# Active Aging and Digital Technology for Elderly Life Security and Health Management: A Survey



## Abstract

This survey paper explores the intersection of active aging and digital technology, focusing on enhancing elderly life security and health management. It examines the role of digital innovations and gerontechnology in promoting active aging, emphasizing the importance of personalized healthcare solutions and smart healthcare systems. Key findings highlight the transformative impact of technologies such as MemoryCompanion and ADAM in improving the quality of life for Alzheimer's patients and assisting elderly individuals with daily tasks. The paper underscores the significance of frameworks like ActiveSelfHAR and FedHome in addressing challenges in human activity recognition and in-home health monitoring. It also identifies methodological gaps in existing studies, particularly concerning socially assistive robots, and calls for further research to validate their effectiveness. The survey emphasizes the necessity for inclusive learning environments and improved socioeconomic status measurement to enhance healthy aging. It concludes that user-centered designs and longitudinal studies are crucial for developing technologies that genuinely enhance the quality of life for older adults. By fostering collaboration between designers and the elderly, technological solutions can be developed that promote independence and dignity in aging populations.

## 1 Introduction

### 1.1 Importance of Active Aging

Active aging is essential for enhancing the quality of life among the elderly, particularly in addressing challenges such as anxiety and loneliness exacerbated during periods of isolation, including the COVID-19 pandemic [1]. The World Health Organization's 'Active Aging' policy highlights the need for structured exercise regimens to improve health-related quality of life (HRQoL), especially for older adults who often lead sedentary lifestyles [2].

As the global population ages and digital technologies advance, active aging becomes increasingly vital in improving the quality of life for older adults [3]. This is particularly important amid rising healthcare costs and the need for sustainable healthcare models [4]. Integrating active aging principles into the design and evaluation of digital technologies is crucial to meet the needs and aspirations of older adults, thereby enhancing their quality of life [5].

Moreover, active aging fosters meaningful relationships, which are critical for the well-being of elderly individuals [6]. With increasing life expectancy, innovative technological solutions are necessary to improve the quality of life for older adults, especially in the context of neurodegenerative diseases like Alzheimer's, where active aging can enhance the quality of life for those affected [7].

The role of technology in geriatric medicine is paramount, addressing challenges faced by geriatricians in improving care quality and life for older adults through innovations [8]. Additionally, understanding the interplay between chronological age, socio-economic status (SES), access to care, and healthy aging is critical for promoting active aging [9]. Active aging not only enhances individual well-being but also has significant societal implications by fostering environments where older adults

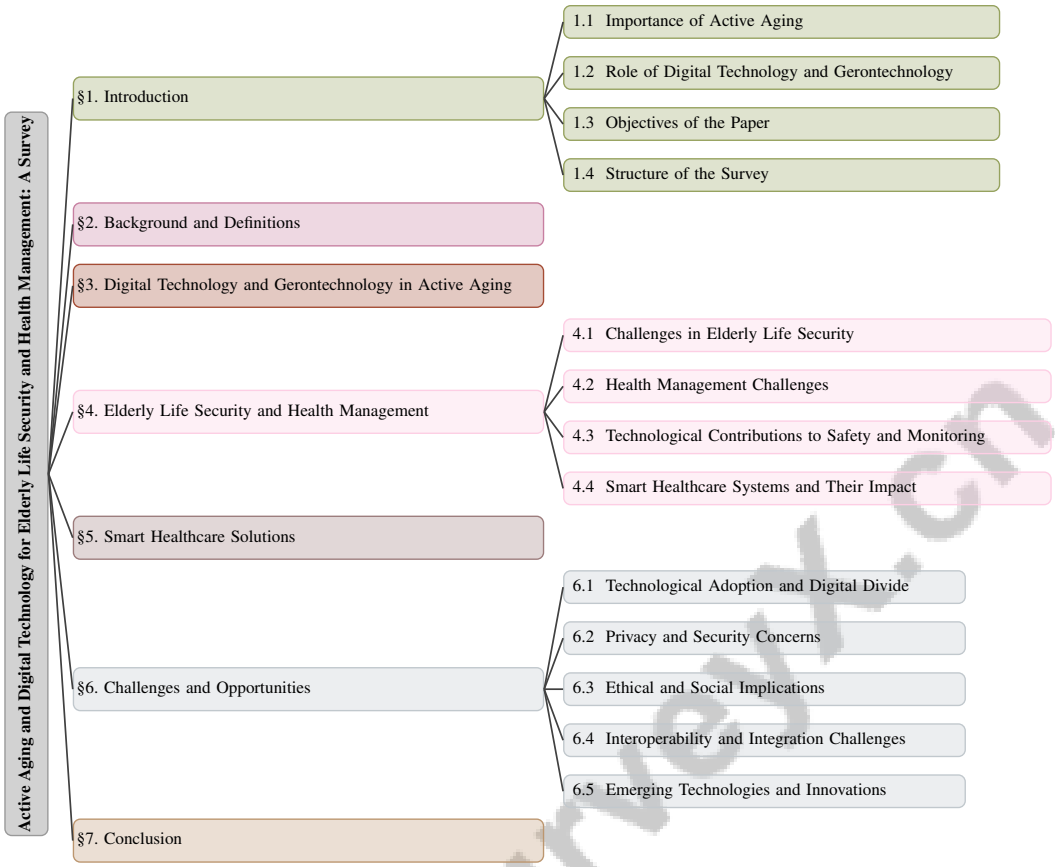


Figure 1: chapter structure

can thrive, actively participate in their communities, and navigate aging challenges with dignity and independence.

### 1.2 Role of Digital Technology and Gerontechnology

Digital technology and gerontechnology are pivotal in promoting active aging by enhancing health management and life security for the elderly. The digital transformation across various service industries parallels the integration of technology to support active aging, focusing on user experience and innovative business models [10]. This transformation is exemplified by socially assistive robots (SARs), which address the growing demand for elderly care services by enhancing health and social care [11].

Gerontechnology merges technology with geriatric care, offering a multidisciplinary approach to meet the specific needs of the elderly. Innovations such as the AI wheelchair Wheelie7, humanoid Rudy Robot, and VitalBand wristband demonstrate how gerontechnology can enhance older individuals' quality of life through assistance and monitoring capabilities [12]. These technologies are integral to developing personalized health management systems that promote independence and active participation in daily life.

Identifying the most desired gerontechnologies among older adults underscores the importance of digital solutions in enhancing life security and health management. By understanding elderly preferences and needs, digital solutions can be tailored for maximum impact and usability [13]. Furthermore, incorporating AI and machine learning into smart healthcare systems enables advanced health monitoring and disease diagnosis, contributing to a safer and more efficient healthcare environment for the elderly.

