, TV, newly developed sensor wristband, wireless blood pressure monitor and scale, and contact, light, motion, temperature, and air quality sensors	To examine the acceptance of the SmartSenior system by older adults	Frequency of use of each service	Home	35 participants (19 female and 12 male; ages 55-88). 4 left during the study. One participant with high blood pressure. Three used a walker or cane, and two used electric walkers	Average 45 days (range 21-56)	User acceptance (self-developed questionnaire, AUQ, in-home evaluations, logging data)	Mixed	Moderate to high user acceptance. The services for general assistance and health, such as audio/video communication, blood pressure monitoring, and communication with a health professional, were rated as very attractive. Promoting social interaction and reminder services were least used/accepted.
2014	[18]	UE	Sensors (details not mentioned), actuators, care-phone, and RFID readers	Autonomy of older adults and people with disabilities in a smart kitchen	NA	Research lab (living labs)	63 participants (40 male, 23 female). 31 formal/informal caregivers. 8 female participants under 60 yrs.13 visual, 13 hearing, 12 cognitive, and 23 motor impairments	NA	Observation notes by some users, situation questionnaire, user's opinion about using the system, i.e., usability, functionality, reliability, satisfaction, and future use	Mixed	positive results for usability, as well as sensory, physical, and cognitive accessibility were obtained. Potentials for supporting daily activities and reducing dependence.

TABLE A1. *(Continued.)* **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
2014	[17]	UE	Socially-assistive humanoid robot	Short-term and a long-term evaluation of a small socially assistive humanoid robot in a smart home environment	NA	Research lab	8 cognitively healthy participants, age mean 77 yrs, range 70-95	Six: 2 sessions over a 2 weeks. Two: 8 sessions over a 3 months	Acceptance through Almere Model	Mixed	The small humanoid robot was trusted by the participants. A cross-cultural comparison showed that results were not due to the cultural backgrounds. Long-term evaluation showed that the participants might engage in an emotional relationship with the robot, but perceived enjoyment might decrease over time.
2013	[62]	UE	Microphones	To develop and evaluate a new user-friendly technology for home automation based on voice command	Audio signal	Research lab	8 healthy participants (5 female, 3male; age mean 79 yrs, 71-88yrs), 7 relatives (5 female, 3 male), and 3 professional caregivers	45 minutes	Participants' perspective regarding voice command, system interruptions, communication with the exterior, and shared electronic calendar.	Qual.	Participants mainly discussed the interest of voice command and how it could improve security, autonomy and, to a smaller extent, loneliness. Concerns about privacy and using systems that would push them into a dependent situation.
2012	[47]	UE	KSERA system containing an interactive robot and smart environments sensors	To introduce a socially assistive robot that acts as a proactive communication interface in smart home environments	Users' health and air quality	Home	16 participants (2male, 14 female; age range 71-90 yrs, mean 77 yrs)	Two sessions	Participants' perspective to the system through questionnaires	Mixed	KSERA system and the robot were both rated as likeable
2012	[46]	UE	KSERA robotic system containing medical sensor, environmental sensor, IP sensor, and Camera	To evaluate the KSERA prototype in a real user environment in terms of technical functionality, reliability, usability, effects on quality of life, and human robot interaction	health status, indoor/outdoor environmental situations, video data (for detection of users' face and intentions)	Research lab	16 cognitively healthy participants (12 female, 4 male; age 71-90 yrs, mean 77 yrs)	NA	Questionnaires to measure individuals' perceptions of the robotic system	Mixed	Conversational abilities of the robotics system was perceived relatively well and robot was perceived relatively mindful, friendly, polite, and safe. Movements were perceived to be slow.
Effect on Users											
2015	[34]	EF	Ambient depth cameras,tags, presence and plug sensors, wristwatch, sleep sensor	Proposing a sensor-based system to support the daily life of people with dementia.	image/depth data, power consumption, motion events, user presence, activity level, sleep duration/interruptions	Home	One female participant diagnosed with aMCImd, 76 yrs, living alone at home	3 months	Patterns, time, and frequency of daily activities and electrical device usage, clinical interviews, participant's statements	Mixed	Improvements were observed in sleeping hours at night, interruptions during night (reduced), tv usage (reduced), personal hygiene, anxiety and depressive symptoms (reduced), activities of daily living (e.g., usage of iron, cooker, etc.), social life and interactions, and management of personal problems
2013	[66]	EF	Assistive technology sensors (not specified)	To evaluate the treatments in the Smart Home IRIS in terms of effects on occupational performance and functional independence of people	NA	Research lab	59 participants (29 female, 30 male; age range 24-81, mean 58yrs). Older adults and those with disabilities	8 months	scores of independence (motor and cognitive scores on Functional Independence Measures), Canadian Occupational Performance Measure (COPM), ratings for performance and satisfaction	Quant.	The use of assistive technologies and home modifications appeared to have impacts on increased functional, independence, better performance, and satisfaction
Mixed											
2019	[35]	UE, EF	Ambient depth cameras, tags, presence sensors, plug sensors, sleep sensors, wristband (watch)	To investigate the long-term effects of Assistive Technology combined with tailored non-pharmacological interventions for people with cognitive impairment	Daily activities and health status (e.g., sleep patterns, physical activity, machine usage, etc.)	Research lab	18 participants (15 female, 3 male; ages 62 yrs and over, mean 73 yrs), 12 with mild cognitive impairment and 6 with Alzheimer's disease	4-12 months	cognitive status (psychological assessment), daily activities, user statements and feedback, system usability (SUS)	Mixed	After several months, the experiment group showed statistically significant improvement in cognitive function compared to the control group. Those who received the sensor-based system showed improvement in domains such as sleep quality and daily activity, as measured by the multi-sensor system. Feedback collected from the participants suggested that the long-term use of multi-sensor system by people with cognitive impairment can be both feasible and beneficial.

