IoT Systems for Healthcare in the Elderly

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Abstract

The ageing population is increasing rapidly, resulting in significant pressure on healthcare systems worldwide. Internet of Things (IoT) systems present a solution to mitigate this problem and reduce the strain for healthcare resources, enabling remote monitoring and care whilst allowing older adults to live more independently. This report reviews current IoT applications in elderly healthcare, explores data collection methods, and examines existing devices and limitations.

1 Introduction

The population of elderly individuals is growing rapidly. According to the United Nations World Social Report (ONU, 2023), the population aged 65 and over has tripled from 1980 to 2021. By 2050, it is estimated that the number of elderly individuals will double, reaching 1.6 billion and constituting 16.7% of the global population. This represents a significant increase from less than 10% in 2022 (ONU, 2022) (see Figures 1 and 2). The population aged 80 and over is expected to grow at an even higher rate (ONU, 2019). In this report, we refer to *elderly* or *ageing* population as individuals aged 65 or older, as defined by the Organisation for Economic Co-operation and Development (OECD) (OECD, 2024).

The ageing population, compared to other groups, is more susceptible to a wide range of health issues, including diabetes, hypertension, Alzheimer's disease, and mobility problems, amongst others (Kirkman et al., 2012; Jackson et al., 2023). Managing these conditions requires ongoing medical care, frequent monitoring, and regular interventions, significantly increasing the need for healthcare services. This rise in healthcare demand, together with the desire of older adults to maintain an independent lifestyle, results in extra pressure on healthcare systems worldwide.

The recent advancements in IoT (Internet of Things) technologies present a promising solution to address these challenges. IoT systems are composed of interconnected devices and sensors, which can collect and transmit data in real-time (Gupta and Gupta, 2016; Guizani and Guizani, 2020). This can allow for continuous monitoring of patients without the need for frequent hospital visits, tracking medication administration and symptoms, and even detecting falls or other emergencies, thus having the potential to ease the strain on healthcare systems, medical staff and hospital resources (Sahu et al., 2021). In addition, the integration of IoT systems with advanced technologies such as machine learning,

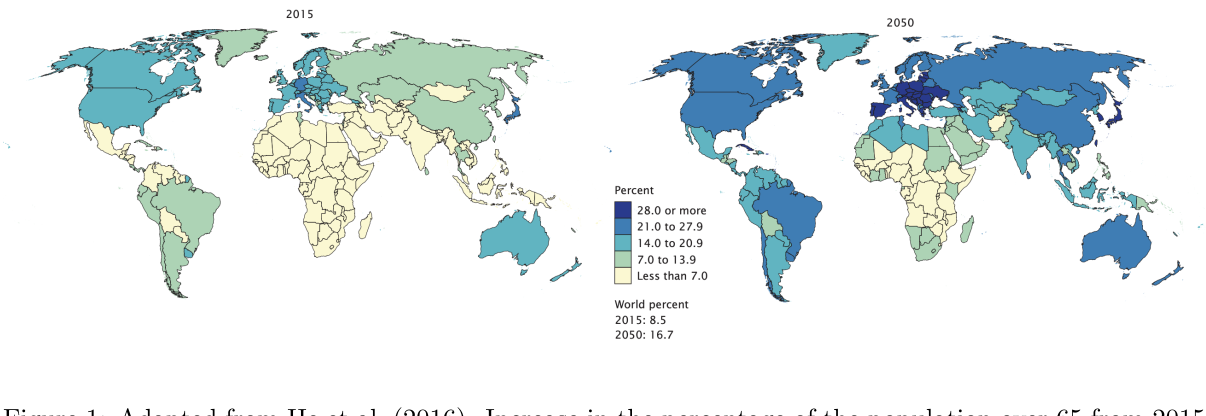

Figure 1: Adapted from He et al. (2016). Increase in the percentage of the population over 65 from 2015 to 2050 in each country worldwide.