Digital technology and gerontechnology foster active aging by enhancing life quality and social connectedness for older adults while establishing a multifaceted ecosystem addressing their diverse

needs and aspirations. This ecosystem encompasses emerging technologies such as virtual reality, digital communication tools, and social networking platforms, while considering the social implications of technology use, including access, inequality, and social participation [5, 14]. By creating inclusive and adaptive environments, these technologies empower older adults to live with dignity and independence, ultimately enhancing their quality of life.

### 1.3 Objectives of the Paper

This survey paper aims to explore the intersection of active aging and digital technology, focusing on enhancing elderly life security and health management. A central objective is to investigate the 'participant' model, encouraging elderly individuals to engage in group activities that promote health and expand social networks [15]. The paper also seeks to understand the profile of gerontechnology use among older adults, particularly in the Spanish context, while identifying factors influencing usage patterns [16].

The survey addresses the usability and accessibility of digital services for older adults, advocating for ethical design principles that enhance their quality of life [17]. It proposes a model of user requirements for inclusive technology, promoting self-management of physical, mental, and emotional health through active engagement [18]. Additionally, the integration of technology into older adults' everyday lives is explored, emphasizing the need for better incorporation of technological solutions [19].

Furthermore, the survey examines the role of family members as essential caregivers and the impact of COVID-19 on family visitation policies, reflecting on implications for elderly care [20]. Addressing older citizens' emotional well-being during the pandemic is a significant objective, with innovative technological solutions like the multimodal chatbot 'Rita' explored to mitigate anxiety and loneliness [1].

The paper evaluates the effects of group exercise frequency on HRQoL in institutionalized elderly individuals, providing a framework for comparing different exercise interventions [2]. It also explores financially viable healthcare models leveraging information technology to improve access and reduce costs, addressing economic challenges posed by an aging population [4].

Additionally, the survey considers the potential of robotic companions that assist with household chores while learning from user interactions, thereby enhancing quality of life [21]. The integration of technology in geriatric care is a focal point, particularly in supporting healthy aging and improving health management for older adults [8]. Through these objectives, the paper aims to provide a comprehensive understanding of how digital innovations can support active aging, ultimately enhancing the quality of life for the elderly.

### 1.4 Structure of the Survey

This survey is organized into key sections to comprehensively explore the role of active aging and digital technology in enhancing elderly life security and health management. The paper begins with an **Introduction** that outlines the significance of active aging and the transformative potential of digital technology and gerontechnology in this domain, including the **Objectives of the Paper**, which articulate the primary aims and scope of the survey.

Following the introduction, the **Background and Definitions** section delves into the conceptual underpinnings of active aging, digital technology, and related concepts, explaining their interconnections and societal relevance.

The core of the survey is divided into thematic sections. **Digital Technology and Gerontechnology in Active Aging** explores innovative tools and frameworks facilitating active aging, highlighting successful case studies and implementations. **Elderly Life Security and Health Management** examines challenges and technological solutions pertinent to life security and health management, including the impact of smart healthcare systems.

The paper continues with a focus on **Smart Healthcare Solutions**, discussing the integration of IoT, AI, and other technologies in elderly care, addressing unique challenges faced by the aging population.

In the publication **Challenges and Opportunities**, the survey thoroughly examines barriers hindering the implementation of digital technology and gerontechnology for older adults, identifying critical issues such as technological adoption challenges, privacy concerns, and ethical dilemmas. It also highlights potential avenues for innovation, emphasizing the need for a multidisciplinary approach to leverage emerging technologies that can improve quality of life and social connectedness among the aging population [5, 10].

Finally, the **Conclusion** synthesizes the key findings and insights from the survey, reflecting on future research and development directions in active aging and digital technology. This structured approach facilitates a coherent progression of ideas, effectively navigating the intricate aspects of the topic while highlighting the crucial role of ongoing innovation in enhancing the quality of life for the aging population. By integrating insights from gerontechnology, which focuses on developing tools to assist older adults, the discussion underscores the necessity of creating accessible solutions that address the unique challenges faced by this demographic, ultimately fostering improved well-being and independence [22, 23, 24, 14].The following sections are organized as shown in Figure 1.

## 2 Background and Definitions

### 2.1 Conceptual Framework of Active Aging and Digital Technology

The framework linking active aging with digital technology focuses on empowering the elderly through innovative solutions that enhance independence and societal participation [3]. It adopts a socio-ecological perspective, integrating healthcare robotics at multiple levels—individual, care partner, community, and policy—to support active aging comprehensively [25]. Health literacy, encompassing knowledge and skills, is crucial for older adults to effectively use digital health resources, thus facilitating active aging [26]. Ethical compliance and responsible research practices are integral to building trust and engagement among elderly users. The participant model enhances social engagement by connecting older adults with peers and caregivers, leveraging community resources [27].

Understanding digital technology adoption involves predictive, enabling, and need factors that influence older adults' engagement with innovations [28]. Machine learning and IoT in healthcare provide adaptive learning and personalized solutions, improving patient outcomes for the elderly [29]. Wearable sensors with energy autonomy ensure continuous monitoring and support [30]. Research areas include telemedicine, AI applications, and digital health innovations, highlighting the interplay between technology, communication, and healthcare outcomes [31]. Socio-material configuration emphasizes designing inclusive technological solutions for older adults [32]. The framework advocates for a multidisciplinary approach in healthcare data analytics [33].

A systems engineering approach promotes interdisciplinary collaboration among health, technology, and policy experts to develop comprehensive aging-in-place solutions [27]. This holistic framework addresses the unique challenges faced by the aging population, leveraging innovations to enhance their quality of life.

### 2.2 Interconnections and Societal Relevance

The interconnections between active aging, digital technology, and gerontechnology are crucial for enhancing elderly life security and health management. A significant challenge is the reluctance of some older adults to adopt new technologies due to fear or unfamiliarity, which limits access to essential services [34]. Involving older adults in gerontechnology design ensures solutions are user-friendly and relevant [16]. Gerontechnology significantly improves life quality but is often affected by stereotypes, which can lead to misaligned technologies [32].

Family involvement is vital, as family members are often primary caregivers. The psychological impact of family separation, especially in nursing homes, highlights the need for technologies that support communication and emotional well-being [20]. The integration of digital technology into healthcare systems is essential for addressing aging population challenges, enhancing quality of life and social connectivity while mitigating potential social inequalities [5, 13, 14]. Smart healthcare solutions, enabled by IoT and AI, offer personalized health management, improving safety and monitoring. These technologies support active aging and contribute to sustainable healthcare models, accommodating the growing demands of an aging society. By fostering inclusivity that considers

older adults' diverse needs, these interconnections can lead to effective, widely accepted technological solutions that enhance their quality of life.