TABLE A1. ***(Continued.)*** **Summary of the reviewed articles. Lit. stand for the literature, citing the article, Ev. stands for evaluation, Dur. stands for Duration, and D Type stands for the data/data analysis type. Under evaluation, UE stands for User Evaluation, SE stands for System Evaluation, and EF represents Effect on the users (see Figure 7). Data shows data type *gathered by the smart home devices* for the purpose of the study (if any). ADL stands for activities of daily living. Under D Type, Quant. stands for Quantitative and Qual. shows Qualitative. Note: for study location mentioned as "care centre", different wordings have been used across different papers such as "nursing home", "long term care facility", etc. We used care centre for all, for consistency.**

year	Lit.	Ev.	Devices	Purpose	Data	Setting	Participants	Dur.	Measures	D Type	Results
Mixed											
2017	[32]	UE, SE	Weight scale, fall detection device, wearable device, environmental sensors	To develop and test an innovative personal health system integrating standard sensors as well as innovative wearable and environmental sensors to allow home telemonitoring of vital parameters and detection of anomalies in daily activities, supporting aging	body weight, heart rate, blood pressure, blood oxygen saturation, ear temperature, glycemia, single derivation electrocardiogram, falls, 3D accelerometry, water tap, refrigerator, dishwasher door opening/closing	Care center	Phase 1: 15 healthy adults; Phase 2: 4 clinicians and 13 patients with cardiac disorders, ages: 53-81 yrs.	Phase 1: 3 months; phase 2: 2 months	Patients' perception of the effectiveness, acceptability and usability, and attractiveness of the system through questionnaire	Mixed	Positive perception of the system by patients and clinicians. Moderate system reliability of 65–70% evidenced some technical issues, mainly related to sensor integration, while the patient's user interface showed excellent reliability (100%).
2015	[50]	SE, UE	IR distance, light, temperature, humidity, and touch sensors, camera, accelerometer	Propose and evaluate a wearable sensor based older adult home care system in a smart environment	Sensor values	Research lab	10 participants, six 65-68 yrs, three 68-71yrs, and one over 71yrs. Two with low eyesight and one with hearing problems	4 days (11am to 5 pm each day)	System's response time, users' activitiy, questionnaire assessing acceptability, adaptability, ease of use, harmness satisfiability	Mixed	System's response time was highly dependant on bandwidth. Male participants had more positive responses. Participants in the younger age group had more positive responses
2012	[57]	UE, EF	Axis 215 PTZ Camera, Videre model mobile robot platform with a mounted with a mounted webcam	To evaluate users' perceptions of privacy and their tendencies to engage in privacy enhancing behaviours (PEBs) by comparing the three conditions: camera, a stationary robot, and a mobile robot	NA	Research lab (R-House Living Lab, a 5-room house used for HRI research)	18 participants (11 female, 7 male; ages 69-88) living independently	About 30 minutes	Privacy attitudes Questionnaire (PAQ) and Negative Attitudes towards Robots (NARS), and modified comfort with household activities (CHA) as pre questionnaires. Questionnaires measuring perception of home monitoring technologies (including Godspeed scale) and the modified CHA Questionnaire. Semi-structured Interviews about perceptions and reaction to monitoring technologies. Observations (video recordings).	Mixed	In home monitoring affected household activities of 15 participants, and participants showed more privacy enhancing behaviours in interactions with a camera.

