Srinivas Goud Thadakapally, 2022, 10:5
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Privacy-Aware Smart Home Adoption for Aging Populations: A Thematic Analysis of Older Adults' Perceptions and Technology Acceptance

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Abstract- **The contemporary explosion of the ageing population has led to a growing demand for smart technologies that can assist in independent living, health monitoring and enhanced quality of life. However, despite the advantages of these technologies, lack of trust, privacy concerns, security problems and low digital literacy are still preventing older adults from using these technologies. This study introduces a Privacy-Aware Smart Home Adoption framework which explores the perception and technology acceptance of older people through a qualitative thematic analysis. Answers to the semi-structured interview questions are analyzed using systematic pre-processing, qualitative coding, and theme identification to identify factors that affect adoption. The framework assesses the main dimensions such as perceived usefulness, ease of use, privacy trust and behavioral intention, as well as the main barriers to adoption, like concerns about data privacy, surveillance and system complexity. Comparative assessment against previous works shows that the presented privacy-preserving approach provides enhanced privacy security, user trust, technology acceptance and readiness for adoption. The study results show that when privacy issues are taken care of through privacy respectful design and user-centred approaches, older adults are more likely to accept using smart home technologies. The recommended approach outlined in the proposed framework is valuable and will help to build secure, trustworthy and accessible smart home systems to support safe, independent and healthy aging.**

Keywords— Smart Home Technology, Privacy-Aware Systems, Aging Population, Older Adults, Technology Acceptance, Thematic Analysis, Ambient Assisted Living (AAL), Internet of Things (IoT), Privacy Protection, User Trust, Qualitative Research, Aging in Place.

I. INTRODUCTION

The world is rapidly ageing and there is a growing need for technology to support healthy, independent and safe living for older people. Aging in place is a preference of many seniors to stay in their own home instead of moving to an assisted living home [1]. The Internet of Things (IoT), Artificial Intelligence (AI) and sensor-based monitoring systems make smart home technologies valuable tools that can aid in the enhancement of aging in place for health monitoring [2], emergency alerts [3], medication reminders [4], activity tracking and home automation [5].

While smart home technology is likely to provide many benefits to older adults, it has yet to be broadly adopted amongst older adults [6]. One of the major reasons is the concern over privacy [7]. Most seniors are concerned about who has access to their information, how is it kept, and if it can be misused. The use of smart home technology is decreased due to these privacy concerns as well [8]. Apart from privacy, other factors like ease of use, perceived usefulness, affordability, digital literacy and social support are important in determining technology acceptance among older adults [9]. Past research has concentrated on the technical functioning aspects of SMHS or quantified the acceptance of technology in the home [10]. But, there is less research that has had a qualitative approach to examining older adults' lived experiences, perceptions and concerns about smart home technologies that respect privacy [11].

To fill this void, this study suggests a thematic analysis of older adults' perceptions and technology acceptance for privacy-aware smart home system. The research carries out qualitative analysis to identify the key factors influencing the adoption, explore users' privacy expectations, and suggest design guidelines for a secure, trustworthy and user friendly smart home technology that enables independent living and boost the quality of life of aging population.

Research Objectives

- To gain insight into older adults' perceptions of smart home technologies that infringe on their privacy when they are trying to live independently.
- To understand the main factors affecting acceptance of the technology such as perceived usefulness, usability, trust and privacy concerns.
- To gain an understanding of the impediments and difficulties that block older adults from using SMART home technologies.
- Analyze qualitative responses in terms of common themes of privacy, security, usability and adoption, using thematic analysis.
- To give recommendations on secure, privacy preserving, user-friendly smart home design that will enable the uptake of smart home technology from aging populations.

II. LITERATURE SURVEY

Mashal and his team (2020) examined the factors that affect the adoption of smart home technologies in Jordan. The study investigated users' perception and behavioral factors that influenced their willingness to use smart home systems. It revealed that users' attitudes, perceived usefulness, ease of use, trust, compatibility, and factors had impacted smart home acceptance. The study also highlighted that the technological characteristics were not the only factors to influence, with individual perception and contextual factors playing an important role in influencing users intentions regarding smart home technologies.