## 3 Digital Technology and Gerontechnology in Active Aging

| Category | Feature | Method |
|---|---|---|
| **Innovative Technologies and Tools** | Adaptive Recognition Systems<br>Monitoring Technologies | ASH[35]<br>RSLM[36], SIVSMS[37] |
| **Case Studies and Successful Implementations** | Data Security and Privacy<br>Health Monitoring Systems<br>Robotic Technologies in Healthcare | PRISM[38]<br>LDBABDS[39], MW[40]<br>IoHRT[41] |

Table 1: This table provides a comprehensive overview of the key categories of innovative technologies and successful case studies in the domain of digital technology and gerontechnology for active aging. It highlights specific features and methods, including adaptive recognition systems, monitoring technologies, and privacy-preserving frameworks, which are instrumental in enhancing the quality of life for older adults.

The advancement of digital technology significantly influences active aging by fostering independence and improving the quality of life for older adults. This section delves into gerontechnology innovations that address the specific challenges faced by the aging population, showcasing tools that promote active aging. Table 1 presents a detailed categorization of innovative technologies and case studies that demonstrate the application of digital solutions in promoting active aging. Figure 2 illustrates the hierarchical structure of digital technology and gerontechnology in active aging, categorizing innovative technologies, case studies, and gerontechnology frameworks. This figure highlights key areas such as healthcare integration, wearable technologies, distributed systems, and various domains like health, housing, mobility, and transport, emphasizing their role in enhancing the quality of life for older adults.

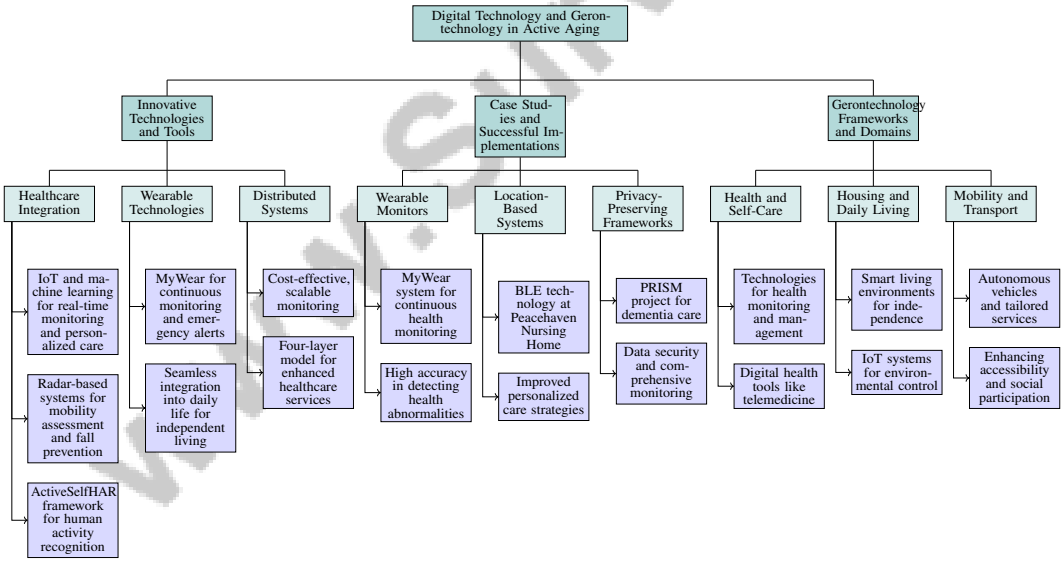


Figure 2: This figure illustrates the hierarchical structure of digital technology and gerontechnology in active aging, categorizing innovative technologies, case studies, and gerontechnology frameworks. It highlights key areas such as healthcare integration, wearable technologies, distributed systems, and various domains like health, housing, mobility, and transport, emphasizing their role in enhancing the quality of life for older adults.

### 3.1 Innovative Technologies and Tools

Innovative technologies are crucial for active aging, enabling older adults to sustain independence and enhance their quality of life. The integration of IoT and machine learning in healthcare facilitates real-time monitoring and personalized care [42]. For instance, radar-based systems using Doppler

speed profiling assess mobility and prevent falls, vital for active aging [36]. The ActiveSelfHAR framework employs advanced algorithms for adaptive human activity recognition, enhancing digital technology's efficacy in supporting active aging [35].

As illustrated in Figure 3, the hierarchical categorization of innovative technologies and tools that support active aging highlights key areas such as healthcare integration, wearable technologies, and distributed systems. Wearable technologies, like MyWear, offer continuous monitoring and emergency alerts, significantly aiding proactive health management [40]. These devices integrate seamlessly into daily life, providing older adults with essential tools for independent living. Gerontechnologies, including health monitoring devices and mobility aids, support active aging by tailoring solutions to older adults' specific needs [13, 12].

Distributed systems in healthcare enable cost-effective, scalable monitoring of multiple subjects, crucial for efficient elderly care [37]. The ongoing technological innovations highlight the continuous evolution of tools facilitating active aging [10]. Comprehensive frameworks, such as the four-layer model, enhance healthcare services for older adults [43].

These technologies foster an ecosystem embedding digital solutions into older adults' daily lives, addressing challenges like social exclusion and service access. By promoting an inclusive learning environment, stakeholders empower older individuals to navigate digital complexities, enhancing social connectedness and well-being [24, 5, 3, 14].

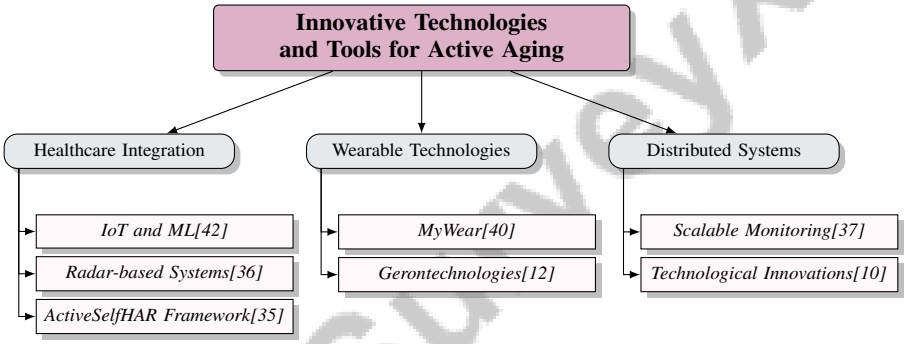


Figure 3: This figure illustrates the hierarchical categorization of innovative technologies and tools that support active aging, highlighting key areas such as healthcare integration, wearable technologies, and distributed systems.

### 3.2 Case Studies and Successful Implementations

Implementations of digital technology in active aging demonstrate innovative solutions' potential to enhance older adults' quality of life. The MyWear system, a smart wearable for continuous health monitoring, achieves high accuracy and precision in detecting abnormalities, highlighting its efficacy in proactive health management [40].