ACKNOWLEDGMENT

This research was undertaken, in part, thanks to funding from the Canada 150 Research Chairs Program, and supported by the Centre for Bioengineering and Biotechnology (CBB) at the University of Waterloo. We would like to thank Rebecca Hutchinson, the Liaison Librarian for Computer Science at University of Waterloo for helping with design of the search query of this systematic review.

REFERENCES

[1] World Health Organization. *Ageing and Health*. Accessed: Jan. 24, 2022. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

[2] L. Liu, E. Stroulia, J. Nikolaidis, A. Miguel-Cruz, and A. R. Rincon, "Smart homes and home health monitoring technologies for older adults: A systematic review," *Int. J. Med. Inform.*, vol. 91, pp. 44–59, Jul. 2016.

[3] G. Demiris, D. P. Oliver, G. Dickey, M. Skubic, and M. Rantz, "Findings from a participatory evaluation of a smart home application for older adults," *Technol. Health Care*, vol. 16, no. 2, pp. 111–118, May 2008.

[4] E. Pietrzak, C. Cotea, and S. Pullman, "Does smart home technology prevent falls in community-dwelling older adults: A literature review," *J. Innov. Health Informat.*, vol. 21, no. 3, pp. 105–112, Jun. 2014.

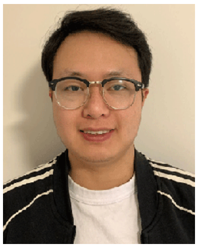
[5] S. Patel, H. Park, P. Bonato, L. Chan, and M. Rodgers, "A review of wearable sensors and systems with application in rehabilitation," *J. Neuroeng. Rehabil.*, vol. 9, no. 21, pp. 1–17, Apr. 2012.

[6] C. Harrington, A. Martin-Hammond, and K. E. Bray, "Examining identity as a variable of health technology research for older adults: A systematic review," in *Proc. CHI Conf. Human Factors Comput. Syst.*, Apr. 2022, pp. 1–24.