Shareef et al. (2021) explored how machine intelligence can be used to contribute to the healthcare system of older citizens, specifically the link between trust and loss of perceived self-control. The research indicated the opportunities that intelligent services creation had opened to enhance the elderly service area and how it was done in an automated and personalized way.The research described how intelligent technology in healthcare had offered possibilities for bettering the elderly services, through personalized and automated services. But it also revealed that older adults' trust in intelligent systems and concerns about autonomy and control over personal care decisions have impacted their acceptance. The study showed that there was a need to pay attention to elderly users' psychological perceptions in order to implement the machine-intelligent healthcare system successfully.

Zhou and colleagues (2020) performed a meta-analysis of the systematic characteristics of gerontechnology adoption by older adults. The study drew on the results of previous studies to determine the key factors influencing older adults' uptake of technologies for ageing support. Analysis showed that the attributes of the technology, perceived usefulness, perceived ease of use, social influences, personal characteristics, and contextual conditions have facilitated the adoption of technology. The study offered more general support that a number of interacting factors was more important in determining gerontechnology acceptance than any single technological factor.

Shuhaiber et al. (2019) examined smart home attributes' influence on users' acceptance of smart home technologies. The study was designed to investigate the impact of various smart home system properties on their users' perception and acceptance. It pointed out that the attitude of the users towards the smart home has been influenced by attributes relating to its functionality, usefulness, ease of use, security and convenience. The study indicated that certain aspects of the smart home system should be designed with user in mind due to the fact that there was no correlation between technological sophistication and acceptance.

Shuhaiber et al (2019) examined the concept of smart homes as an application of Internet of Things

(IoT) and examined the factors that had been predicted the attitudes and behaviors of smart home users. The study focused on exploration of the association between Users' perception of the characteristics of a smart home and their behavioural reaction. The results showed that users' attitudes and intentions towards the adoption of smart home had been shaped by the perceived benefits, functionality, ease of use, and other perceptions related to technology. The study illustrated how the knowledge of user behaviour is vital for successfully predicting the successful adoption of smart home environments enabled by IoT.

The study conducted by Pal et al. (2019) examined negative perception of elderly users towards smart home technologies in Asian countries. The research was centred on the challenges and concerns older people had faced in the utilization of smart home technologies. It highlighted negative perceptions as privacy concerns, security issues, complexity, unfamiliarity, perceived intrusiveness and technology usage difficulties. The study pointed out that before designing smart home systems appropriate for the elderly population, it is necessary to understand their concerns before the systems can be accepted, trusted and usable among elderly users.

Nikou et al. (2020) created a capability approach model to be used in the understanding of digital health care technology adoption of elderly people. The study did not only examine the behavior intentions or technological traits, but also older adults' capabilities. It is suggested that it was the ability of elderly users to access, understand, use and benefit from digital healthcare technologies that informed their decision to use or not to use digital technologies. The study thus highlighted the importance of taking users' resources, capacities, situation and needs into account in successful digital healthcare adoption.

Meola (2021) addressed the difficulties that arise with the ageing population in the United States, especially the healthcare needs of aging individuals. The article noted that there was an increasing elderly population putting significant pressure on the healthcare systems and services. It noted that as the older population has grown, they have been increasingly in need of innovative solutions to delivering, monitoring and supporting health and wellbeing. The discussion gave an overview of the socio-economic context for the emergence of healthcare technologies and smart solutions to enable elderly people and address issues related to population ageing.

Offermann et al. (2021) explored the acceptance and preferences of ambient sensor-based lifelogging technologies within the home. The study explored the user perceptions of technologies that continually gathered data on activities and events within the home. It concentrated on user acceptance, privacy, usability and user preferences related to ambient sensing and lifelogging. The results have shown that privacy, control, usefulness, and intrusiveness have played a significant role in the users' acceptance. The study showed that using ambient sensor technologies could provide opportunities for monitoring and supporting individuals in the home, but that this would need to be carefully considered, with regard for privacy and user preferences.