At Peacehaven Nursing Home in Singapore, BLE technology monitored residents' locations, improving personalized care strategies [39]. The PRISM project, focusing on privacy-preserving healthcare for dementia, developed a framework ensuring data security while providing comprehensive monitoring [38].

The IOHRT framework's versatility was demonstrated through case studies involving robotic tasks, enhancing task performance and user satisfaction, showcasing robotics' potential in augmenting healthcare delivery for older adults [41].

These case studies illustrate digital technologies' transformative impact on promoting active aging. By integrating advanced technologies like wearable monitors, location-based systems, privacy-preserving frameworks, and robotic assistance, these implementations provide insights into enhancing elderly quality of life. Wearable monitors enable continuous physiological monitoring, while location-based systems ensure safety in smart home environments. Privacy-preserving frameworks address surveillance concerns, safeguarding dignity. Collectively, these advancements emphasize autonomy and personalized health management, allowing seniors to age in place with greater safety and comfort [44, 45, 46, 47, 48].

### 3.3 Gerontechnology Frameworks and Domains

Gerontechnology integrates innovations with geriatric care to meet aging populations' unique needs, enhancing life quality, safety, and independence. Key domains include health and self-care, housing and daily living, mobility and transport, communication and governance, and work and leisure [12].

The health and self-care domain focuses on technologies facilitating health monitoring and personalized management, essential for proactive health management and reducing healthcare burdens [8]. Digital health tools, like telemedicine, exemplify gerontechnology's potential to transform elderly healthcare [25].

In housing and daily living, gerontechnology emphasizes smart living environments supporting independence. IoT-integrated systems for environmental control ensure safety and comfort, adapting to changing needs and mitigating risks [42].

Mobility and transport innovations, like autonomous vehicles and tailored services, enhance accessibility and social participation [13]. The communication and governance domain develops technologies to facilitate access and connectivity, addressing the digital divide and promoting inclusion [34].

The work and leisure domain focuses on technologies promoting lifelong learning and engagement, enhancing well-being and satisfaction through digital platforms offering educational and recreational resources [16].

Gerontechnology frameworks adopt a multidisciplinary approach, integrating digital technologies into everyday life to enhance care quality and well-being while considering socio-cultural and technological factors influencing acceptance [22, 14]. By integrating innovations across life aspects, gerontechnology empowers older adults to live independently, maintain health, and actively participate in society, enhancing their quality of life.

## 4 Elderly Life Security and Health Management

Addressing elderly life security and health management involves tackling specific challenges that impede effective security measures and healthcare services for this vulnerable demographic. This section examines these multifaceted challenges, focusing on technological integration, healthcare accessibility, and social support systems, to enhance older adults' well-being and life security.

### 4.1 Challenges in Elderly Life Security

Ensuring life security for the elderly requires overcoming complex challenges, particularly in technological integration and healthcare management. A critical issue is the lack of reliable diagnostic tools for early disease detection, such as Alzheimer's, compounded by a limited therapeutic window, necessitating advanced technologies for timely intervention [7]. Digital technology in healthcare presents additional challenges; many older adults face barriers like inadequate digital literacy and limited access to user-friendly technologies, hindering their adoption of digital solutions for enhanced life security [13]. Moreover, integrating AI into smart healthcare systems raises concerns due to insufficient accountability mechanisms and regulatory frameworks, which can impede the safe deployment of AI-driven solutions crucial for older adults' security and well-being [49].

As illustrated in Figure 4, the primary challenges in ensuring life security for the elderly can be categorized under technological integration, social factors, and healthcare management. This figure highlights key issues such as the reliability of diagnostic tools, the acceptance of gerontechnology, and the allocation of healthcare resources, drawing from various academic sources to emphasize the complexity of addressing these challenges.

Social factors significantly impact elderly life security, affecting gerontechnology acceptance and effectiveness. The willingness of older adults and caregivers to embrace technology depends on personal, physical, socio-cultural, and technological factors [22, 23, 13, 14]. Loneliness and social isolation exacerbate older adults' vulnerability, with a lack of community support and restrictive visitation policies further complicating these challenges. Comprehensive strategies are needed to promote social engagement and support networks.

Healthcare systems often struggle with resource allocation for frail and elderly patients, who typically have longer hospital stays due to multimorbidity. Current inefficiencies highlight the need for

innovative, sustainable models to meet the rising demands of an aging population while maintaining high care standards. As the U.S. population aged 65 and older is projected to reach 83.7 million by 2050, solutions like healthcare robotics and gerontechnology are essential for supporting healthy aging and independence. However, ethical considerations regarding balancing enhanced care with preserving older adults' autonomy and privacy must be addressed [50, 25, 51].

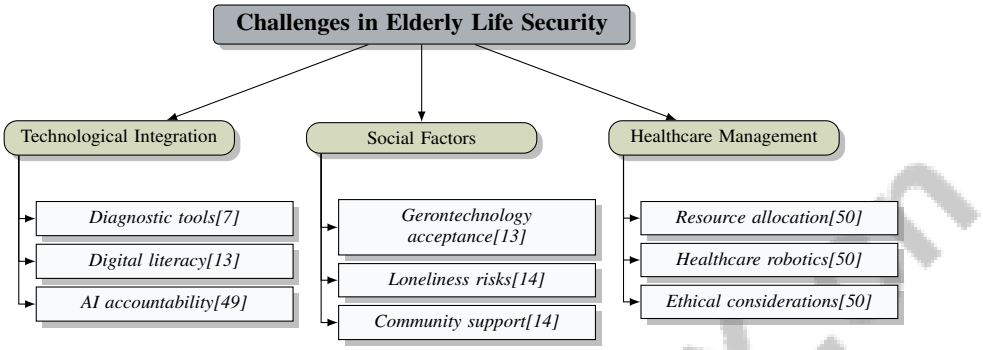


Figure 4: This figure illustrates the primary challenges in ensuring life security for the elderly, categorized under technological integration, social factors, and healthcare management. It highlights key issues such as diagnostic tool reliability, gerontechnology acceptance, and resource allocation, drawing from various academic sources to emphasize the complexity of addressing these challenges.

### 4.2 Health Management Challenges

Managing elderly health involves navigating challenges, particularly as digital technologies integrate into healthcare systems. A primary concern is the vulnerability of smart health systems to security breaches and privacy violations, inadequately addressed by current measures [52]. This is critical, as the elderly rely on these systems for continuous monitoring, making them susceptible to data breaches compromising personal health information.

Managing multiple chronic conditions, common among the elderly, poses substantial challenges, increasing risks of functional decline, social isolation, and mental health issues [50, 22, 23, 46]. Comprehensive care plans for multimorbidity are essential, yet healthcare systems often lack resources and coordination for integrated care, resulting in fragmented service delivery.