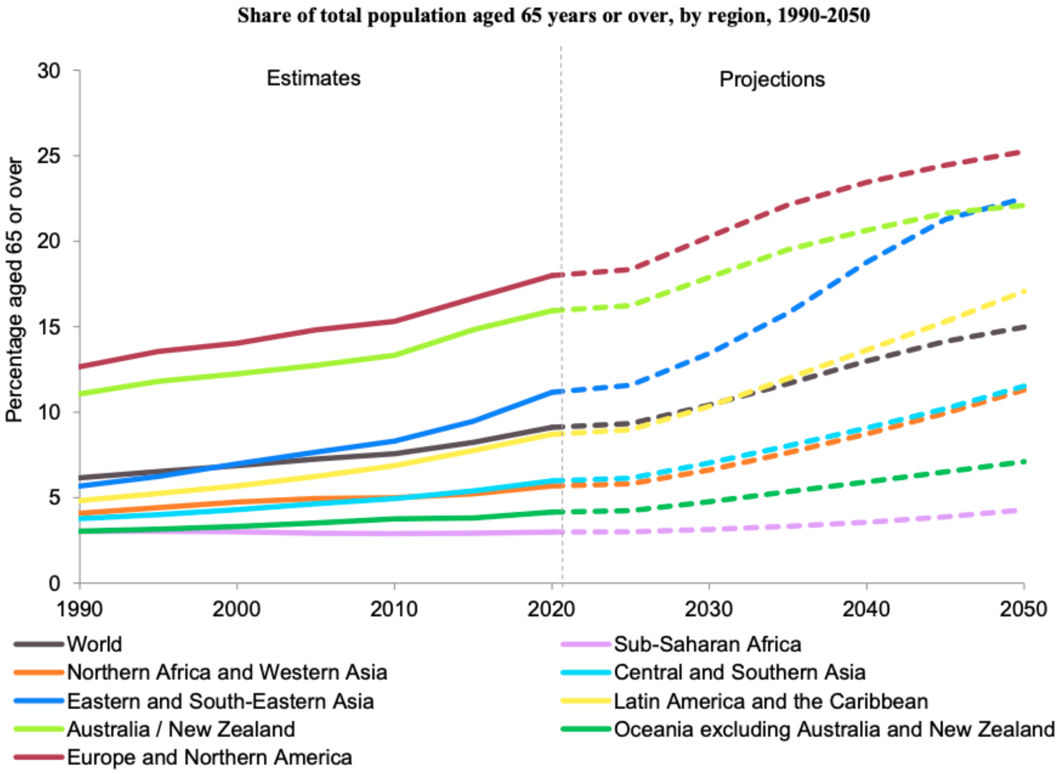

Figure 2: Sourced from ONU (2019).

artificial intelligence, data communications and cloud computing has further enhanced their capabilities (Qian et al., 2021; Kumar, 2024). Not only do these systems improve healthcare outcomes, but they also contribute to a higher quality of life for elderly individuals, enabling them to manage their health conditions from home and thus to live independently for longer (Facchinetti et al., 2023).

In summary, IoT systems offer a revolutionary approach to healthcare, with a particular target for the elderly, enabling more efficient management of chronic diseases and promoting independence, all while soothing the pressure on healthcare systems. This paper explores the applications of IoT in healthcare for older adults, from remote monitoring systems to fall detection devices, discussing ongoing technologies, challenges and limitations that still need to be addressed to make these systems more effective and accessible.

2 Areas of Application of IoT Systems for Elderly Care

IoT systems are applied across various domains to improve healthcare for the elderly, from remote monitoring to emergency detection. (Tun et al., 2021) identified eleven different areas of application, summarised in Table 1, each addressing specific healthcare needs among older adults. Perez et al. (2023) further described applications of IoT systems for different types of impairment. Most of these applications have overlapping components that can be fitted into multiple use cases. In this section, we give an overview of the most relevant applications of IoT systems for the elderly population.

The most widely known application of IoT systems is monitoring. For the ageing group, use cases range from aged care monitoring, tracking general well-being indicators for individuals over 65, to chronic patients.

Aged care monitoring involves tracking various activities, including diet and body weight, communication and social interactions, general health indicators, and ambient assisted living aspects (e.g. optimizing room temperature and humidity). These systems aim to help elderly individuals live independently and safely. On the other hand, **chronic disease monitoring** focuses on tracking specific (chronic) health conditions, like diabetes, heart disease, hypertension, dementia, etc., that require constant management. The U.S. Center for Disease Control and Prevention (CDC) (CDC, 2024) estimated that approximately 85% of elders have at least one chronic health condition, and 60% have at least two.

