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Health Smart Homes: User Perspectives

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Abstract. Health Smart Homes aim to assist the health and well-being of elderly people through digital technologies, by helping them to continue their daily living activities with safety and independence. This paper presents a landscape review to evaluate the effectiveness and feasibility of Health Smart Home technologies for advancing autonomy and quality of life from the perspectives of elderly users. The review was derived from an initial search of peer reviewed journals from three different data sources: PubMed (3808 papers), Google Scholar (7987 papers), and Scopus (595 papers). Of these, fourteen articles eventually met the inclusion criteria for the review and were subjected to further data extraction and quality assessment. The aim of this paper is to identify the perceptions of users by reviewing Health Smart Homes functions, services, benefits and implementation. Health Smart Homes could provide more opportunities to deliver IT-based health services by proactively monitoring and customizing the user environment, to the user's needs and preferences.

Keywords. Health Technology, Ageing, Self-Management

Introduction

In recent years, many new IT advances have occurred around the emerging technologies of the Internet of Things (IoT) applications [1] and Cloud Computing services [2]. These technologies connect a variety of standalone devices and system infrastructure such as sensors and actuators. As such they provide a set of building blocks to construct Smart Home solutions based on gathering data and sending control messages, typically over Wireless Sensor Networks (WSN) using standardized communication protocols [3]. A Smart Home is a living area inbuilt with an integrated system that actively monitors and controls the physical environment by interconnecting with sensing devices [4].

In the healthcare sector, Health Smart Homes can assist in providing continuous health monitoring and supporting well-being for assisted living through digital technologies, especially for elderly people [5]. The process of ageing results in a gradual decrease in physical and mental function and an increase in chronic disease and geriatric syndromes. An increase in elderly subjects-of-care places strain on current healthcare services and encourages consideration of automated environments [6]. Currently, Health Smart Home configurations could be used to help geriatric and disabled people to remain living independently longer with their health conditions and support other ageing individuals who wish to stay living at their homes comfortably and safely rather than being cared for in a hospital or an aged care facility [7].

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Health Smart Homes serve as platform solutions for detecting changes in health conditions, decrease the risk of falls, improve sleep patterns, address vulnerability issues, monitor bathroom activities, provide social connectedness and promote independent living [8]. The technological capabilities required for implementing Health Smart Homes comprise a wide range of sensors, health standards protocols, algorithms and communication devices, which must be used together to manage and promote health sustainability [9]. In the past few years, some of the challenges to successful adoption and implementation faced by Health Smart Homes have been performance, integrity, comprehensive infrastructure, flexible system architecture and interoperable functioning of devices in coordination with subsystems to provide automated home solutions [10]. The aim of this paper is to characterize the landscape of Health Smart Homes from the perspectives of the user (i.e. occupier) by reviewing their functions, services, benefits and implementation. In the future, there will be more opportunity to deliver IT-based services through proactive monitoring and customization to meet user needs and preferences. Therefore, this paper will contribute to a broader understanding of the acceptance and perceptions of Health Smart Homes and inform future user perspectives associated with deployed healthcare information systems.

1. Methodology

This paper is a scoping review based on papers selected from PubMed, Google Scholar, and Scopus. PubMed is a search engine which accesses the MEDLINE database, covering all the life sciences and biomedical sectors. Google Scholar automatically collects published articles on all topics broadly from recognized peer reviewed publications. Scopus covers the Web of Science (WOS) database which includes health sciences, life sciences, physical sciences and social sciences.

To design a unified framework, one needs to identify more precisely the healthcare actors' functionality requirements, and the use of an architecture-based approach in contributing towards self-management. The search terms were thus initially selected to analyze the topic area broadly, in the above three distinct areas: System Architecture, User Requirements and Self-Management. Thus, a repetitive trial of search formulas were developed and applied, leading to the refinement of search terms which were ultimately included on the basis of iterative inspection of their results.

Search of articles published from 2008 onwards provided a 10-year search window to focus on the latest Health Smart Home technologies. A final query string for terms occurring anywhere in titles or abstracts or bodies of text was designed as follows:

> "smart home" OR "ubiquitous home" OR "automated home" OR "ambient assisted living" AND "aged people" OR "gerontechnology" OR "ageing population" AND "quality of life" OR "self-management" OR "self-care".