Barriers related to digital literacy and accessibility further complicate digital health technology adoption. Many older adults struggle with complex health management systems, limiting their engagement with these technologies. The digital divide underscores the need for user-friendly interfaces and comprehensive support systems to enable all older adults to benefit from healthcare advancements. Emerging technologies can enhance quality of life and social connectedness but may exacerbate social inequalities if not designed with older adults' needs in mind [5, 18, 13, 14].

Ethical implications surrounding AI and machine learning in health management must also be considered. The lack of transparency in AI algorithms and potential bias in decision-making processes pose risks to equitable treatment for elderly patients. Developing and implementing gerontechnology with ethical considerations is essential to address the elderly's complex needs, fostering trust and ensuring the efficacy of health management solutions while balancing technology benefits with fundamental rights [53, 22, 51].

A comprehensive strategy is vital to address health management challenges, including strengthening digital health systems' security and privacy frameworks, enhancing care coordination for multimorbidity, bridging the digital literacy gap, and ensuring ethical AI deployment. These components are crucial for navigating the challenges posed by increasing digital technology integration in healthcare [54, 48, 55]. By tackling these issues, healthcare systems can better support the elderly population's health and well-being.





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### 4.3 Technological Contributions to Safety and Monitoring

Digital technologies have significantly enhanced safety and monitoring for the elderly, offering innovative solutions that improve healthcare delivery and management. The MyWear system exemplifies this by providing a comprehensive health monitoring solution through a smart garment with multiple functionalities, enhancing user safety and health management [40]. This integration allows for continuous monitoring of vital signs, enabling real-time analysis and emergency alerting, critical for proactive health management in older adults.

The HealthFog framework illustrates the role of digital technologies in enhancing safety and monitoring by offering a lightweight fog service for real-time heart disease diagnosis using deep learning and IoT [56]. This approach facilitates quick health data processing at the network's edge, reducing latency and ensuring timely interventions essential for maintaining older adults' well-being.

Integrating Multi-access Edge Computing (MEC) in healthcare systems enhances safety by improving service delivery efficiency through local data processing and storage [57]. This capability allows for rapid health data analysis, enabling swift responses to potential health issues, crucial for sustaining elderly individuals' autonomy at home.

Cooperative architectures for data offloading and sharing in healthcare demonstrate significant improvements in reducing latency and enhancing data privacy and security [58]. These architectures facilitate efficient data management, ensuring sensitive health information is protected while enabling seamless communication between healthcare providers and patients.

Predictive analytics play a vital role in informing prescriptive models that optimize healthcare resource allocation, enhancing safety and monitoring for the elderly [59]. By leveraging data-driven insights, healthcare systems can allocate resources more effectively, ensuring timely and appropriate care for older adults.

Interactive educational gerontechnologies actively engage elderly users in identifying fall risks, contributing to enhanced safety and monitoring [60]. These technologies empower older adults to take an active role in their health management, fostering a proactive approach to safety and well-being.

Systems designed to improve health monitoring for the elderly facilitate early detection of changes in daily activities that may indicate health issues, helping to sustain their autonomy at home [61]. Such systems are integral to creating supportive environments that promote independence and enhance older adults' quality of life.

Incorporating SMART systems, which effectively recognize abnormal actions, is crucial for timely interventions and support, ensuring elderly individuals' safety in various settings [62]. These systems enhance monitoring capabilities, allowing for rapid responses to potential emergencies.

Gerontechnologies offer significant benefits in enhancing safety and health monitoring for older adults [44]. By integrating advanced technologies into everyday life, these innovations provide comprehensive support for the elderly, ensuring their safety and well-being in an increasingly digital world.

### 4.4 Smart Healthcare Systems and Their Impact

Smart healthcare systems have transformed elderly care, offering advanced solutions that enhance patient outcomes and improve quality of life. The integration of predictive and prescriptive analytics in healthcare settings has led to better resource allocation for frail and elderly patients, improving health outcomes and ensuring efficient resource use [59]. These systems leverage data-driven insights to optimize healthcare delivery, addressing the unique needs of the aging population.

Non-invasive glucose measurement methods exemplify the integration of optical techniques like spectroscopy into smart healthcare systems [63]. These technologies enable continuous health monitoring without discomfort, facilitating better management of chronic conditions such as diabetes, prevalent among older adults.

CommSense wearable technology demonstrates the potential of smart systems to enhance communication metrics, achieving an average balanced accuracy of 77.9

Security is a critical concern in smart healthcare systems, as evidenced by the HealthGuard framework, which effectively detects malicious activities with 91

The integration of blockchain technology plays a pivotal role in enhancing patient privacy and data security in smart healthcare applications [64]. However, challenges such as scalability and interoperability must be addressed to fully realize blockchain solutions' potential in healthcare settings.

The ethical implications of AI in smart healthcare systems necessitate a comprehensive framework to preserve public trust and ensure patient safety [49]. Regulatory oversight is crucial for guiding AI technologies' development and deployment, ensuring responsible and ethical use in elderly care.

Smart healthcare systems significantly enhance elderly care by leveraging advanced technologies such as artificial intelligence (AI), machine learning (ML), and natural language processing (NLP) to create personalized, efficient, and secure healthcare solutions. These systems facilitate continuous and remote monitoring through smart homes equipped with wearable sensors and communication technologies, allowing elderly individuals to maintain independence while receiving real-time health support. By minimizing reliance on traditional healthcare facilities, these innovative approaches improve patient outcomes and overall quality of life for the aging population, addressing the urgent need for sustainable healthcare models in light of rising life expectancy and the increasing prevalence of chronic conditions among the elderly [50, 46, 47]. By leveraging advanced technologies such as predictive analytics, non-invasive monitoring, and robust security frameworks, these systems empower older adults to live independently and with dignity while supporting healthcare providers in delivering personalized and effective care.

# 5 Smart Healthcare Solutions

## 5.1 Integration of IoT and AI in Smart Healthcare

The integration of Internet of Things (IoT) and Artificial Intelligence (AI) in smart healthcare systems is revolutionizing elderly care by enhancing quality of life and healthcare delivery. As illustrated in Figure 5, this figure highlights key applications, technological frameworks, and enhancements in security and data processing, underscoring the transformative impact of these technologies. IoT devices enable continuous health monitoring through real-time data on vital signs and environmental conditions, facilitating timely interventions and personalized healthcare [65]. The combination of AI and IoT advances data processing and predictive analytics, crucial for proactive health management and informed decision-making [58].

Federated learning significantly contributes to this integration by enabling collaborative training of medical diagnosis models on private datasets, thereby preserving data privacy while enhancing personalized care [66]. The FedHome framework exemplifies this approach with its cloud-edge architecture for personalized health monitoring [66]. Such frameworks aggregate data from multiple sources while maintaining user confidentiality [64].