	Application Area	Definition	Example Applications
1	Aged Care Monitoring	Monitoring health status and general well-being of elderly people.	Ambient Assisted Living Active Aging Monitoring of Diet and Body Weight Communication and Social Activities Improving Quality of Life Group Monitoring
2	Chronic Disease Monitoring	Continuous health monitoring and support for elderly patients with chronic diseases.	Diabetes Monitoring Telehealth Systems for Cardiovascular Disease Home-based Monitoring for Chronic Illnesses
3	Human Activity Recognition (HAR)	Detecting and classifying activity patterns to detect abnormal movements or behaviors.	HAR in Smart Homes Monitoring Daily Activities for Safety Locating and Navigating for Elderly Care
4	Clinical Applications	Supporting medical care in clinical settings, such as disease detection, prediction, and treatment.	Illness Prediction Medication Dispensers Disease Detection Systems Support in Emergency Reception
5	Emergency Conditions	Detecting and responding to emergency situations faced by elderly people.	Fall Detection Systems Emergency Response Alerts Fall Risk Measurement and Reduction
6	Mental Health	Monitoring and assisting with mental health conditions like dementia, depression, and anxiety.	Panic Button for Emergency Assurance Monitoring for Depression and Loneliness Cognitive Assistance for Dementia
7	Movement Disorders	Monitoring abnormal movements in elderly individuals suffering from motor function issues.	Tracking Parkinson's Disease Wearable Sensors for Motor Function Mobility Assistance Systems
8	Rehabilitation	Supporting rehabilitation and recovery from surgery or injury using IoT technology.	IoT-enabled Physical Therapy Real-time Monitoring of Rehabilitation Progress Post-surgery Recovery Assistance
9	Preventive Measures	Preventing health risks by detecting early warning signs and reducing potential health issues.	Pressure Ulcer Prevention Fall Risk Reduction Tracking Early Health Deterioration
10	Accessibility for Caregivers	Enhancing caregivers' ability to manage multiple elderly patients through real-time data access.	Remote Monitoring Platforms for Caregivers Supporting Multiple Patients Simultaneously Efficiency in Elderly Care
11	Supply Chain and Self-Management	Assisting elderly individuals with medication management and daily routines independently.	Smart Medication Dispensers Reminders for Self-care Tasks Managing Daily Health Routines

Table 1: Summary of IoT application areas in elderly healthcare, identified in Tun et al. (2021).

