Evolution of Smart Homes for the Elderly

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ABSTRACT
Smart home technology provides benefits for the elderly in six primary categories: safety, health and nutrition, physical activity, personal hygiene and care, social engagement, and leisure. Safety is about detecting and mitigating, if not removing, hazards from the user's environment. Social engagement relates to the smart home functions that allow the elderly to combat social isolation, such as by connecting the elderly with friends and family. Leisure activities are about how a smart home can allow users to spend their free time. Physical Activity relates to the concept of movement from the user, such as having them engage in non-sedentary activities. Nutrition and Health is related to the monitoring of a user's state of health. Personal hygiene and care encompasses the ways that a smart home can improve the user's well-being and assist in his/her daily activities. This workshop paper will present existing technologies in the aforementioned fields and highlight areas where development is lacking. In addition, an evaluation on past smart home designs is conducted to determine whether they fulfill the six proposed primary categories.

CCS CONCEPTS
• General and reference~Surveys and overviews

• Networks~Home networks

KEYWORDS
Elderly; Smart home; Wireless; Network;

1. INTRODUCTION
Over the coming half century, global population demographics will continue to gradually shift from younger age groups to older age groups. According to a 2015 United Nation's report on world population ageing, the United States of America has 66 million people aged 60 years or older (20.7% of their population), which is projected to grow to 92 million (26.1%) and 108 million (27.9%) in 2030 and 2050 respectively [39]. With this steady increase in older populations, it will inevitably lead to a shortage of healthcare personnel and nursing home spots. As mentioned in the 2013 World Health Organization report, the shortage of healthcare workers stood at 7.2 million and was predicted to grow to 12.9 million by 2035 [40]. Strategic use of personnel should be in place in order to maximize the effectiveness of a limited workforce. Furthermore, automation of certain tasks or enabling the elderly to perform those tasks would relieve some of the burden experienced by healthcare workers.

One currently developed system that aims to provide relief to this burden is the smart home. Smart homes aim to promote independence among the elderly in their own home by acting as both an assisted living device and monitoring system [24]. Through a combination of hardware, such as sensors and actuators, and software, the elderly are able to conduct their daily activities with minimal assistance from others. Intervention from others, such as healthcare personnel, would only be required if the system detects emergencies or anomalies in either the user's behavior or the environment. This especially holds true in the case of Interne-based care. With the introduction of the Internet of Things approach, ordinary objects can communicate through an overarching network and provide automated services to its users [44]. Communication between objects in a smart environment, such as between a sensor and an actuator, is one of the foundations of a smart home that enables independent lifestyle to be achieved.

The aims of this paper are outlined as follows:

1. Increase awareness of available technologies to be later incorporated into smart homes and tailored to individuals;
2. Evaluate the effectiveness of the technologies in order to inform future smart home designers of past systems that have been attempted and to provide a base from which they can build upon.

By increasing the awareness of available technologies and evaluating their respective effectiveness, the implementation of a fully functional, efficient, and user-friendly Smart Home can be theoretically constructed and physically implemented in total consideration of the essential needs of the elderly.

This paper is segregated as follows: methodology (identification and categorization of research articles), findings (further categorization and overview of available smart home technologies), discussion (analysis of resulting current research), and conclusions.

2. METHODOLOGY
In order to maximize the efficacy of a smart home, there should be a large focus on the concept of a multi-functional structure. A fully functional smart home should appeal to all the essential needs of the elderly in order to improve and enhance their daily living. Thus, using a thorough mind-mapping approach, the functions of a smart home are divided into 6 primary categories in this work, based on the Activities of Daily Living (ADLs), of an elderly person: Safety, Health, Physical Activities, Personal Care and Hygiene, Social Engagement, and Leisure (see Fig. 1). From the central idea of a smart home, concrete applications of the smart home were identified by determining their membership into one or more of these categories.