Wearable devices with accelerometers and gyroscopes demonstrate IoT's role in enhancing elderly safety through automatic fall detection, providing real-time alerts to emergency services [35]. HealthGuard uses machine learning algorithms to detect anomalies in data from smart healthcare devices, improving security and reliability [67].

Edge computing enhances smart healthcare by enabling real-time data processing at the network edge, reducing latency, and ensuring immediate responses to health anomalies [58]. Blockchain technology further strengthens data security and privacy, addressing trust issues in healthcare transactions [64]. The MyWear system exemplifies effective real-time data analysis and cloud integration, facilitating prompt alerts and monitoring [40].

Innovative frameworks like PAGE employ a past-agnostic generative replay mechanism to create synthetic data, optimizing resource allocation and enhancing user experience by monitoring health metrics based on user activities [68, 35]. Cooperative architectures for data offloading and sharing significantly reduce latency and energy consumption while enhancing data privacy and security [58].

The integration of ensemble deep learning with edge computing in HealthFog further exemplifies the potential of these technologies, reducing response times while maintaining high accuracy [56]. This advancement is crucial for sustaining the autonomy of elderly individuals by ensuring timely and accurate health interventions.

The integration of IoT and AI in smart healthcare systems offers a robust framework for enhancing elderly care, empowering older adults to live independently while supporting healthcare providers in delivering efficient, secure, and personalized care. Future research should address privacy concerns and explore the economic viability of sensor-based technologies, particularly in developing countries [69].

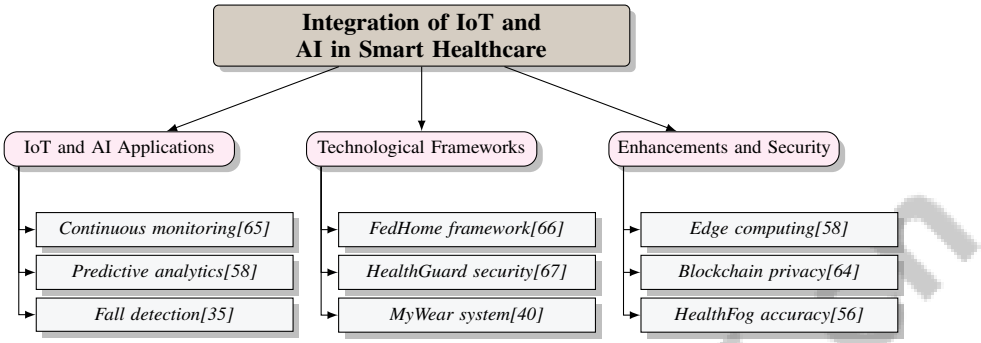


Figure 5: This figure illustrates the integration of IoT and AI in smart healthcare, highlighting key applications, technological frameworks, and enhancements in security and data processing.

### 5.2 Smart Healthcare Devices and Systems

Smart healthcare devices and systems are crucial in modern healthcare delivery for the elderly, offering advanced solutions that enhance patient outcomes and quality of life. These systems leverage edge intelligence to improve service efficiency by reducing latency and enhancing decision-making [70]. By processing data closer to the source, edge intelligence minimizes data transmission delays, ensuring timely interventions and personalized care.

Smart medical devices facilitate real-time monitoring and management of health conditions, providing critical insights into patient health. Equipped with IoT capabilities, these devices enable continuous monitoring of vital signs, physical activity, and environmental conditions, crucial for proactive health management among the elderly. By leveraging real-time data from wearable sensors and smart home technologies, these systems offer comprehensive insights into older adults' health, tracking physiological indicators like stress levels and blood pressure, while monitoring location and activity patterns [39, 45, 48]. The deployment of these devices allows for data collection, which can be analyzed to detect patterns and predict potential health issues.

However, implementing smart healthcare systems presents challenges, particularly regarding security. Experiments with smart medical devices reveal vulnerabilities to adversarial threats that can compromise health data integrity and patient safety [71]. Ensuring robust cybersecurity measures is crucial to protect sensitive health information and maintain trust among elderly users.

The successful deployment of smart healthcare devices relies on addressing security issues—such as vulnerabilities to cyberattacks and data privacy concerns—and ensuring effective interoperability among devices and systems. This interoperability is essential for seamless data exchange, enabling comprehensive healthcare solutions that leverage IoT, AI, and advanced data analytics to enhance patient care and operational efficiency [72, 73, 54, 50]. Seamless integration of devices from various manufacturers is necessary to create a cohesive healthcare ecosystem that supports comprehensive care delivery for the elderly, allowing healthcare providers to access and utilize data from diverse sources effectively.

Smart healthcare devices and systems play a pivotal role in modernizing healthcare delivery for the elderly. By harnessing advanced technologies such as edge intelligence and IoT, these systems deliver efficient, secure, and personalized care solutions. Innovations in these areas not only reduce latency and energy consumption but also leverage AI to identify and predict high-risk health conditions, ultimately lowering medical costs and improving treatment outcomes. This integrated approach empowers older adults to manage their health more effectively, facilitating independent living while preserving dignity through enhanced self-monitoring, self-management, and timely interventions based on comprehensive health data [48, 70]. Future research should continue to address security and

interoperability challenges while exploring the potential of emerging technologies to further enhance smart healthcare systems.

### 5.3 Data Security and Privacy in Smart Healthcare

| Method Name | Security Frameworks | Technological Integration | Ethical Considerations |
|---|---|---|---|
| BPFISH[74] | Bpfish Framework | Blockchain Technology | Privacy Protection |
| C-DP[75] | Blockchain Structure | Blockchain Integration | Personalized Privacy Protection |
| CAPF[52] | Context-Aware Privacy | Internet OF Medical | Privacy-preserving Techniques |
| FGSM[76] | Robust Defenses | Blockchain | - |

Table 2: Comparative Analysis of Security Frameworks, Technological Integrations, and Ethical Considerations in Smart Healthcare Methods. This table provides an overview of various methodologies employed to enhance data security and privacy in smart healthcare systems, highlighting their respective frameworks, technological integrations, and ethical considerations.

The implementation of smart healthcare solutions necessitates a robust framework to address data security and privacy concerns, which are paramount given the sensitive nature of health information. Current studies grapple with challenges related to data quality, integration complexity, and ethical concerns, underscoring the need for comprehensive strategies to ensure data integrity and user trust [77]. Table 2 presents a comparative overview of different methodologies employed in smart healthcare to address these challenges, focusing on their security frameworks, technological integrations, and ethical considerations.

The BPFISH framework exemplifies an approach to safeguarding patient privacy by enabling medical centers to train local models without sharing sensitive data, thus mitigating risks associated with data breaches and unauthorized access [74]. This framework highlights the importance of preserving patient privacy while facilitating the development of personalized healthcare models.