[7] J. Chung, G. Demiris, and H. J. Thompson, "Ethical considerations regarding the use of smart home technologies for older adults: An integrative review," *Annu. Rev. Nursing Res.*, vol. 34, no. 1, pp. 155–181, 2016.
[8] D. Pal, T. Triyason, and S. Funikul, "Smart homes and quality of life for the elderly: A systematic review," in *Proc. IEEE Int. Symp. Multimedia (ISM)*, Dec. 2017, pp. 413–419.
[9] M.-A. Choukou, T. Shortly, N. Leclerc, D. Freier, G. Lessard, L. Demers, and C. Auger, "Evaluating the acceptance of ambient assisted living technology (AALT) in rehabilitation: A scoping review," *Int. J. Med. Informat.*, vol. 150, Jun. 2021, Art. no. 104461.
[10] D. Moher, "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *Ann. Internal Med.*, vol. 151, no. 4, p. 264, Aug. 2009.
[11] J. Abdi, A. Al-Hindawi, T. Ng, and M. P. Vizcaychipi, "Scoping review on the use of socially assistive robot technology in elderly care," *BMJ Open*, vol. 8, no. 2, Feb. 2018, Art. no. e018815.
[12] A. J. Pearce, B. Adair, K. Miller, E. Ozanne, C. Said, N. Santamaria, and M. E. Morris, "Robotics to enable older adults to remain living at home," *J. Aging Res.*, vol. 2012, pp. 1–10, Dec. 2012.
[13] L. Hung, C. Liu, E. Woldum, A. Au-Yeung, A. Berndt, C. Wallsworth, N. Horne, M. Gregorio, J. Mann, and H. Chaudhury, "The benefits of and barriers to using a social robot PARO in care settings: A scoping review," *BMC Geriatrics*, vol. 19, no. 1, pp. 1–10, Dec. 2019.
[14] M. Boeker, W. Vach, and E. Motschall, "Google scholar as replacement for systematic literature searches: Good relative recall and precision are not enough," *BMC Med. Res. Methodol.*, vol. 13, no. 1, p. 131, Dec. 2013.
[15] G. Demiris and B. K. Hensel, "Technologies for an aging society: A systematic review of 'smart home' applications," *Yearbook Med. Informat.*, vol. 17, no. 1, pp. 33–40, 2008.
[16] R. Jamwal, H. K. Jarman, E. Roseingrave, J. Douglas, and D. Winkler, "Smart home and communication technology for people with disability: A scoping review," in *Disability and Rehabilitation: Assistive Technology*. Taylor & Francis, 2020, pp. 1–21.
[17] E. Torta, F. Werner, D. O. Johnson, J. F. Juola, R. H. Cuijpers, M. Bazzani, J. Oberzaucher, J. Lemberger, H. Lewy, and J. Bregman, "Evaluation of a small socially-assistive humanoid robot in intelligent homes for the care of the elderly," *J. Intell. Robotic Syst.*, vol. 76, no. 1, pp. 57–71, Sep. 2014.
[18] R. Blasco, Á. Marco, R. Casas, D. Cirujano, and R. Picking, "A smart kitchen for ambient assisted living," *Sensors*, vol. 14, no. 1, pp. 1629–1653, Jan. 2014.
[19] N. K. Suryadevara, S. C. Mukhopadhyay, R. K. Rayudu, and Y. M. Huang, "Sensor data fusion to determine wellness of an elderly in intelligent home monitoring environment," in *Proc. IEEE Int. Instrum. Meas. Technol. Conf.*, May 2012, pp. 947–952.
[20] C. Werner, N. Kardaris, P. Koutras, A. Zlatintsi, P. Maragos, J. M. Bauer, and K. Hauer, "Improving gesture-based interaction between an assistive bathing robot and older adults via user training on the gestural commands," *Arch. Gerontology Geriatrics*, vol. 87, Mar. 2020, Art. no. 103996.
[21] A. Akl, J. Snoek, and A. Mihailidis, "Unobtrusive detection of mild cognitive impairment in older adults through home monitoring," *IEEE J. Biomed. Health Informat.*, vol. 21, no. 2, pp. 339–348, Mar. 2017.
[22] O. Aran, D. Sanchez-Cortes, M.-T. Do, and D. Gatica-Perez, "Anomaly detection in elderly daily behavior in ambient sensing environments," in *Human Behavior Understanding* (Lecture Notes in Computer Science), vol. 9997, 2016, pp. 51–67.
[23] H. Saner, N. Schütz, A. Botros, P. Urwyler, P. Buluschek, G. du Pasquier, and T. Nef, "Potential of ambient sensor systems for early detection of health problems in older adults," *Frontiers Cardiovascular Med.*, vol. 7, p. 110, Jul. 2020.
[24] B. Pais, P. Buluschek, G. DuPasquier, T. Nef, N. Schütz, H. Saner, D. Gatica-Perez, and V. Santschi, "Evaluation of 1-year in-home monitoring technology by home-dwelling older adults, family caregivers, and nurses," *Frontiers Public Health*, vol. 8, Oct. 2020, Art. no. 518957.
[25] E. E. Stone and M. Skubic, "Unobtrusive, continuous, in-home gait measurement using the Microsoft Kinect," *IEEE Trans. Biomed. Eng.*, vol. 60, no. 10, pp. 2925–2932, Oct. 2013.
[26] Y. Booranrom, B. Watanapa, and P. Mongkolnam, "Smart bedroom for elderly using Kinect," in *Proc. Int. Comput. Sci. Eng. Conf. (ICSEC)*, 2014, pp. 427–432.