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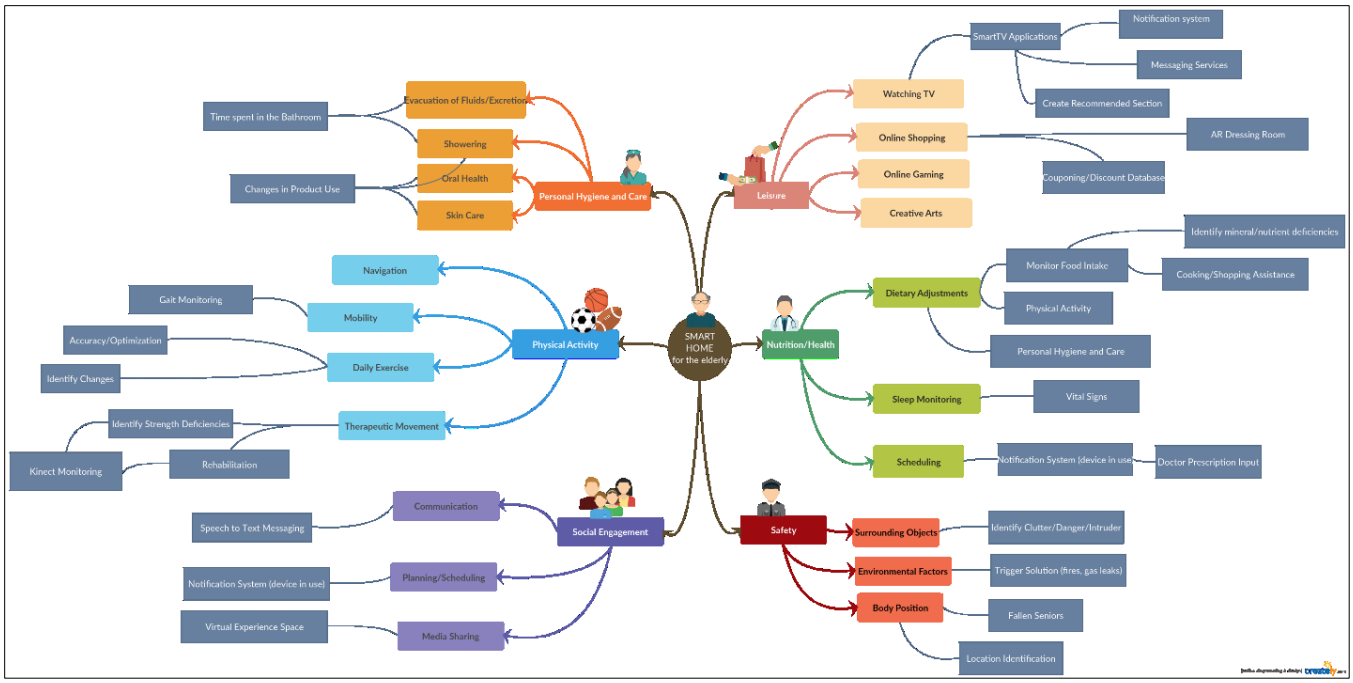

Figure 1: Defining categories for the evolution of the smart home

Note that as the formation of a fully-functional smart home is still being developed, the technologies described in this conceptual study may or may not be previously implemented. In addition, the list of identified technologies is likely to be largely improved and adapted with time.

In order to identify appropriate content, major scientific research article databases (such as Research Gate, Science Direct, PLOS, Google Scholar, Microsoft Academic Research, and Directory of Open Access Journals) were examined with the use of certain keywords, including: *smart home, elderly, wireless,* and *network*. In particular, a "method-of-elimination" approach was taken. First, articles with similar scope were excluded. These were identifiable by the fact that they covered the same technology, but only from a slightly different perspective. From every "set" of similar articles, the non-excluded article was chosen based on the study's breadth in its respective ADL field. The remaining articles were chosen according to how diverse of the smart home technology could be applied to its ADL field. In addition, the age and applicability of the proposed technology was a factor in whether an article was to be excluded. By cross-referencing among numerous databases, we have increased the diversity of our article sample set to more accurately reflect the current progress in each ADL category. While we acknowledge that our sample is merely a subset, we are confident that we parsed through sufficient reputable databases to make our sample fairly representative of the overall progress in each ADL category. In addition, continual searching was undergone by the referencing of articles to other articles.

Other criteria included availability of the literature in English and a focus on internet/network-based technologies. Thus, solely physical adaptations were not included in this conceptual study. Moreover, similar methods that produced parallel results were chosen by the earliest study. In total, 31 studies were identified to meet the above criteria.

3. FINDINGS

The identified smart home technologies are primarily categorized by the previously mentioned ADLs with a secondary categorization method based on the technical purpose with respect to the elderly.