The initial search resulted in PubMed (3808 papers), Google Scholar (7987 papers), and Scopus (595 papers). From this set of articles, 166 articles were selected based on the article titles, from which 82 articles were further selected by abstracts, and finally 14 articles were selected based on the scope of introduction, conclusion and full-text review. The remaining articles were rejected as they did not provide enough information covering the above three specific areas on Smart Home technologies. Duplicate articles were excluded. The full citations of the papers selected are provided in the References section.

Evaluation was conducted only for articles on specific studies: systematic reviews were excluded as they concentrated on summarizing evidence rather than analysis of user perspectives. Each finally selected article was then evaluated by the researchers in consultation. Articles were examined irrespective of study designs and various countries with different Smart Home technologies designs were included.

2. Results

The fourteen finally selected studies all included people of ages above 65 years. The health purposes of the Health Smart Homes for study participants were heterogeneous. Some studies included healthy older adults, while other studies included patients with neurological disabilities, dementia, Chronic Obstructive Pulmonary Disease (COPD), acquired brain injury, diabetes, Alzheimer's disease and other chronic diseases. The range of cases presented in these papers is summarized in Table 1. Most of the studies assessed with Health Smart Homes included multiple actors: most commonly elderly people, caregivers, healthcare staff and medication advisors.

Table 1. Study results of users in Health Smart Homes describing by operational model function, user requirements, system requirements and improvement outcome.

Paper Ref	Operational Model Functionality	User Requirement	System Architecture	Outcomes
[11]	Self-management system for physical exercise and performance evaluation	Usability, functionality, scalability	Proposed health system infrastructure	Patient engagement, self-management, care delivery
[13]	Cognitive assistance for participants social-activities and daily activities	Usability, quality of life	Inbuilt Smart Home	Interpersonal relationships, community life, physical, cognitive behaviourals
[14]	Monitoring the activity, diet and exercise compliance of diabetes patients	Accessibility, quality of life	Inbuilt Smart Home	Self-management education, low cost health-assistance, behavioural monitoring
[19]	Monitor senior adults' daily behaviours and the living environment	Feasibility, quality of life	Inbuilt Smart Home	Interoperability, behavioural monitoring
[20]	Monitor the physical and cognitive function	Acceptance, perception	Inbuilt Smart Home	Self-management, behavioural monitoring
[16]	Motivational gaming system to increase the physical activity of elders with complex chronic conditions	Scalability, integrity, user-friendly	Inbuilt Smart Home	Self-management
[21]	Monitor the physical activity	Functionality	Home automation	Behavioural patterns
[24]	Monitor inhaling, exhaling and heartbeats	Adaptability	Inbuilt Smart Home	Self-management

[15]	Cognitive assistance for rehabilitation patients with traumatic brain injury (TBI)	Functionality, patient safety	Proposed TAMPA Smart Home	Medication management, behavioural patterns
[22]	To assist mobility impaired patients	Efficacy, user compatibility	Inbuilt Smart Home	Quality of life, self-efficacy and safety
[18]	Monitoring an elderly person in a fall detection system	Compatibility , ease to use	Integrated Smart Home	Quality of life
[12]	To regulate indoor air quality through control of external environment.	Low-cost solution	Proposed Smart Home	Quality of life
[17]	Multimodal sound corpus acquisition labelling used for sound and speech recognition.	Compatibility , ease to use	Sweet Home project	Wellbeing, reliance
[23]	Monitor various memory disorders, sensory problems	Accessibility, efficiency	Home automation	Quality of life

2.1. Operational Model Functionality

From the reviewed fourteen papers, it was evident that Health Smart Homes, equipped with monitoring technologies and application features, are used to address a range of health and well-being issues in the elderly people. In the papers, it was reported that engaging people with technology is perceived as an appropriate approach to support ageing. The technologies can further be classified into specific categories of as follows.

2.2. Physiological Health Smart Home Monitoring

Four papers cited physiological monitoring as one of the most widely used applications for assessing physiological measures such as vital signs. This also enables assurance of medication compliance by caregivers who monitor behavioural patterns, and by users for self-medication management. Daily alert systems notify user performance and provide feedback to healthcare professionals (doctors and nurses). Similarly, family members who wish to visit, call or text elders also receive similar alerts [15, 16, 20, 24].