[27] Y. Charlon, W. Bourennane, F. Bettahar, and E. Campo, "Activity monitoring system for elderly in a context of smart home," *IRBM*, vol. 34, no. 1, pp. 60–63, Feb. 2013.
[28] C.-C. Yang and Y.-L. Hsu, "Remote monitoring and assessment of daily activities in the home environment," *J. Clin. Gerontology Geriatrics*, vol. 3, no. 3, pp. 97–104, 2012.
[29] A. Andreadis, R. Zambon, and O. Parlangeli, "TV as an experience conveyer for better acceptance of ICT services by older adults," *Universal Access Inf. Soc.*, vol. 20, pp. 359–374, Jul. 2020.
[30] I. Mishkhal, S. A. Al-Kareem, H. H. Saleh, and A. Alqayyar, "Deep learning with network of wearable sensors for preventing the risk of falls for older people," *IOP Conf. Mater. Sci. Eng.*, vol. 928, no. 3, 2020, Art. no. 032050.
[31] C. VandeWeerd, A. Yalcin, G. Aden-Buie, Y. Wang, M. Roberts, N. Mahser, C. Fnu, and D. Fabiano, "HomeSense: Design of an ambient home health and wellness monitoring platform for older adults," *Health Technol.*, vol. 10, no. 5, pp. 1291–1309, 2020.
[32] L. Pigini, G. Bovi, C. Panzarino, V. Gower, M. Ferratini, G. Andreoni, R. Sassi, M. W. Rivolta, and M. Ferrarin, "Pilot test of a new personal health system integrating environmental and wearable sensors for telemonitoring and care of elderly people at home (SMARTA project)," *Gerontology*, vol. 63, no. 3, pp. 281–286, 2017.
[33] L. Walsh, A. Kealy, J. Loane, J. Doyle, and R. Bond, "Inferring health metrics from ambient smart home data," in *Proc. IEEE Int. Conf. Bioinf. Biomed. (BIBM)*, Nov. 2014, pp. 27–32.
[34] A. Karakostas, I. Lazarou, G. Meditskos, T. G. Stavropoulos, I. Kompatsiaris, and M. Tsolaki, "Sensor-based in-home monitoring of people with dementia using remote web technologies," in *Proc. Int. Conf. Interact. Mobile Commun. Technol. Learn. (IMCL)*, 2015, pp. 353–357.
[35] I. Lazarou, T. G. Stavropoulos, G. Meditskos, S. Andreadis, I. Y. Kompatsiaris, and M. Tsolaki, "Long-term impact of intelligent monitoring technology on people with cognitive impairment: An observational study," *J. Alzheimer's Disease*, vol. 70, no. 3, pp. 757–792, 2019.
[36] C. F. Corbett, E. M. Combs, P. J. Wright, O. L. Owens, I. Stringfellow, T. Nguyen, and C. R. Van Son, "Virtual home assistant use and perceptions of usefulness by older adults and support person dyads," *Int. J. Environ. Res. Public Health*, vol. 18, no. 3, p. 1113, Jan. 2021.
[37] A. S. Billis, A. Batziakas, C. Bratsas, M. S. Tsatali, M. Karagianni, and P. D. Bamidis, "Enabling active and healthy ageing decision support systems with the smart collection of TV usage patterns," *Healthcare Technol. Lett.*, vol. 3, no. 1, pp. 46–50, Mar. 2016.
[38] H. Son and H. Kim, "A pilot study to test the feasibility of a home mobility monitoring system in community-dwelling older adults," *Int. J. Environ. Res. Public Health*, vol. 16, no. 9, p. 1512, Apr. 2019.
[39] M. Lussier, A. Aboujaoudé, M. Couture, M. Moreau, C. Laliberté, S. Giroux, H. Pigot, S. Gaboury, K. Bouchard, P. Belchior, C. Bottari, G. Paré, C. Consel, and N. Bier, "Using ambient assisted living to monitor older adults with Alzheimer disease: Single-case study to validate the monitoring report," *JMIR Med. Informat.*, vol. 8, no. 11, Nov. 2020, Art. no. e20215.
[40] H. Wang, W. Hua, L.-G. Ding, J. Wang, K.-P. Chen, and S. Zhang, "Home monitoring system improves the detection of ventricular arrhythmia and inappropriate shock," *Chin. Med. J.*, vol. 125, no. 19, pp. 3421–3424, Oct. 2012.
[41] F. Cavallo, R. Esposito, R. Limosani, A. Manzi, R. Bevilacqua, E. Felici, A. Di Nuovo, A. Cangelosi, F. Lattanzio, and P. Dario, "Robotic services acceptance in smart environments with older adults: User satisfaction and acceptability study," *J. Med. Internet Res.*, vol. 20, no. 9, p. e264, Sep. 2018.
[42] N. Raghunath, C. Pereyda, J. F. Frow, D. Cook, and M. Schmitter-Edgecombe, "Learning-enabled robotic assistive support: Understanding older adult opinions and comparing them to younger adult opinions," *Gerontechnology, Int. J. Fundam. Aspects Technol. Serve Ageing Soc.*, vol. 19, no. 3, Jul. 2020.
[43] S. Rus, S. Helfmann, F. Kirchbuchner, and A. Kuijper, "Designing smart home controls for elderly," in *Proc. 13th ACM Int. Conf. Pervasive Technol. Rel. Assistive Environments*. New York, NY, USA: Association for Computing Machinery, 2020, pp. 1–10.
[44] T. G. Stavropoulos, G. Meditskos, A. Briassouli, and I. Kompatsiaris, "Multimodal sensing and intelligent fusion for remote dementia care and support," in *Proc. ACM Workshop Multimedia Personal Health Health Care*. New York, NY, USA: Association for Computing Machinery, 2016, pp. 35–39.