Blockchain technology enhances data security within smart healthcare systems. The integration of a blockchain-assisted privacy-aware data-sharing model ensures data integrity and mitigates potential attacks, providing a secure infrastructure for managing health information [75]. This approach demonstrates blockchain's potential to address security challenges by offering a decentralized and tamper-proof ledger for health data transactions.

The Context-Aware Privacy Framework (CAPF) further contributes to data security by integrating enhanced security measures and privacy-preserving techniques into context-aware health systems, safeguarding user data from unauthorized access and ensuring compliance with privacy regulations [52]. This framework is vital for creating a secure environment that respects user privacy while delivering personalized healthcare services.

However, deploying AI technologies in smart healthcare introduces ethical challenges that must be addressed to maintain public trust. These challenges include transparency, responsibility, bias, privacy, safety, autonomy, and justice, which are critical for ensuring the ethical integration of AI in healthcare [49]. Addressing these challenges requires a comprehensive ethical framework that guides the development and implementation of AI solutions in healthcare settings.

Despite these advancements, limitations persist, such as reliance on relatively small datasets and a focus on specific types of adversarial attacks, which can limit the generalizability of security solutions [76]. Future research should aim to broaden the scope of these studies to encompass a wider range of security threats and develop more robust solutions capable of withstanding diverse adversarial scenarios.

## 6 Challenges and Opportunities

### 6.1 Technological Adoption and Digital Divide

The digital divide and the inadequacies of current technologies significantly hinder the adoption of digital innovations among the elderly. A key barrier is the reluctance of older adults to engage with digital and robotic devices, exacerbating the digital divide and limiting their interaction with these innovations [21]. Concerns over data privacy and security further deter engagement, as managing extensive medical data while ensuring patient privacy remains a critical challenge in smart healthcare

systems [65]. Resource constraints and the complexity of existing algorithms limit scalability and effectiveness [78], while data scarcity in recognizing abnormal actions impedes the adoption of intelligent monitoring systems essential for elderly care [62, 35].

Organizational resistance to change and the complexity of integrating new technologies further complicate the adoption process [10]. The variety and complexity of available technologies make systematic assessments of their effectiveness challenging [12], and researchers encounter difficulties in evaluating the acceptance of various gerontechnologies among older adults [13]. Existing monitoring methods, both contact and contactless, face challenges such as high costs, limited scalability, and privacy concerns [37]. Additionally, challenges in AI-driven healthcare include transparency in AI decision-making, accountability for outcomes, and potential biases in algorithms, which can lead to healthcare disparities [49].

Methodological weaknesses in current studies, such as small sample sizes and inconsistencies in outcome measures, hinder the establishment of clear clinical applications [11]. Furthermore, achieving high diagnostic accuracy while maintaining low response times remains a core obstacle in cloud-based healthcare systems, underscoring the need for technological adoption among the elderly [56].

Enhancing digital literacy, designing intuitive interfaces, and implementing robust security measures are crucial to fostering a more inclusive digital environment, significantly enhancing the quality of life for older adults through improved health management and social engagement [55, 10].

Figure 6 illustrates the hierarchical structure of factors influencing technological adoption and the digital divide among the elderly. It categorizes the barriers, challenges, and strategies for enhancing adoption, highlighting key issues such as reluctance, privacy concerns, and the complexity of technologies. This visual representation underscores the multifaceted nature of the digital divide and the critical need for targeted interventions to address these challenges.

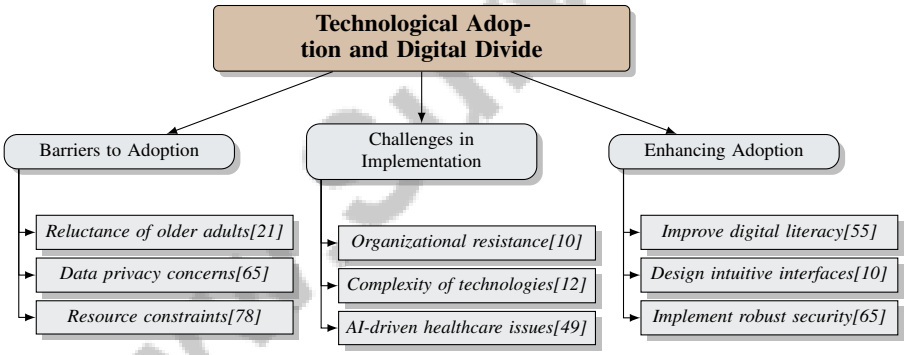


Figure 6: This figure illustrates the hierarchical structure of factors influencing technological adoption and the digital divide among the elderly. It categorizes the barriers, challenges, and strategies for enhancing adoption, highlighting key issues such as reluctance, privacy concerns, and the complexity of technologies.

### 6.2 Privacy and Security Concerns

The integration of digital technology in elderly care raises significant privacy and security concerns, particularly regarding the leakage of sensitive healthcare data and the risks associated with centralized data aggregation. Centralized storage systems in smart healthcare are vulnerable to cyberattacks, potentially resulting in substantial privacy breaches [79]. The inability to aggregate user data across organizations for training robust machine learning models while maintaining privacy remains a critical challenge [80]. The normalization of surveillance in smart healthcare systems raises ethical concerns about privacy infringements and the potential exploitation of older adults' data [44]. Implementing robust security measures, such as AES128 encryption used in systems like MyWear, is essential for securing data transmission [40]. However, the complexity and interconnectedness of medical devices complicate the detection and response to malicious activities, as existing methods often fall short [67].

The Internet of Medical Things (IoMT) technologies face privacy and security challenges in managing large data volumes and ensuring system upgrades [81]. Hybrid approaches, such as offloading data to edge servers and utilizing blockchain for sharing, have been proposed to enhance privacy and security while improving Quality of Service (QoS) [58]. These methods aim to mitigate the risks associated with centralized data processing by distributing tasks across decentralized networks. A discrepancy exists between users' awareness of security risks and their actual behaviors, as many do not take adequate measures to secure their data in mobile health (mHealth) applications [82], highlighting the need for improved user education regarding security practices in digital healthcare environments.

Privacy-preserving techniques, such as federated learning, offer potential solutions by enabling decentralized training of machine learning models without compromising user privacy [83]. These approaches are vital for maintaining data privacy and security in smart healthcare systems, particularly concerning elderly care. Addressing privacy and security concerns in digital technology for the elderly necessitates a multifaceted approach, including robust encryption, decentralized data processing, and enhanced user education. By focusing on developing digital solutions tailored to the unique needs of older adults, technologies can enhance healthcare delivery while prioritizing privacy and security. This approach is essential for fostering trust and engagement, as it addresses significant privacy concerns associated with surveillance technologies, ensuring that the right to privacy and dignity remains central in their design and implementation [44, 23, 13, 5, 55].