The paper by Helal et al. [15] investigates inbuilt Smart Home remote monitoring technology used to monitor the activity, diet and exercise compliance of diabetes patients and evaluate the effects of alternative medicine and behaviour regimens by activity recognition and analyzing of chewing motions. This helps to improve the effectiveness of diabetes self-management education along with individual behavioural monitoring of the patients. Another example, by Lim et al. [16] describes an integrated inbuilt user-friendly Smart Home system used to monitor physical activity and weight management through a motivational exercise gaming system, to increase the physical activity of elders with complex chronic conditions (e.g. diabetes and congestive heart failure) by self-management.

A similar example is provided by Tomita et al. [20] where a Smart Home technology is used to monitor the physical and cognitive function of community dwelling older patients. It has been shown that formal or informal caregiving can positively impact patients mental and physical conditions, and thus, improve the quality of life of patients living at home or alone in a community. A Smart Home inbuilt technology, Vital Radio, described by Adib et al. [24] is used to self-monitor vital signs and heart rates of multiple elderly patients at a time after exercise by evaluating user aspiration. This self-managing solution is used to monitor the minute movements caused by inhaling, exhaling and heartbeat without body contact.

2.3. Functional Health Smart Home Monitoring

Two papers reported that functional monitoring is a widely used application to measure Activities of Daily Living (ADLs) such as routine work, nutrition, sleep patterns of elderly residents and assistance provided by caregivers [11, 12].

In the paper by Terius-Padron et al. [11] a proposed health system infrastructure creates a use case to monitor a COPD patient's physical activities as advised by the doctor, to test the set-up of the devices including accelerometers, using activity recognition from video, and measuring breathing performance and air quality to improve health conditions of an end user by providing performance feedback. This user-centered designed self-management system technologically builds multi-use cases with similar user requirements to organize a feasibility framework. Any disturbances in sleeping patterns could reduce mobility functions and social contact of elderly people. Also, Smart Homes can monitor dietary habits of patients to measure the quality of their nutrition. However, with the data collected from Smart Home sensors, it is sometimes difficult for the caregiver to identify daily user needs such as cleaning, cooking, showering etc. as it varies from person to person. Another similar example, by Fong and Fong [12] describes an integrated system architecture used to self-manage user performance. This cost-effective proposed Smart Home control management system (based on a Bayesian framework algorithm) is used to regulate indoor air quality through control of air-conditioning and heating system and to monitor elderly asthma patients, minimizing the risks and improving their quality of life.

2.4. Social Interaction Health Smart Home Monitoring

The paper by Levasseur et al. [13] investigates a Smart Home inbuilt technology, identifies the needs of people and user acceptance with acquired brain injury in the development of a collective community Smart Home by the Human Development Model-Disability Creation Process (HDM-DCP) model designed for cognitive assistance for a participant's social activities and daily activities, by identifying the stakeholder's interpersonal relationships needed for independent living. Personalized needs with TBI patients such as mobility and personal care support is provided by caregivers. Lack of knowledge on Health Smart Homes and usage of technologies is a drawback for many caregivers in identifying user needs. Healthcare providers nevertheless wish to actively monitor daily activities of the users in these situations.

Another example, by Vacher et al. [17] describes a Smart Home Project used for multimodal sound corpus acquisition and labelling techniques for speech and sound recognition. This is used to detect distress situations and social inclusion for the well-being of the elderly person, as reduced socialization or communication often leads to distress conditions. Caregivers support informed through smart technologies in this way can improve the elder's safety. This proposed inbuilt voice technology system is designed to monitor the behavioural patterns of the patients and improve their stability. It is easy to connect an existing system by adapting to the user's preferences. However, limited supporting evidence is provided on how social interactions could improve a person's independence [13, 17].

2.5. Safety Health Smart Home Monitoring

The paper by Yu et al. [18] investigates a new computer vision-based, directed acyclic graph support vector machine (DAGSVM) system integration for Smart Homes used to build a fall detection system based on posture recognition. It is compatible, convenient and not affected by background noise in the environment. In the associated fall prevention study, fall detection signals were sent to the caregivers. An addition of multiple cameras yielded good performance with a fall detection rate of 97.08%. Another example, by Yu et al. [19] describes an inbuilt Smart Home technology (unobtrusive sensors) used to monitor a person's daily behaviours in the living environment of their residential homes. This uses the application of unobtrusive sensors for mobility function, interoperability, hazards and abnormalities, and behaviour monitoring to achieve limited supporting evidence on fall prevention and mobility functions to maintain independence and quality of life of persons at their living environment [18, 19, 20].