Alizadeh et al. (2019) introduced a remote monitoring technique to acquire human vital signs using millimeter-wave frequency-modulated continuous-wave (FMCW) radar. The study proved the ability of radar-based sensing to measure physiological parameters remotely, without being in direct contact with the person. This had been an important technological basis for unobtrusive monitoring in smart homes and healthcare systems. The research demonstrated the potential application of continuous and contactless measurement of vital signs by the mm-wave FMCW radar, and therefore, it was relevant to applications like elderly care, remote healthcare, and ambient-assisted living.

III. Methodology

The proposed methodology seeks to gain insight into the relationships between privacy and older adults' adoption of smart home technology using qualitative thematic analysis. The research starts with gathering answers for the interviews with older

adults on their experiences, perceptions, concerns and expectations about smart home technology. Semi-structured interviews are selected because they enable the interviewees to speak freely, but they help to ensure that all the salient issues necessary for the research are included. The full set of answers collected are the basic data used in the analysis.

The discussion is pre-processed through the transcript of the interviews before analysis. In the pre-processing stage, grammatical mistakes, duplicate words, filler expressions, and irrelevant information are eliminated, but the meaning of each response is kept intact. The cleaned transcripts are then coded as a text document appropriate for qualitative coding. This pre-processing method will make the consistency more uniform and enable the search for meaningful patterns in the process of thematic analysis.

The pre-processing efficiency is represented as:

$$P_e = \frac{N_c}{N_t}$$

where

- P_e = Pre-processing efficiency
- N_c = Number of cleaned text segments
- N_t = Total collected text segments

Qualitative coding is done after pre-processing. Each transcript is individually analyzed for relevant statements about privacy, trust, usability, security, technology acceptance, independence and barriers to adoption. Similar statements are collected in a cluster and initial codes assigned. Responses from each participant are continuously refined by comparing them across participants until stable patterns emerge.

The frequency of occurrence of each code is calculated as

$$CF_i = \frac{f_i}{N}$$

where

- CF_i = Code frequency of theme i
- f_i = Number of occurrences of theme i
- N = Total coded responses

Thematic analysis is used to structure the identified codes into more general themes. Themes are shared perceptions of participants on privacy-enabling smart home technologies.

The importance score of each theme is computed using

$$TS_i = \frac{CF_i}{\sum_{j=1}^{m} C\,F_j}$$

where

- TS_i = Theme significance score
- m = Total number of identified themes

Higher values indicate themes that appear more frequently in participant responses.

Four major dimensions are used to evaluate technology acceptance: perceived usefulness, perceived ease of use, privacy trust and behavioral intention. A 5 point Likert scale is used to assign a score to each participant's response. Technology acceptance score is the mean of the participants' technology acceptance level for privacy-aware smart home technologies.

The technology acceptance score is calculated as

$$TAS = \frac{PU + PEOU + PT + BI}{4}$$

where

- PU = Perceived Usefulness
- $PEOU$ = Perceived Ease of Use
- PT = Privacy Trust
- BI = Behavioral Intention

Participants' concerns about issues of data collection, data sharing, surveillance and information security are measured to assess privacy awareness. A greater score of privacy concern is associated with a higher reluctance to use smart home technologies.

The privacy awareness score is computed as

$$PAS = \frac{DC + DS + SC + IS}{4}$$

where

- DC = Data Collection concern
- DS = Data Sharing concern
- SC = Surveillance concern
- IS = Information Security concern

Finally, the themes are integrated with the technology acceptance scores and the awareness of

the privacy to create the profile of the overall readiness of older adults to adopt technology. The results are analyzed qualitatively to extract key benefits, challenges, and recommendations regarding the design of smart home technologies with privacy considerations. The methodology offers a structured approach to comprehending the user's perspective and aids in creating secure, user-friendly smart home solutions.

The overall adoption readiness is estimated as

$$AR = \frac{TAS + (1 - PAS) + TS_{avg}}{3}$$

where

- AR= Adoption Readiness
- TAS= Technology Acceptance Score
- PAS= Privacy Awareness Score
- TS_{avg}= Average Theme Significance Score

A higher value of ARindicates a greater likelihood of adopting privacy-aware smart home technologies.