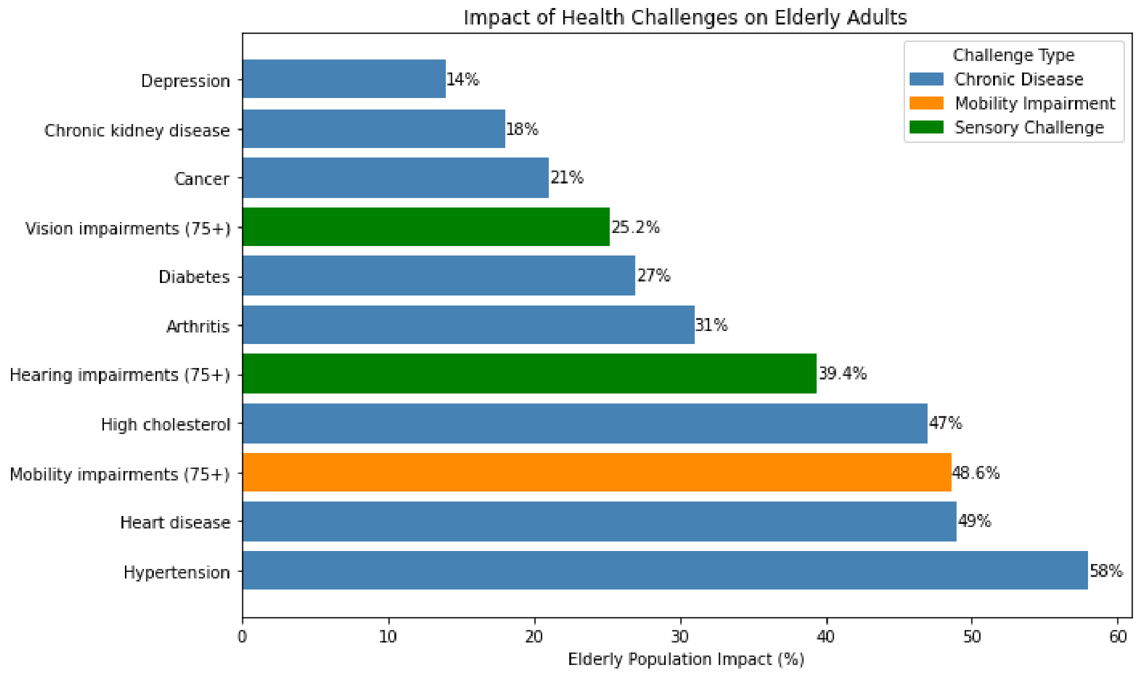

Figure 3: Percentage of elderly population affected by specific health conditions, separated by categories of chronic diseases, mobility impairments or sensory challenges. Data retrieved from Perez et al. (2023).

58% of the ageing population suffers from hypertension, and almost 50% have high cholesterol or heart disease (Perez et al., 2023). We can conclude that chronic conditions encompass one of the biggest, most relevant health challenges for older adults.

Human Activity Recognition (HAR) is a technology that IoT systems use to monitor daily activities and detect any anomalous conditions, such as falls or prolonged inactivity. HAR helps caregivers ensure that older adults are following their prescribed routines and staying active. This application is especially relevant for individuals with mobility impairments or early signs of cognitive decline. **Movement disorders or impediments** range from chronic cognitive conditions like Parkinson's disease to any other physical difficulty, such as hardness to bend, climb steps or carry relatively heavy. According to the CDC (CDC, 2024), only 14.2% of the adult population under 65 experience any mobility disability, while 40% of the elderly do. **Sensory challenges** are another area of application that include decline in hearing, vision, smell, taste, and touch senses. Correia et al. (2016) showed that these impediments correlate with several health conditions, including depression, cognitive decline, slower gait speed, reduction of nutritional compromise, balance, and even mortality.

In Figure 3, we have plotted the percentage of the elderly population that are affected by specific health conditions, classified as chronic, mobility, and sensory.

IoT systems are helpful not only for monitoring but also for **clinical applications**, such as disease detection (heart attack or seizure), prediction, or treatment (medical dispensers or hearing or visual aids). **Emergency conditions** can also be detected through monitored data, allowing quicker emergency responses and identifying the category of the emergency to mitigate it in advance or send the appropriate care as fast as possible. IoT devices can also be used for **rehabilitation purposes**, focused on improving the recovery of elderly individuals from surgeries or injuries. These IoT systems track the patient's progress during physical therapy sessions and provide real-time feedback to both the patient and the healthcare provider (Guizani and Guizani, 2020).

Mental health applications are also amongst the use cases of IoT systems. IoT devices monitor behavioural patterns and help detect early signs of mental illness. Additionally, IoT systems provide caring tools to help with loneliness and depression, on top of also aiding with mental disorders such as dementia or memory loss.

IoT systems in elderly care also offer notorious benefits in **preventive healthcare**. These devices help monitor risks like pressure ulcers and falls, enabling early interventions. For **caregivers**, IoT provides real-time access to health data, allowing them to manage multiple patients more effectively. Lastly, IoT tools like medication dispensers enhance responsible consume of medication and encourage elderly individuals to **manage their health independently**.

3 IoT Solutions, Data Collected and Sensors Used

IoT solutions in elderly healthcare leverage various types of sensors to collect data. The types of data collected depend on the specific application, and the systems are typically divided into *wearable devices*, *smart infrastructures*, and *mobile IoT* devices. Table 2 summarises the types of data collected and sensors used for various specific applications.