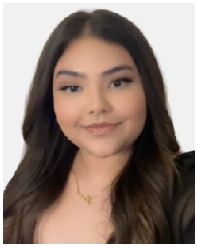
[45] C. Kostaki and C. Goumopoulos, "Development and evaluation of an exergaming application for improving seniors' well-being," in *Proc. 20th Pan-Hellenic Conf. Informat.* New York, NY, USA: Association for Computing Machinery, 2016, pp. 1–6.
[46] K. Werner, J. Oberzaucher, and F. Werner, "Evaluation of human robot interaction factors of a socially assistive robot together with older people," in *Proc. 6th Int. Conf. Complex, Intell., Softw. Intensive Syst. (CISIS)*, Washington, DC, USA: IEEE Computer Society, 2012, pp. 455–460.
[47] E. Torta, J. Oberzaucher, F. Werner, R. H. Cuijpers, and J. F. Juola, "Attitudes towards socially assistive robots in intelligent homes: Results from laboratory studies and field trials," *J. Hum.-Robot Interact.*, vol. 1, no. 2, pp. 76–99, Jan. 2013.
[48] X. Ma, N. Goonawardene, and H. P. Tan, "Identifying elderly with poor sleep quality using unobtrusive in-home sensors for early intervention," in *Proc. 4th EAI Int. Conf. Smart Objects Technol. Social Good*. New York, NY, USA: Association for Computing Machinery, Nov. 2018, pp. 94–99.
[49] J. Kowalski, A. Jaskulska, K. Skorupska, K. Abramczuk, C. Biele, W. Kopeć, and K. Marasek, "Older adults and voice interaction: A pilot study with Google home," in *Proc. Extended Abstr. CHI Conf. Human Factors Comput. Syst.* New York, NY, USA: Association for Computing Machinery, 2019, pp. 1–6.
[50] M. N. Al Hossain, A. Pal, and S. K. A. Hossain, "A wearable sensor based elderly home care system in a smart environment," in *Proc. 18th Int. Conf. Comput. Inf. Technol. (ICCIT)*. Khulna, Bangladesh: Khulna Universit, Dec. 2015, pp. 329–334.
[51] M. Gövercin, "Assessing the usability of an AAL-system within 35 seniors' homes in a clinical field trial," *Gerontechnology*, vol. 13, no. 2, pp. 122–123, Jun. 2014.
[52] A. N. Aicha, G. Englebienne, and B. Kröse, "Continuous measuring of the indoor walking speed of older adults living alone," *J. Ambient Intell. Humanized Comput.*, vol. 9, no. 3, pp. 589–599, Jun. 2018.
[53] M. Lussier, S. Adam, B. Chikhaoui, C. Consel, M. Gagnon, B. Gilbert, S. Giroux, M. Guay, C. Hudon, H. Imbeault, F. Langlois, J. Macoir, H. Pigot, L. Talbot, and N. Bier, "Smart home technology: A new approach for performance measurements of activities of daily living and prediction of mild cognitive impairment in older adults," *J. Alzheimer's Disease*, vol. 68, no. 1, pp. 85–96, Mar. 2019.
[54] D. Riboni, C. Bettini, G. Civitarese, Z. H. Janjua, and R. Helaoui, "SmartFABER: Recognizing fine-grained abnormal behaviors for early detection of mild cognitive impairment," *Artif. Intell. Med.*, vol. 67, pp. 57–74, Feb. 2016.
[55] D. E. Jachan, U. Müller-Werdan, N. A. Lahmann, and S. Strube-Lahmann, "Smart@home—Supporting safety and mobility of elderly and care dependent people in their own homes through the use of technical assistance systems and conventional mobility supporting tools: A cross-sectional survey," *BMC Geriatrics*, vol. 21, no. 1, p. 205, Mar. 2021.
[56] J. Yu, N. An, T. Hassan, and Q. Kong, "A pilot study on a smart home for elders based on continuous in-home unobtrusive monitoring technology," *HERD, Health Environments Res. Design J.*, vol. 12, no. 3, pp. 206–219, Jul. 2019.
[57] K. Caine, S. Šabanovic, and M. Carter, "The effect of monitoring by cameras and robots on the privacy enhancing behaviors of older adults," in *Proc. 7th Annu. ACM/IEEE Int. Conf. Human-Robot Interact.* New York, NY, USA: Association for Computing Machinery, Mar. 2012, pp. 343–350.