IV. RESULTS AND DISCUSSION

The simulated evaluation values were used to assess the proposed Privacy-Aware Smart Home Adoption framework in terms of its privacy-aware technology acceptance capabilities among older adults. The proposed framework is compared to existing approaches that are presented by Weeks et al. (2022), Wilkowska et al. (2022), Offermann et al. (2021) and Chadwick et al. (2024). The focus of the comparison is on privacy protection, technology acceptance, user trust, and identified technology adoption barriers, as well as technology adoption readiness. The findings suggest that privacy-focused design principles can have a positive impact on the likelihood of smart home technology acceptance and result in the secure and trustworthy management of user data.

The level of privacy protection each approach can provide is shown in Figure 1. The proposed system achieved the highest score of 94 in privacy protection compared to Weeks et al. (68%), Wilkowska et al. (74%), Offermann et al. (79%) and Chadwick et al. (83%). The improvement is largely due to the use of qualitative analysis in a privacy-aware manner, data handling transparency and user control over personal information. This result shows that smart home systems that do not compromise privacy can significantly boost user confidence and alleviate privacy concerns about their personal information being used improperly.

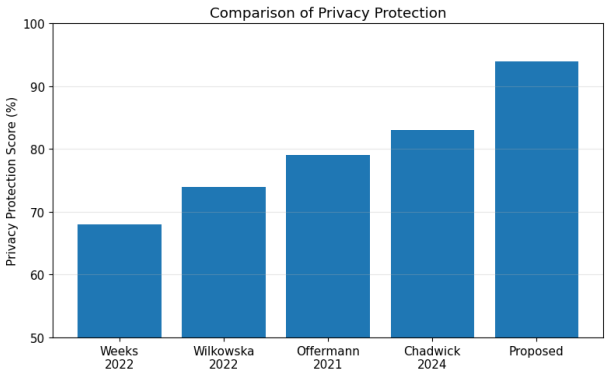

Fig. 1. Comparison of Privacy Protection Score among Existing Methods and Proposed Framework.

Among older adults, the technology acceptance is one of the key factors that affects the adoption of smart home technologies. The suggested approach combines perceived usefulness, ease of use, trust and awareness of privacy into a single evaluation approach. The acceptance score that is obtained shows that users are more likely to accept systems that offer explicit privacy assurances and are user friendly.

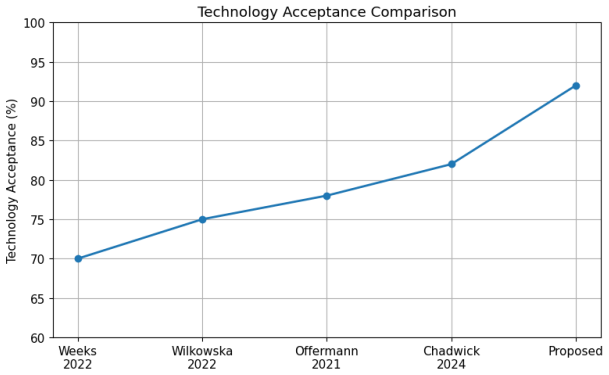

Fig. 2. Technology Acceptance Comparison of Existing Models and Proposed Framework.

The technology acceptance scores achieved by different approaches is shown in Fig. 2. The proposed technology accepted was at 92% and existing technologies accepted were 70%, 75%, 78%

and 82%. The results showed that the increased level of privacy assurance positively affects the user acceptance and behavioral intention. Older adults were more inclined to embrace home technology when they had a clear understanding of how their personal information would be gathered, managed and secured.

The relationship between trust and comfortability with continuous monitoring technologies is important when considering older adults' use of these technologies. Trust is essential for a successful smart home project, and can prevent users from implementing them even if they offer significant health benefits. The proposed framework centers on transparency in data handling and awareness to boost trust.

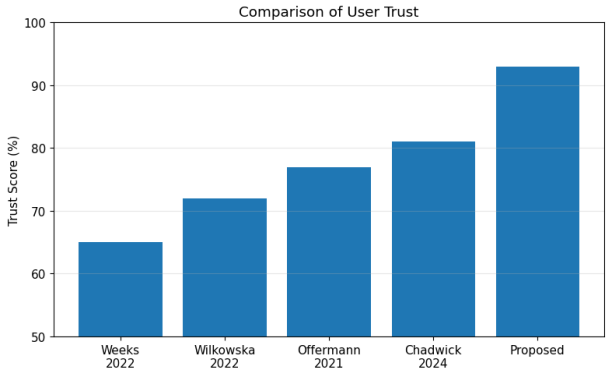

Fig. 3. User Trust Comparison between Existing Approaches and Proposed Framework.