Application	**Data Types Collected**	**Sensors Used**
Chronic Disease	Blood pressure Heart rate Blood glucose levels	Photoplethysmography (PPG) Electrocardiography (ECG) Oscillometric sensors
Hypertension	Blood pressure	Digital sphygmomanometer Oscillometric methods Pulse oximeter
Heart Disease	Heart rate Blood pressure ECG signals	Electrocardiography (ECG) Photoplethysmography (PPG) Eulerian Video Magnification (EVM)
Diabetes	Blood glucose levels	Non-invasive glucose monitors PPG sensors Microneedles Trans-dermal devices
Mobility Impairment	Gait analysis Movement patterns Fall detection Navigation	Accelerometers Gyroscopes Pressure sensors EEG sensors Eye-tracking sensors
Mental Health	Sleep patterns Physical activity Stress indicators	Heart rate sensors Accelerometers Galvanic skin response sensors
Alzheimer's and Dementia	Location data Behavioural patterns	Wearable trackers Environmental sensors
Preventive Care (e.g., Fall Detection, Pressure Ulcers)	Body position Movement Vital signs	Pressure sensors Accelerometers Vital sign monitors
Rehabilitation	Progress in physical therapy Movement patterns	IoT-enabled physical therapy sensors Motion tracking sensors

Table 2: Summary of IoT applications, data types, and sensors used in elderly healthcare

For **chronic disease monitoring**, devices such as digital sphygmomanometer (used to measure blood pressure) for hypertension monitoring, heart rate trackers for heart disease, and glucose monitors for diabetes are widely used. These devices often collect physiological data (Farahani et al., 2018), including blood pressure, heart rate, and blood glucose levels. Approaches for heart disease such as photoplethysmography (PPG) for blood flow volume, electrocardiography (ECG) for heart rate, and eulerian video magnification (EVM) for the variation of face pixels over time are all commonly integrated into wearables like smartwatches or wristbands (Bayoumy et al., 2021).

For **mobility impairments**, IoT systems utilize a combination of wearable, smart home, and mobile IoT devices. Wearables like accelerometers, gyroscopes, and pressure sensors are embedded in smartwatches, fitness bands, or clothing to monitor gait, detect falls, and assess mobility. Smart home systems, including motion sensors and pressure mats, track movement within the home and alert caregivers to issues like falls or abnormal inactivity. Mobile IoT devices, such as smart canes, walkers, and electroencephalography (EEG)-controlled or eye-tracking-controlled wheelchairs, provide both short- and long-distance mobility assistance, giving elderly individuals greater independence (Chen et al., 2017).

For **mental health and cognitive decline**, IoT systems use wearable sensors like accelerometers, heart rate monitors, and galvanic skin response sensors to track behavioural and physiological signals related to stress and activity. Additionally, microphones and cameras (smart environment) monitor voice changes and facial expressions, while smartphones collect social data, such as text messages and web activity, to detect mood shifts. These systems, combined with intelligent algorithms, can help monitor conditions like depression. Videogames using virtual reality (VR) and augmented reality (AR) also assist in treating mental health by combining physical exercise with cognitive tasks (Tene et al., 2024).

Lastly, for **preventive care**, IoT systems focus on collecting data that signals early warning signs of conditions such as pressure ulcers, fall risks, and declining physical health. These systems often rely on pressure sensors, vital sign monitors, and environmental sensors to track factors like body position and temperature, ensuring that risk factors are detected early and acted upon before they lead to complications.

4 Existing IoT Systems and Devices

Several IoT end-to-end systems and devices have been used to address healthcare needs for the elderly in the past years. The CardioMEMS™ HF System (Ciotola et al., 2024) helps remotely monitor heart failure patients by measuring pulmonary artery pressure through implantable sensors, providing critical insights for managing heart conditions. In mobility solutions, self-driving trolleys in rural areas assist the elderly by offering transportation, relying on GPS and motion sensors to navigate independently (Reuters, 2017).