### 6.3 Ethical and Social Implications

The use of digital technology in elderly care presents significant ethical and social implications that must be carefully considered to uphold the dignity and autonomy of older adults. A primary concern is the impact of newer technologies on the privacy and autonomy of the elderly, as these innovations often involve extensive data collection and monitoring [51]. The integration of surveillance technologies in smart healthcare systems raises questions about privacy violations and ethical boundaries in monitoring older adults [44]. Current studies frequently overlook these ethical implications, focusing on technological benefits while inadequately addressing potential privacy infringements. This oversight can lead to scenarios where older adults face constant surveillance, infringing on their personal freedoms and autonomy [44]. The normalization of such practices necessitates robust ethical guidelines that balance technological benefits with individual rights.

Moreover, ethical considerations extend to the design and implementation of digital technologies, emphasizing the importance of involving older adults in the development process. Ensuring that technologies are user-friendly and aligned with their needs fosters acceptance and trust. This participatory approach improves usability and empowers older adults by involving them in the design and decision-making processes of solutions that directly affect their lives. By incorporating their insights, more effective gerontechnologies can be created that support meaningful activities, enhance safety, and promote independence in aging [84, 24, 13, 85, 86].

The social implications of digital technology in elderly care include the potential for exacerbating existing inequalities. The digital divide, characterized by disparities in access to technology and digital literacy, can hinder certain populations—particularly older adults and marginalized groups—from fully benefiting from technological advancements. This divide not only exacerbates social inequalities but also limits opportunities for engagement and participation in a digital world, highlighting the need for inclusive design and strategic digital transformation efforts that account for diverse user experiences and capabilities [5, 14, 10, 86, 55]. Targeted efforts to improve digital literacy and ensure equitable access to resources are essential.

### 6.4 Interoperability and Integration Challenges

Interoperability and integration challenges are significant barriers to effectively implementing digital technologies in elderly care. Current studies often highlight the lack of comprehensive integration among various technologies, resulting in interoperability issues among devices from different manufacturers [47]. This fragmentation impedes seamless information exchange and coordination across healthcare platforms, which is crucial for providing holistic care for older adults. Existing studies frequently operate in silos, with limited integration across city services, complicating the deployment of smart healthcare solutions [87]. This siloed approach not only hinders resource efficiency but

also fails to address funding and deployment challenges critical for successful integrated healthcare systems.

Moreover, the advancement of IoT in healthcare is often obstructed by inadequate security measures necessary to protect sensitive health data, which poses significant integration challenges for providers [54]. The absence of standardized protocols for data exchange exacerbates these challenges, making achieving interoperability among diverse systems difficult. Addressing interoperability and integration challenges requires a concerted effort to develop standardized protocols and frameworks that facilitate seamless communication between devices and systems. Collaboration among stakeholders, including technology developers, healthcare providers, and policymakers, is essential to create an integrated ecosystem that supports efficient healthcare delivery for the elderly. This approach enhances care quality and enables older adults to leverage the benefits of innovative digital technologies, ultimately improving health outcomes and quality of life. By addressing barriers to gerontechnology acceptance and considering the diverse needs of older adults and their caregivers, more effective healthcare solutions can be developed [22, 23, 13].

### 6.5 Emerging Technologies and Innovations

Emerging technologies offer significant opportunities for innovation in elderly care, particularly through the integration of Internet of Things (IoT) and Artificial Intelligence (AI) within healthcare systems. These advancements are pivotal in enhancing the quality of life for older adults by providing responsive and adaptive healthcare solutions. For instance, radar-based systems enable non-intrusive and continuous monitoring, crucial for improving elderly care [36]. Additionally, SINDI technology, which combines sensor data with medical knowledge, exemplifies innovation potential by offering advanced risk prediction and management capabilities [88].

The exploration of compact deep neural networks and compressive sensing highlights emerging trends driving innovation in smart healthcare, facilitating the development of efficient and scalable solutions [42]. These technologies can enhance data integration techniques, improve security protocols, and support low-power solutions for continuous health monitoring, addressing critical needs in elderly care [46]. HealthFog demonstrates innovation opportunities by integrating ensemble deep learning with fog computing for real-time health monitoring and diagnosis, with potential applications beyond heart disease [56].

Future research should focus on refining algorithms for specific applications and optimizing resource allocation to enhance the effectiveness of these technologies [78]. Expanding security scenarios and developing strategies to improve user engagement with security policies are crucial for ensuring the safe deployment of digital solutions in elderly care [82]. Zaki emphasizes the importance of leveraging data for competitive advantage, aligning with innovation opportunities in digital technology for elderly care [10].

Moreover, enhancing the scalability of blockchain technologies and developing standardized protocols can improve interoperability and data security in smart city applications, providing a robust framework for integrating emerging technologies into healthcare systems [64]. Future research should also prioritize larger, multi-center clinical trials and develop standardized treatment protocols for new therapeutic interventions, such as photobiomodulation (PBM) for Alzheimer's disease [7]. In the realm of gerontechnology, future research should explore new technology development and assess their impact on older adults' quality of life, highlighting innovation opportunities [13]. Expanding evaluation criteria and exploring new technologies in different cultural contexts could enhance understanding of gerontechnology effectiveness [12]. By addressing these areas, emerging technologies can significantly improve elderly care, ensuring that advancements align with the needs and preferences of older adults, ultimately enhancing their quality of life and supporting the development of inclusive and effective healthcare solutions.

## 7 Conclusion

Digital technology and gerontechnology are pivotal in revolutionizing active aging and health management for the elderly. Tools like MemoryCompanion illustrate the potential of personalized digital interventions to enhance care for Alzheimer's patients, suggesting alternatives to conventional care-

giving methods. Similarly, systems like ADAM have proven effective in aiding daily activities, thereby improving life quality for older adults.

Smart healthcare solutions, such as the ActiveSelfHAR framework, address cross-subject challenges in human activity recognition, showing promising performance and practical applications. The FedHome framework further exemplifies advancements in in-home health monitoring, achieving high accuracy and efficient communication across various datasets.

The role of health professionals in understanding and promoting gerontechnologies is crucial, as these innovations significantly contribute to the well-being of the elderly. However, existing studies, particularly on socially assistive robots, require further exploration to confirm their effectiveness in elder care.

Future research should focus on creating inclusive digital learning environments that enable older populations to adapt and thrive. Additionally, enhancing the measurement of socioeconomic status and examining long-term intervention impacts on healthcare access are vital for advancing healthy aging.

A systematic evaluation of gerontechnologies can guide investment and development in technologies aimed at improving life quality for older adults. Moreover, the importance of user-centered design in smart wearable health devices and the necessity for longitudinal studies to validate findings in diverse settings are identified as critical areas for future exploration.

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