[58] M. Vacher, B. Lecouteux, P. Chahuara, F. Portet, B. Meillon, and N. Bonnefond, "The sweet-home speech and multimodal corpus for home automation interaction," in *Proc. 9th Int. Conf. Lang. Resour. Eval. (LREC)*, Rue Mathématiques, Laboratoire d'Informatique de Grenoble, Université de Grenoble, Grenoble Cedex, France, 2014, pp. 4499–4506.
[59] M. Vacher, B. Lecouteux, and F. Portet, "Multichannel automatic recognition of voice command in a multi-room smart home: An experiment involving seniors and users with visual impairment," in *Proc. Annu. Conf. Int. Speech Commun. Assoc. (INTERSPEECH)*. Grenoble Cedex, France: Univ. Grenoble Alpes, 2014, pp. 1008–1012.
[60] M. Vacher, F. Aman, S. Rossato, and F. Portet, "Development of automatic speech recognition techniques for elderly home support: Applications and challenges," in *Human Aspects of IT for the Aged Population. Design for Everyday Life*. Springer, 2015, pp. 341–353.
[61] M. Vacher, B. Lecouteux, J. S. Romero, M. Ajili, F. Portet, and S. Rossato, "Speech and speaker recognition for home automation: Preliminary results," in *Proc. Int. Conf. Speech Technol. Hum.-Comput. Dialogue (SpeD)*, 2015, pp. 1–10.
[62] F. Portet, M. Vacher, C. Golanski, C. Roux, and B. Meillon, "Design and evaluation of a smart home voice interface for the elderly: Acceptability and objection aspects," *Pers. Ubiquitous Comput.*, vol. 17, no. 1, pp. 127–144, 2013.
[63] L. D. Tsuchiya, L. F. Braga, O. de Faria Oliveira, R. W. de Bettio, J. G. Greghi, and A. P. Freire, "Design and evaluation of a mobile smart home interactive system with elderly users in Brazil," *Pers. Ubiquitous Comput.*, vol. 25, no. 2, pp. 281–295, 2021.
[64] M. Vujović, M. Ristanović, M. Miloš, and F. J. P. Lòpez, "Health monitoring modular panel interface design and evaluation," *Thermal Sci.*, vol. 22, no. 4, pp. 1–13, 2018.
[65] K.-P. Chen, Y. Dai, W. Hua, J.-F. Yang, K. Li, Z.-G. Liang, F.-R. Shen, S.-L. Chen, Y.-G. Su, Y.-S. Ding, and S. Zhang, "Reduction of atrial fibrillation in remotely monitored pacemaker patients: Results from a Chinese multicentre registry," *Chin. Med. J.*, vol. 126, no. 22, pp. 4216–4221, Nov. 2013.
[66] J. Ocepek, A. E. K. Roberts, and G. Vidmar, "Evaluation of treatment in the Smart Home IRIS in terms of functional independence and occupational performance and satisfaction," *Comput. Math. Methods Med.*, vol. 2013, Nov. 2013, Art. no. 926858.
[67] J. Gregar, *Research Design (Qualitative, Quantitative and Mixed Methods Approaches)*, 4th ed. Thousand Oaks, CA, USA: SAGE, 2014, pp. 195–210.
[68] M. H. Chignell, A. Quan-Haase, and J. Gwizdka, "The privacy attitudes questionnaire (PAQ): Initial development and validation," in *Proc. Human Factors Ergonom. Soc. Annu. Meeting*. Los Angeles, CA, USA: SAGE, vol. 47, no. 11, Oct. 2003, pp. 1326–1330.
[69] T. Nomura, T. Kanda, T. Suzuki, and K. Kato, "Psychology in human–robot communication: An attempt through investigation of negative attitudes and anxiety toward robots," in *Proc. RO-MAN 13th IEEE Int. Workshop Robot Human Interact. Commun.*, Jan. 2004, pp. 35–40.
[70] J. Brooke, "SUS—A quick and dirty usability scale," *Usability Eval. Ind.*, vol. 189, no. 194, pp. 4–7, 1996.
[71] C. Bartneck, D. Kulić, E. Croft, and S. Zoghbi, "Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots," *Int. J. Social Robot.*, vol. 1, no. 1, pp. 71–81, Jan. 2009.
[72] M. Ghafurian, J. Hoey, and K. Dautenhahn, "Social robots for the care of persons with dementia: A systematic review," *ACM Trans. Hum.-Robot Interact.*, vol. 10, no. 4, pp. 1–31, Dec. 2021.