Note that not all studies found procured physical devices; rather, studies may have incorporated a review on social acceptance of technologies for the purpose of pursuing the optimal solution for implementations at a later date.

3.1 Safety

The subject of safety, in regards to a smart home, is about detecting hazards in order to prevent impairment due to the elderly, environmental hazards, or other personnel. The use of network-based systems is highly significant, especially in terms of safety, for the purposes of contacting family members or caregivers in the case of an emergency. Since the topic of safety is vital in independent elderly care, most smart home researchers have tended to focus on the safety of elderly persons, thus resulting in some of the products shown in Table 1. This category has focused mostly on sensors, from an early work using ultrasonic sensors [14] to the latest in form of a sensory network [1]. These studies include fall detection [32, 42, 23, 20], indoor tracking [14, 41], detection of unwanted personnel [1], and notification of external trigger [28].

3.2 Health and Nutrition

Monitoring vital signs, state of health and adequate nutrition intake are some of the functions encompassed by smart health and nutrition technologies. The health of the elderly generally deteriorates as they age, which means that technologies delaying the onset of disease and disability is vital to ensuring their independent lifestyle for as long as possible. This aspect is summarized in Table 2, including the latest works on medication

intake reminders [43] and assessing cognitive function [25], as well as earlier works on health monitoring and alert [31, 9, 4, 30].

Table 1: Literature on the safety aspect

Purpose	Devices	Implementation	Date
Fall Detection	Single Camera	Computer vision-based fall detection system: To distinguish postures: ellipse fitting and projection histogram along axis of ellipse; To classify posture: directed acyclic graph support vector machine combined with detected floor information Dataset: 15 97.08% detection 0.8% false detection	2012 [42]
	Circular microphone array	Detects sound (steered response power with phase transform technique), enhances signal (beamforming), classifies (mel-frequency cepstral co-efficient features) Dataset: 120 100% sensitivity 97% specificity	2012 [23]
	Android mobile phone	Identifies orientation of body, accelerometer determines fall direction; integrated with contextual data in Smart Home (PIRmotion, door contact, pressure mats, power usage detectors); results fused with Dynamic Bayesian network	2014 [20]
	Low-cost array of infrared detectors	Sensor's low-element-count infrared array technology can locate and track thermal target (size, location, velocity); analyzes target motion and monitor target inactivity	2004 [32]
Indoor Tracking	Ultrasonic sensors	Waiting for Access	2003 [14]
	Omni-directional vision sensor	Sensor provides 360° panoramic image; pre-processed and stored in database, update background information database using pattern recognition algorithms; MHoEI based technique identifies moving and still objects Improve tracking efficiency by 58.5%	2015 [41]
Detection of Unwanted Personnel	Sensor network (binary motion sensors, pressure, toilet flush, cabinet drawers and doors)	Detection of irregular visits are identified through a Markov modulated multidimensional non-homogeneous Poisson process (M3P2), modelling occurring random events during a sequence of time intervals	2016 [1]
Notification of External Triggers	Network of environmental sensors (passive infrared, motion, pressure, doors/windows)	Interaction with user via computer-activated telephone, loudspeakers, or television is appropriately initiated based on sensor input (ex. open door/window, telephone ring); external contact triggered if no user response to prompt	2004 [28]

Table 2: Literature on the health and nutrition aspect

Purpose	Devices	Implementation	Date
Medication Intake Reminders	Medication monitoring system (RFID-based pillbox, RFID-tagged pill bottle), medication scheduler, smart phone, online central server, sensors (pressure, light, noise)	Through RFID tags, pill bottle movement (take out/replace) in the pill box can be monitored. Medication scheduler provides formal representation of proper medication intake. Mobile social network designed to provide medication reminders and social interactions among network members.	2015 [43]
Assessing Cognitive Function	Door/window entry point sensor, PIR motion detectors, flood sensors, power usage sensors, central online database	Wireless sensors collect data and send to a central web site for carers/relatives to view. Clustering algorithms are used to analyze the data. Recurrent neural networks are used as a predictive model for anomalies.	2011 [25]
Health Monitoring and Alert	IP digital camera, GSM modem, medical wearable sensors (e.g. Pulse oximeter sensor and blood pressure sensor), microcontroller, environmental sensors (e.g. Weight sensors and motion detectors)	System monitors elderly activities through sensor activation. Web interface enables real-time monitoring of elderly such as vital signs. Alerts activated in event of water leakage, high temperature or smoke/gas.	2009 [30]
	Networked sensors (e.g. Pyroelectric infrared sensors, magnetic sensors, piezoelectric accelerometer) and computers	Smart home makes assisted living decisions based on sensor-ID feedback. Activity sensors detects movement in home, while actimetry sensors detect anomalies (e.g. falls) through accelerometers. Smart home user information accessible via online database.	2001 [31]
	Generic activity sensors (infrared, accelerometers, magnetic contacts), Vegetative integrity sensors (plethysmograph), Disorder-specific sensors	Measures circadian activity, vegetative state, and state variables of specific organs for certain diseases. Sensors collect information for data fusion, which will trigger appropriate alarms if certain thresholds exceeded and alert health professionals.	2002 [9]
	Motion sensor network	Apply probabilistic techniques (mixture models) to analyze smart home user behaviour. Each cluster represents a different event type.	2005 [4]