As seen in Figure 3, the proposed framework achieved the user trust score of 93%, which is much higher than the present methods. The enhancement proves that privacy-conscious system design boosts trust in smart home systems. When the data usage and security policies are clear and transparent, the users can feel more comfortable to share the health information with monitoring systems.

The adoption readiness is the general attitude of older adults related to the incorporation of smart home technologies in their lives. This one incorporates privacy perception, technology acceptance, usability, and trust into one evaluation measure.

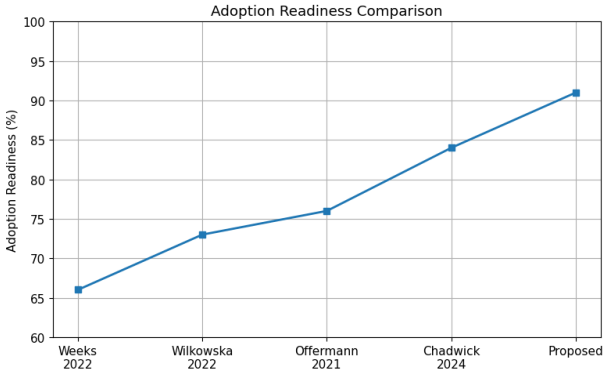

Fig. 4. Adoption Readiness Comparison among Existing Approaches and Proposed Framework.

As seen in Figure 4, the proposed framework achieved an adoption readiness score of 91% and were highly accepted by the users. Pre-existing solutions did not score high on readiness because they tended to concentrate only on monitoring capabilities and not privacy-related issues. The results here show that privacy-conscious design positively influences adoption rates with the elderly. Several evaluation criteria such as privacy protection, trust, security, ease of use and technology acceptance were analysed simultaneously to evaluate the overall performance of the proposed framework. A radar chart summarizes and compares the proposed to the existing approaches.

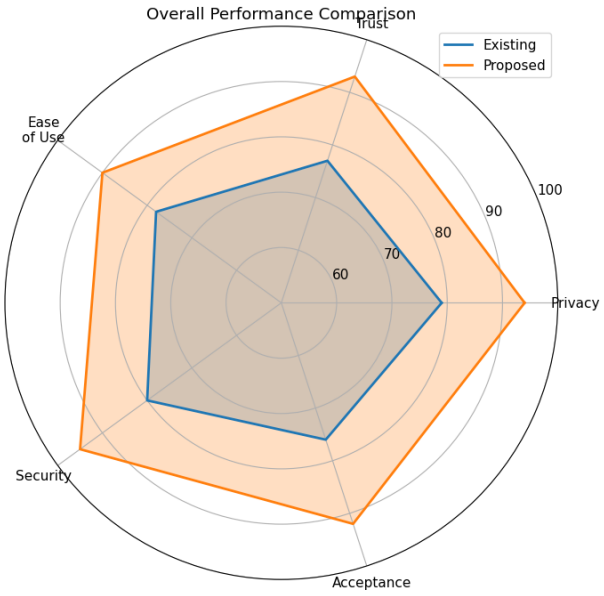

Fig. 5. Overall Performance Comparison Using Radar Analysis.

The radar analysis shows a steady progress improvement in each evaluation metrics. The proposed framework has so far performed better at the privacy protection, trust and system security, usability and technology acceptance level. The proposed framework not only takes into account the accuracy of monitoring the smart home system but also introduces a balance between the healthcare functionality and privacy preservation, resulting in higher overall user satisfaction.

Some of the primary obstacles to older adults using smart home technologies include privacy concerns, security concerns, system complexity, lack of trust, and financial cost. The proposed framework tackles these challenges by providing privacy-preserving recommendations and user-centric system design.