For cognitive challenges, VitaVitaVR (VivaVita VR, 2022) uses virtual reality to engage elderly patients with Alzheimer's, while AngelSense GPS (Wigg, 2020) provides real-time tracking to prevent wandering in dementia patients. For sensory impediments, Sonantic AI Voice Platform (Napolitano, 2022) assists elderly individuals with speech impairments by using microphones and AI-based voice synthesis to improve communication, and Oticon Opn™ Hearing Aids (Plyler et al., 2020) analyses environmental sounds to enhance hearing. In addition, the HandTalk system Sarji (2008) translates sign language into speech via smartphone cameras, facilitating communication for elderly individuals with hearing or speech impairments.

In safety and independence, the Lifeline™ Fall Detection System (Burwinkel et al., 2020) detects falls using wearable accelerometers, sending alerts to caregivers.

These IoT products only compound a small share of the market nowadays. Incorporating wearable sensors, smart environments, and mobile devices, these systems boost the independence, safety, and healthcare management of elderly individuals. We have selected two recent systems to explore more in-depth:

4.1 System 1: Integrated Wearable IoT and Long-Term Care Management System

The Integrated Wearable IoT and Long-Term Care Management System (Wang and Hsu, 2023) combines wearable IoT devices with an intelligent management platform to continuously monitor key vital signs, such as heart rate, blood pressure, and body temperature, offering real-time data to caregivers and healthcare providers. What sets this system apart is its focus on managing chronic conditions like cardiovascular disease and diabetes, allowing for continuous tracking of critical health parameters and immediate detection of abnormalities.

One standout feature is its electronic fencing capability, which is particularly beneficial for dementia patients. The system sets virtual boundaries and alerts caregivers if the patient strays outside safe zones, improving safety without constant supervision. The system also includes AI-powered analytics for advanced decision-making, nutrition tracking, and medication management, enabling a more holistic approach to elderly care.

Technologies such as machine learning are employed to analyze trends in the collected data, providing predictive analytics that can warn of upcoming health issues, such as a fall or a sudden rise in blood pressure. Cloud connectivity allows communication with healthcare providers, enhancing remote care as well.

The primary benefits of the system are its comprehensive care approach and real-time alerting, which reduces the need for hospital visits and fosters independent living. However, challenges include power supply dependency, as wearables require regular charging, and potential privacy concerns due to continuous health monitoring and data transmission. Despite these issues, the system provides a significant step forward in elderly healthcare, incorporating such a wide collection of use-cases.

4.2 System 2: Smart Flooring IoT System for Fall Detection

The Smart Flooring IoT System for Fall Detection (Alharbi et al., 2023) is designed to monitor falls in elderly individuals without requiring wearables. This system uses Radio Frequency Identification (RFID) tags embedded into smart carpets to detect when a fall occurs. The RFID tags transmit signals to nearby readers, triggering an alert system and notifying caregivers or family members in real-time. What makes this solution unique is its non-intrusive nature, as it integrates directly into the environment, avoiding the need for elderly individuals to wear any devices.

The system utilizes machine learning algorithms to improve the accuracy of fall detection, specifically using models like Random Forest and K-Nearest Neighbors (KNN). KNN, in particular, achieves a 99% accuracy in detecting falls. This approach offers a higher degree of precision, ensuring false positives or missed events are minimized. Additionally, the system's ability to function without wearable devices reduces the discomfort or inconvenience for elderly users, who may forget to wear or charge sensors.

While smart flooring is a novel and effective solution, other fall detection methods still rely on wearable sensors (Karar et al., 2022). Although wearables have been the most common approach, they pose practical limitations as they rely on users to consistently wear and maintain the devices, which may not always be realistic, particularly in critical moments like an unexpected fall.

5 ML and AI in Elderly Healthcare IoT Systems

Machine Learning (ML) and Artificial Intelligence (AI) have significantly advanced elderly healthcare IoT systems by enhancing data processing and decision-making capabilities. ML algorithms, including deep learning (DL) models such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), can process extensive amounts of sensor data to predict health deterioration, detect falls, or assess mental health conditions. For instance, CNNs have been effectively applied in ECG signal analysis for heart health monitoring, identifying arrhythmias and other heart irregularities with high accuracy (Khan et al., 2023)