MOOJAN GHAFURIAN is a Research Assistant Professor in the Faculty of Engineering at the University of Waterloo. She got her PhD from the Pennsylvania State University and was the Inaugural Wes Graham postdoctoral fellow from 2018-2020 at the Cheriton School of Computer Science at the University of Waterloo. Her research interests and background are in human-computer/robot interaction, artificial intelligence, social robotics, assistive technologies, affective computing, and cognitive science. Her research explores computational models of how humans interact with intelligent systems to inform user-centered design of emotionally intelligent systems in multiple domains.



KANG WANG is a Ph.D. candidate at the School of Public Health Sciences at the University of Waterloo. He is a member of Ubiquitous Health-care Technology Lab (UbiLab). His research interest revolves around population-level surveillance and remote patient monitoring, especially focusing on using smart home technologies to provide healthcare monitoring for the aging population to live more independently through AI algorithms.

ISHA DHODE is a HBSc. Psychology (Hons) candidate at the University ofWaterloo. She is currently working as an undergraduate researcher and completing her honors thesis at the Whole Family Lab. Her research interests revolve around promoting healthy relationships between families and children in the face of adversity.



MANNAT KAPOOR is a HBSc Candidate pursuing Health Science with a Pre-Clinical Specialization at the School of Public Health Sciences at the University of Waterloo. She is an undergraduate research assistant at the Ubiquitous Healthcare Technology Lab (UbiLab). Her research interests include health surveillance, specifically with the use of smart technology.

PLINIO P. MORITA (Member, IEEE) is a leading researcher in the use of AI and IoT for public health and global health initiatives. At the UbiLaboratory, his research team focuses on the use of big data and AI to improve current public health surveillance mechanisms and support countries in the monitoring of health indicators (e.g., physical activity, sleep, and sedentary behavior), and environmental factors (e.g., heat-waves and extreme air pollution). Prof. Morita's research team has developed large-scale data collection ecosystems for supporting local initiatives in Canada and low and middle income countries (LMIC) in their efforts to better understand the impact of the COVID-19 pandemic on health behaviors, the impact of extreme air pollution on child and maternal health in LMICs (in partnership with UNICEF Mongolia), and the impact of heatwaves on seniors around the globe (in partnership with Health Canada and the Public Health Agency of Canada).

KERSTIN DAUTENHAHN (Fellow, IEEE) is Canada 150 Research Chair in Intelligent Robotics in the Faculty of Engineering at University of Waterloo in Ontario, Canada where she directs the Social and Intelligent Robotics Research lab. She became IEEE Fellow in 2019 for her contributions to Social Robotics and Human-Robot Interaction. From 2000-2018 she coordinated the Adaptive Systems Research Group at University of Hertfordshire, UK. Her main research areas are human-robot interaction, social robotics, assistive technology and artificial life. She holds senior editorial positions for international journals.