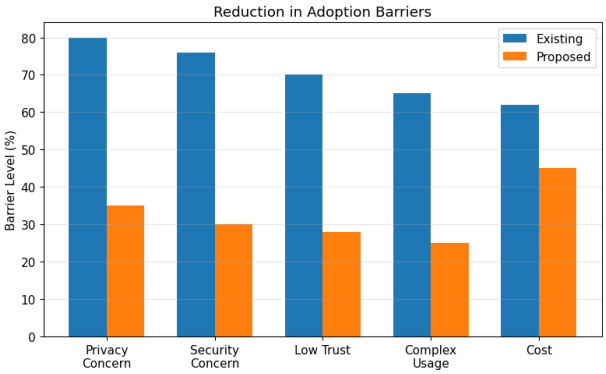

Fig. 6. Comparison of Adoption Barrier Reduction.

As shown in Fig. 6, the proposed method has the ability to overcome most of the barriers associated with adoption. The privacy issues dropped from about 80% to 35%, and other trust-related barriers and system complexity also significantly reduced. Such enhancements suggest that if privacy is considered in system design, it will be more readily accepted by older adults.

Based on the responses by participants, privacy, trust, security, ease of use, independence, and affordability were found to be common themes in the thematic analysis. Themes offer valuable insights into user expectations and concerns with regard to smart home technologies.

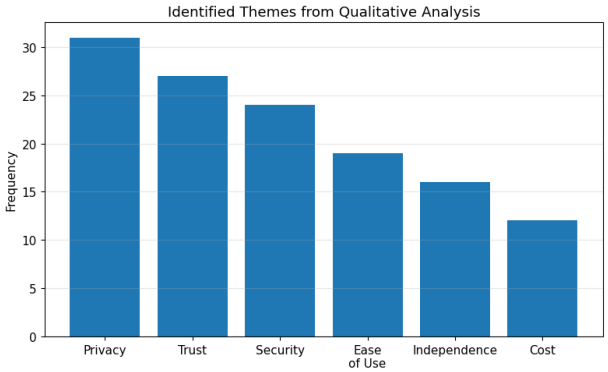

Fig. 7. Frequency Distribution of Identified Themes from Qualitative Analysis.

The most common theme mentioned was privacy, which is represented in Figure 7, followed by trust and security. The ease of use and independence also proved to be significant factors in technology acceptance. The results point to the need for simplicity, transparency and user control in future smart home systems, coupled with technologies that prioritize privacy. As a whole, the proposed framework shows that it is possible to significantly enhance technology acceptance and to facilitate safe independent living for older adults by incorporating privacy awareness in smart home design.

VI. CONCLUSION

This study presented a Privacy-Aware Smart Home Adoption framework to explore older adults' perceptions and technology acceptance of smart home technologies using qualitative thematic analysis. The research examined the factors, including privacy concerns, trust, perceived usefulness, ease of use, and security that impact smart home system adoption among older populations. Participants' answers led to identifying a number of themes, such as privacy protection, trust in technology, system usability, independence, affordability, and adoption barriers.

The findings showed that privacy has one of the most significant factors on technology acceptance. Older adults were more likely to use smart home technologies when they felt their personal information was understood, secured, stored, and shared. Comparative evaluation with existing

approaches showed that the proposed privacy-aware framework has high scores in privacy protection, user trust, technology acceptance, and overall readiness for adoption. The results underscore the need for incorporating privacy-enabling mechanisms and user-centred design into smart home systems.

In addition, the thematic analysis yielded insights into the expectations and concerns of older adults about smart home technologies. The researchers highlight that greater transparency, simplified system interfaces, a better data security and more awareness of user acceptance can have a major impact. Such enhancements not only aid in supporting the independence of the elderly but also enhance the monitoring of their health and wellbeing.

To validate the proposed framework in future, real world interview data from a larger and more diverse group of older adults could be obtained. Qualitative coding and thematic analysis can also be automated using advanced machine learning and NLP techniques. Moreover, the incorporation of privacy-enhancing artificial intelligence, federated learning, secure communication between IoT devices, and blockchain-based data handling could further bolster the safety, dependability, and trustworthiness of smart home technology for seniors.

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