Table 3: Literature on physical activity aspect

Purpose	Devices	Implementation	Date
Daily Exercise	Wireless remote sensors, fitness testing platform (iFit)	Traditional fitness tests and specialized "iFit" test focused on flexibility, grip strength, balance and reaction time.	2013 [36]
Training – Fall Prevention	Various balance boards (e.g. Wii balance board), pressure sensor boards, camera/recording systems	Weight shifting activities on balance boards and activities where sequence of foot movements must be followed	2013 [10]
	Kinect sensor, Inertial sensor, 42" TV	Perform four in-home balancing exercise routines daily over six weeks. Physiotherapist monitors and adjusts exercise intensity via web-interface	2014 [19]
Daily Activity Monitoring	Wireless sensor network - sensor units (electrical, force, contact with ZigBee module sensing units)	Activity labelling performed via analysis of sequence of active sensor-IDs and time of day. Irregularities in behavior identified through depth-first traversal of search space (labelled activity sequences) with apriori pruning methods.	2012 [35]

3.3 Physical Activity

Physical activity encompasses all events related to the movement of the elderly, ranging from exercise applications to behavior recognition systems (see Table 3). Daily exercise [36] or training applications [10, 19] are crucial to the maintenance of good health and prevention of accidents such as falls. Behavior recognition systems [35] allow autonomous monitoring of the elderly, which would relieve the burden on health care personnel.

3.4 Personal Hygiene and Care

Personal hygiene and care encompass technologies that can improve users' well-being by assisting in their daily activities. These technologies help users to live more convenient lives and to experience a higher quality of life. Though substantial research has been conducted in assistive guidance technologies, technologies related to cleanliness and hygiene are less prominent and only undertaken recently, as evident in Table 4. This aspect covers assistive navigation [26], especially for the blind, assistance guidance in terms of household appliances [5], oral hygiene care [13] and home cleaning [37].

3.5 Social Engagement

The aspect of social engagement relates to smart home functions that allow the elderly to combat social isolation, such as by connecting with friends and family. Additionally, with the introduction of technology created for the purpose of assisting the elderly, new studies have been conducted regarding the possible relationship between elderly people and automated robots. In this context, Table 5 details social engagement in terms of planning [29], the pioneering work on human contact and communication [8], social media [34], and interactions with robots on a social level [12, 22].

Table 4: Literature on the personal hygiene and care aspect

Purpose	Devices	Implementation	Date
Assistive Navigation	Laser sensor, markers, Inertial measurement unit, CMOS camera	Navigation module Position estimation performed via pattern matching of markers placed throughout environment. Kalman filter acts as a back-up if no markers detected. Path planning done by creating Voronoi diagrams and using Dijkstra's algorithm. Laser sensors used for obstacle detection. Object Recognition Module Taking snapshots of scene ahead of user and comparing objects to those in a predefined database. Communicates object to user via speech	2015 [26]
Assistive Guidance	RFID-based system, power analyzer, multimedia prompting devices (e.g. iPad, screen, speakers)	Guide user based on active power, reactive power and line-to-neutral signatures of appliance. Users guided on appliance operation via prompts from multimedia devices.	2015 [5]
Oral hygiene care	Oral hygiene kits	Generate visual image of patient's brushing patterns and making recommendations when necessary	2013 [13]
Home Cleaning	Vacuum cleaning robots (e.g. Roomba, Samsung Navibot SR8855, Neato XV-11, etc.)	Technical study evaluated navigation, cleaning capabilities and energy consumption of 7 different cleaning robots. Human factor study evaluated user acceptance and adaptability via 9 robots in different households.	2014 [37]