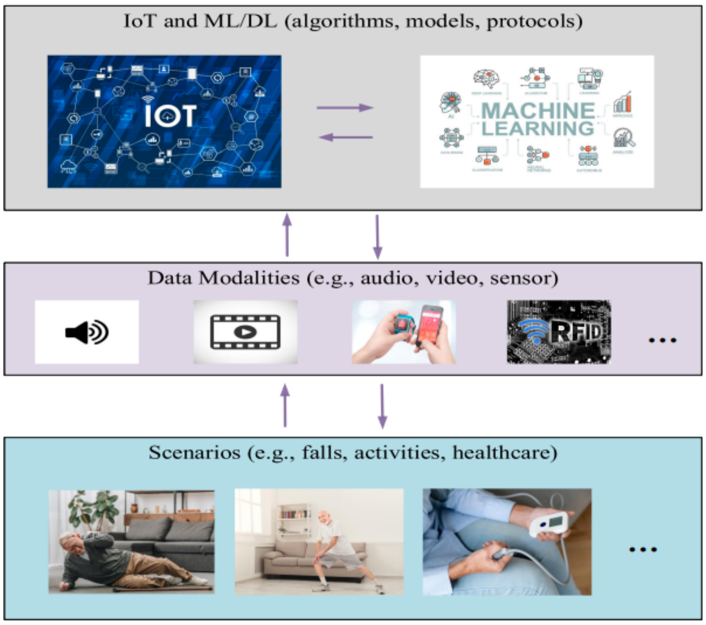

Figure 4: Integration of IoT with Machine Learning and Deep Learning Technologies. Sourced from Qian et al. (2021).

In fall detection and activity recognition, Support Vector Machines (SVM) and k-Nearest Neighbors (k-NN) have been popular for classifying motion patterns based on data from accelerometers and gyroscopes. Alharbi et al. (2023) demonstrated that SVMs effectively distinguished between normal movements and falls by analyzing acceleration data. Similarly, k-NN has achieved 99% accuracy for fall detection in smart flooring systems. Nevertheless, challenges such as data scarcity, privacy concerns, and the need for real-time low-energy consumption.

6 Limitations and Ongoing Challenges

Although IoT systems hold great potential for elderly healthcare, ongoing challenges still limit their effectiveness and usability amongst the older population. These include the user interface design, dependency on power supply, privacy and security, interoperability and connectivity of devices, context awareness and long-term support:

- **Usability and utilising the user interface:** Many older adults struggle to interact and learn user interfaces (GUIs) (Takano et al., 2023). Since we are interested in healthcare applications, this can be particularly challenging for elderly users with declining memory function, limited mobility, or any cognitive impairment. IoT devices such as smart home systems or wearable health monitors often require interaction via smartphone apps or touchscreens, which elderly users may find overwhelming or unintuitive. Even the correct and daily placement of wearable sensors can be a challenge in itself. Voice-based systems (e.g. Alexa or Google Home) operate through spoken instructions. However, voice commands are not always easily understood or remembered by elderly users, particularly those with speech impairments (Song et al., 2022).
- **Privacy and security:** The security and privacy of sensitive health data collected by IoT devices represent a significant concern. Although several privacy and security protocols for IoT systems exist (Butpheng et al., 2020; Chataut et al., 2023), there are still many systems that are released to customers, ignoring these issues. Unauthorised access to these systems cannot only comprise the violation of privacy policies, but it could also allow external users to interrupt or manage health-related services for elderly patients (Al Khatib et al., 2024).
- **Interoperatibity and compatibility of devices:** Elderly individuals may use multiple IoT devices, as no system today encompasses all possible applications of IoT systems in elderly healthcare scenarios (Al Khatib et al., 2024). The lack of standardized systems across different manufacturers makes it difficult to integrate data from various devices into a unified system.
- **Power supply:** The reliance of IoT systems, particularly wearables devices, on batteries presents another significant limitation. Many elderly users struggle with the need to recharge their devices frequently, particularly if their cognitive abilities are impaired or if they suffer from dexterous mobility impairments, among others. The necessity to frequently recharge devices may cause interruptions in continuous monitoring, potentially compromising the effectiveness of these systems in critical situations (Stavropoulos et al., 2020).
- **Context awareness:** Many current IoT systems lack the capability to adapt to a user's environment, physical state or emotional condition (Wang and Hsu, 2023; Al Khatib et al., 2024; Rad et al., 2024). For example, a wearable device might detect an increase in heart rate but may not be able to distinguish whether this increase is due to physical exertion or a medical emergency. This reduces the accuracy and effectiveness of the systems.
- **Long-term support and maintenance:** IoT devices, specifically those from startups, often do not provide long-term support (Mohamad Jawad et al., 2022), leaving users unattended when companies discontinue or stop updating their products. This creates reliability issues, especially in healthcare, where ongoing maintenance and functionality are crucial for patient safety.