2.6. Cognitive Support Health Smart Home Monitoring

People with dementia and other neurological disorders needs assistance in ADL activities and in some cases 24 hours of assistance is provided by nurses and family caregivers because of a person's poor cognitive capability. Four papers discuss Health Smart Home prompts such as alarm and reminders to help the elderly residents to complete tasks [14, 21, 22, 23].

The Tampa Smart Home described by Jasiewicz et al. [14] is a supportive environment that helps in assisting cognitive rehabilitation patients with Acquired Brain Injury by continuously monitoring the movements and remembering the appointments and patients progress with clinical staff. Discharge eligibility of rehabilitative patients is determined based on patient's behavioural patterns. Patient safety and tracking and medication management is done by an RFID-based method. Another example, by Lotfi et al. [21] describes a standard home automation system with sensors are used to monitor the physical activity of dementia patients and their behavioural patterns are noted from the case studies by the users and caregivers. A limited number of dementia occupants participated in the ADL activities, and identifying changing patterns in the behaviour of patients is closely observed by caregivers. However, multiple occupancy research studies using semantic modelling yields better results. A similar example is provided by Gentry [22] where a Smart Home for neurological disability patients is used to assist mobility impaired patients through caregivers or family support. Future research establishing efficacy in areas of patient safety and medication management would improve circumstances for a disability group or occupant. An experimental home automation infrastructure protocol, described by Lapointe et al. [23] is used to measure the quality of life by monitoring memory disorders, aphasia, agnosia, and sensory problems in mild to moderate Alzheimer's patients. Evaluation of verbal prompts maximizes the prompting efficiency and improves quality of life to patients and their caregivers.

3. Discussion

This Health Smart Home literature review indicates contemporary focus areas from the user perspective including self-management, monitoring behavioural patterns, physical activities, medication management and motivational strategies. Also, there is a clear aspiration that the usage of Health Smart Homes would empower elderly patients, caregivers and healthcare professionals for improving longevity of life.

Users within these studies engaged in educational management to understand their health condition and their key role in self-managing by following the instructions of healthcare professionals in home monitoring interventions [15]. Studies with less participation and knowledge in the engagement of integrated Health Smart Home interventions reported lower effectiveness in achieving desirable behavioural patterns and levels of physical activities in the initial testing phase. Additionally, users with more self-motivation were found to improve their health performance and more actively monitor vital signs and their physical activity. By using Health Smart Homes, setting user goals can be accomplished to motivate the participants to stay healthy at home, which has been shown to reduce hospital admissions [17].

A major limitation identified is the feasibility issues for implementing and maintaining Health Smart Homes in rural and remote areas rather than in cities. Major privacy concerns were also reported in designing future smart home technologies. Also, in some studies, it was indicated that safety concerns, data management protocols and ethical considerations should be addressed in protecting the user of the Health Smart Home, with respect to communication devices and sensors [11].

Most of the usability of Health Smart Home technology papers lacked detail in explaining the application of the Unified Theory of Acceptance and Use of Technology (UTAUT) theoretical model for analyzing the responses of the users. A targeted conceptual framework for such usability studies in future research would help to improve the acuity with which impacts on quality of life of consumers could be assessed [12].

4. Conclusion

The advanced technologies development in Health Smart Homes, which tends to dominate the literature, can be usefully augmented by insights on user perspectives such as the functionality, integration and user acceptance. Overall, the papers indicated that there is wide acceptance that the user involvement is needed in all stages of Health Smart Home system design, implementation, testing, and that development of a framework that empowers end user satisfaction would be useful. Lack of knowledge on user profile, clinical effectiveness and integration with the existing systems will influence the future research on organizing a proposed "unified framework" for this purpose [25]. On the other hand, the failure of a system, implementation and testing is often linked with lack of communication and collaboration between users and technology developers. Nurses, clinicians and healthcare providers are experts in domain with knowledge about Health Smart Home system needs and potential functional requirements. Indeed, it is also important for elderly people and disabled patients to actively participate for their own well-being rather than being passive recipients and relying on others such as their caregivers.

The sorts of technologies and level of complex consequences identified in this paper demonstrate that there is generally an emphasis in Health Smart Homes research on the technical aspects rather than in meeting user needs, either directly or indirectly. Therefore, further user-focused research must be used to explore Health Smart Homes, alongside the health benefits and cost effectiveness factors, to understand how we can best empower the elderly user for independent living and self-caring in their own space. Together, these considerations highlight the gap between the current adaptive Health Smart Home systems and future user preferences, that would be needed to ensure user-acceptance and integration.

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