3.6 Leisure

Leisure defined in the context of a smart home pertains to the daily activities of an elderly person performed with additional time. As leisure is not considered one of the vital activities of daily living by most researchers, there is a large deficit of leisurely implementation. Thus, most of the articles reviewed in the following table are studies conducted, encouraging researchers to begin developing assistance in leisurely activities for the elderly. While the leisure section is certainly lacking in relevant literature, its presence would still help to underscore the role that smart homes could play in the leisurely aspect of the elderly's lives, cognitively and physically. In fact, the role of serious games is expected to be more prominent for ageing care. A summary of the relevant literature is shown in Table 6; these range from gardening [45], to digital gaming [27, 38], to entertainment in general [15].

Table 5: Literature on the social engagement aspect

Purpose	Devices	Implementation	Date
Planning, Reminders + Contact	AuditHIS system (real time multi-threaded audio processing system)	Video communication through TV (largely accepted by elderly participants); TV calendar (mostly disregarded, preferred a physical calendar or a vocal reminder system)	2013 [29]
Contact and Communication	Internet TV, Android TV box, Android Smartphone	Elderly's family and friends send multimedia content, including messages, via the Internet that appear on the elderly's TV screen	2012 [8]
Social Media	HOPES toolbox, social-media tools (Facebook, YouTube)	Four design principles derived from the analyzation of a digitally enabled elderly support network to provide personalized assistance through the exchange of information in a social-media environment	2015 [34]
Robot Social Interaction	The Violets Nabaztag/ Karotz (social robot)	Dialog system with elderly who can respond with 20 different RFID cards – good morning dialog (weather, advice on activity level, weighing of participants), going out and coming home dialog (key lock switch), daily activities, etc.	2015 [12]
	Care-O-bot3	Increase in positive feedback with animated, non-synchronized robot	2015 [22]

Table 6: Literature on the leisure aspect

Purpose	Devices	Suggestions	Date
Gardening	Sensor network	Supports elderly's physical inabilities by monitoring soil, air temperature, humidity, ambient light; implement self-sufficient irrigation systems, install optical sensors for plant disease detection	2015 [45]
Digital Gaming	Computer, 3D modelling	Intention to use digital game technology was correlated with user's physical exercise and the game's narrative and level of social interaction	2015 [38]
	Computer games: Brain Age, Tetris	Improve cognitive functions in the elderly with 4 weeks of gaming	2012 [27]
Watching TV, Music, Gaming, Digital Drawing	Sensory Device Combinations (cameras, motion sensors, temperature sensors)	Adaptable system based on elderly needs (sounds to replace low eyesight, visual cues or buttons to replace faint hearing)	2014 [15]

3.7 Previous Smart Home Design Projects

In addition to individually designed smart home technologies, there have been a number of fully constructed smart home projects that have incorporated different aspects of the 6 primary categories. Table 7 displays the general focus of each smart home, defined by their focus on assisting the elderly. The categories are considered to be addressed if at least one aspect of the house fulfills a part of that particular ADL. Most of the projects (86%) addressed the aspect of safety [18, 6, 16, 17, 7, 33, 21]. Followed by an emphasis on physical activity [6, 7, 33, 21] (57%), then health and nutrition [16, 7, 33] (43%). Only one project (14%) each addressed social engagement [7] and leisure [16], and none considered personal hygiene and care.

Table 7: Literature on smart home design projects

	Safe-ty	Health/ Nutrition	Physical Activity	Personal Hygiene and Care	Social Engage-ment	Leisure
Aware Home (1999) [18]	✓					
LARES Sweet-home project (2003) [6]			✓			
CASIS project (2006) [16]	✓	✓				✓
Vision-based Smart Home Care system (2006) [17]	✓					
ROBOCARE Assistive Home Robot (2007) [7]	✓	✓	✓		✓	
TigerPlace (2009) [33]	✓	✓	✓			
U-CARE system (2012) [21]	✓		✓			

4. DISCUSSION

From the extracted articles identified, majority of smart home technologies appeared to fall into the categories of Safety or Health/Nutrition. This is further confirmed through a brief analysis on past implemented smart home designs where there has been a large focus on aspects of Safety, Health/Nutrition, and Physical Activity and less so on Personal Hygiene and Care, Social Engagement, and Leisure. It is understood that majority of smart home designs are geared towards more obvious and imminent threats to elderly care. While more recent researchers have begun to incorporate these other 'minor' aspects, they remain largely unconsidered in the realm of smart home design. This is especially shown through the lack of available technologies found in the categories of Personal Hygiene and Care, Social Engagement, and Leisure. However, this does not make these ADLs less important and should be considered in future works as the goal of a smart home is to fully engage elderly with the technical aspects of living that can achieve an optimal quality of life.