Table 3 includes existing limitations in current IoT systems introduced in Section 4.

7 Conclusions

The integration of IoT technologies into elderly healthcare applications has the potential to transform the health industry by addressing challenges such as the growing elderly population and the increased pressure on healthcare systems it entails. In this review paper, we have outlined the motivations behind

System	Application Area	Limitations
CardioMEMS™ HF System (Ciotola et al., 2024)	Remote heart failure monitoring by measuring pulmonary artery pressure.	Dependency on power supply, privacy and security concerns.
Self-driving trolleys for the elderly (Reuters, 2017)	Mobility assistance for the elderly in rural areas.	Context awareness, power supply, interoperability issues.
VitaVR for Cognitive Challenges (VivaVita VR, 2022)	Virtual reality therapy for cognitive issues (e.g., Alzheimer's).	Usability of user interface, long-term support, context awareness.
AngelSense GPS for Alzheimer's (Wigg, 2020)	Real-time tracking for Alzheimer's patients to prevent wandering.	Privacy and security concerns, dependency on power supply.
Sonantic AI Voice Platform (Napolitano, 2022)	AI-based speech synthesis for elderly individuals with speech impairments.	Usability (voice recognition challenges), interoperability.
Oticon Opn™ Hearing Aids (Plyler et al., 2020)	Hearing aids with environmental sound analysis for elderly users.	Usability, power supply dependency, context awareness.
HandTalk for Sign Language (Sarji, 2008)	Real-time sign language translation via smartphone app.	Usability, privacy and security, interoperability.
Covid Shield Mobile App (Ahmed et al., 2020)	Contact tracing and remote vital monitoring during COVID-19.	Usability (smartphone interface), privacy and security concerns.
Lifeline™ Fall Detection System (Burwinkel et al., 2020)	Fall detection and emergency alerts for elderly individuals.	Usability, context awareness, long-term support.
Integrated Wearable IoT and Long-Term Care Management System (Wang and Hsu, 2023)	Comprehensive health monitoring with wearable devices and electronic fencing for dementia.	Usability, context awareness, long-term support, power supply.
Smart Energy Data System for Activity Recognition (Franco et al., 2023)	Monitoring activity patterns based on energy usage for elderly care.	Usability, context awareness, privacy and security.
Smart Flooring IoT System for Fall Detection (Alharbi et al., 2023)	Fall detection via RFID tags in smart floors.	Privacy and security, interoperability, long-term support.
Wearable Sensors with AI for Fall Detection (Karar et al., 2022)	Fall detection using wearables with AI for real-time analysis.	Usability, power supply dependency, long-term support.

Table 3: Summary of IoT Systems, Applications, and Limitations in Elderly Healthcare

the use cases of IoT devices for the ageing population and highlighted various application areas with specific examples.

We discussed the data types that can be collected for each application and identified the most suitable sensors for different situations. Additionally, we provided an overview of modern IoT systems designed for elderly care, focusing on two specific products for fall detection and comprehensive monitoring. We analysed functionalities, technologies, and limitations. We further summarised the impact of recent advancements in machine learning and artificial intelligence in IoT systems, particularly how these have been applied to the elderly population group.

In conclusion, we can attest to the importance of IoT systems in revolutionizing elderly healthcare. These technologies provide more efficient, real-time, and personalized healthcare solutions that enhance the quality of life for older adults by enabling them to live independently whilst managing the health conditions they are more susceptible to. Although continued innovation is still needed to tackle the current limitations, IoT systems have great promise to enhance the quality of healthcare for the elderly.

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