Especially in the case of social engagement, a study found in the International Journal of Geriatric Psychiatry shows that loneliness has a significant impact on mood, such as cases of depression [11]. In addition, the development of social robots has not reached a level where it is completely satisfying elderly people's needs. Since most elderly have limited technological experience, social robots must prove to be more reliable in order for the elderly to recognize the need of one. Thus, the social aspect of the elderly's daily living still requires a significant amount of work in order to compensate the growing social divide that comes with age.

Leisure, likewise, has not been largely addressed by many smart home technologies. However, in order to account for all aspects of elderly living, leisurely activities should be considered especially with the consideration for those who are limited in their physical abilities. Since the elderly have an increase in their amount of free time, the way they spend their time will determine their physical and cognitive ability to lead an independent lifestyle.

Surprisingly, even less attention has been given to the topic of Personal Hygiene and Care. Despite the amount of attention received in care-based assistive technologies, there is scarce notable work on hygiene technologies in a smart home. Good hygiene has been linked to significant reductions in disease-contraction [2], which is essential to the elderly – it will enable them to continue living an independent, healthy lifestyle. Consequently, there is an opening for more development in areas of hygiene and care.

As for one of the major themes of smart home design, multiple features of safety have been incorporated into smart technologies. From fall detection to environmental warnings, researchers have worked hard to ensure that the first use of a smart home is to prevent any harm from coming to such elderly persons. The main issue with safety, however, is privacy concerns regarding video monitoring. In order to ensure a safe environment, many designs integrate the use of surveillance so as to monitor behaviors and detect anomalies. This use of surveillance has been questioned many times in terms of privacy invasion. Although researchers have been made aware of this issue and some have provided alternative options in order to avoid this dispute, any topic regarding safety will tend to invade privacy to an extent as it must account for a type of monitoring system in order to detect an emergency.

Though research in health monitoring systems in smart homes has developed significantly, nutrition-based smart technologies have been underrepresented in smart home environments. Malnutrition plays a substantial role in frailty among the elderly [3], which could lead to the onset of diseases or death. In order to keep the elderly in good health, smart homes should incorporate more technologies that could monitor and provide feedback on adequate nutrition.

For applications regarding physical exercise, one notable challenge in its implementation are from the space limitations in the user's home. In study [19], a major challenge to participant recruitment stemmed from the lack of free space in the home to conduct the exercises. Due to the vast array of benefits provided through exercise, smart homes should be designed with exercise in mind for its elderly users.

Although these 6 primary categories account for the major aspects of daily living, other features of smart home designs can be continually developed in the future. Such features include the need for financial management and home repairs. For future smart home designers, it is essential to consider human factors in their designs, such as acceptance of certain technologies among the elderly. While there may be many ideas of how to meet their current needs, a consideration for the social acceptance of the technologies is important to the success of the smart home. In this study, many of the technologies implemented and tested with elderly participants show that many of them are largely accepting of home technologies only if they prove useful.

5. CONCLUSIONS

The emergence of the smart home design stems from the incoming shift in population demographics to older age groups. Smart home technologies are designed with the purpose of assisting the elderly with daily living via a format that is user-friendly. From the analysis of technologies that were divided up into 6 primary categories of ADL (Safety, Health/ Nutrition, Physical Activity, Personal Hygiene and Care, Social Engagement, and Leisure), it was noted that there was less focus on the latter 3 topics as most smart home designers focus on the more threatening aspects of elderly care. By acknowledging the previously implemented ways of assisting the elderly, the development of smart home technologies can continue to grow and improve upon itself. In addition, by categorizing available assistive technologies, elderly persons will have the opportunity to tailor and personalize their smart homes to meet their individual needs and provide them with the most optimal assisted living environment.

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