IoT and LiDAR Technologies in Healthcare

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Abstract. Integrating sensor-based smart environments on the Internet of Things can continuously monitor human daily activities and alert caregivers to early signs of cognitive decline or mobility issues. This chapter presents one such sensor the Light Detection and Ranging (LiDAR) sensors that are effective for indoor and outdoor health monitoring, accurately tracking movements and identifying health issues discreetly. They can track movements and identify health issues discreetly, making them preferable to wearable sensors and cameras. This Introduction chapter provides the emerging technologies that are assistive for human gait analysis monitoring for effective reasoning.

Keywords: Internet of Things, LiDAR, Artificial Intelligence,Human Activities of Daily Living

1 Introduction

The aging population is a global phenomenon with significant implications for healthcare systems, particularly in countries like Australia, where a large segment of the elderly actively seeks to maintain independent living. Recent data from the Australian Bureau of Statistics reveals that the proportion of Australians aged 65 and over is rapidly rising, with projections suggesting that this demographic will make up nearly 25% of the population by 2050[1]. This increase in the elderly population is already placing considerable strain on healthcare resources, as the current system struggles to meet the escalating demand for age-related services.

Furthermore, a 2023 poll indicated that many older Australians are deeply concerned about the accessibility and quality of healthcare, especially regarding the management of chronic conditions and the prevention of age-related disabilities. Falls, mobility issues, and cognitive decline represent some of the foremost health concerns for older adults. These challenges are further intensified by a shortage of healthcare professionals, which restricts the delivery of timely and adequate care. This situation highlights the urgent need for innovative solutions that facilitate independent living while providing comprehensive health monitoring and prompt interventions[2].

Despite the existence of numerous technologies aimed at assisting this demographic, their adoption rates remain surprisingly low. Several factors contribute

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to this disparity. Many elderly individuals perceive existing technologies as overly complex or difficult to use, resulting in frustration and subsequent abandonment. Concerns regarding privacy and the perceived intrusiveness of monitoring devices, particularly those equipped with cameras, also inhibit their usage[3]. Furthermore, there is often a lack of trust in the effectiveness and reliability of these systems, alongside a belief that they may diminish rather than enhance their sense of independence. These barriers underscore the necessity for developing solutions that are not only technologically advanced but also user-friendly, privacy-conscious, and tailored to meet the specific needs and concerns of the elderly population[4].

In Australia, unique challenges further complicate the landscape of elderly care. The country's large geographic expanse creates significant disparities in healthcare access, especially in rural areas. Elderly individuals in these regions often face isolation from essential services, leading to delays in treatment and increased health risks. The shortage of healthcare workers, particularly in geriatric care, exacerbates these challenges. Integrating Internet of Things (IoT) sensor-based smart environments offers a promising solution. IoT systems can continuously monitor older adults' daily activities at home, tracking health indicators and identifying early signs of cognitive decline or mobility issues. This enables timely alerts for individuals and caregivers, addressing potential health problems proactively[5].

Among emerging technologies, LiDAR (Light Detection and Ranging) sensors are particularly promising for indoor health monitoring. Known for their precision in spatial mapping, LiDAR can track movements and identify patterns indicative of health issues, such as gait disorders. Furthermore, LiDAR provides a discreet monitoring method compared to wearable sensors and cameras. The country's vast geographic expanse leads to significant disparities in healthcare access, especially in rural areas, where elderly individuals often face isolation from essential services. This situation results in delayed treatments and increased health risks, exacerbated by a shortage of healthcare workers specializing in geriatric care. A solution to these challenges is the integration of Internet of Things (IoT) sensor-based smart environments[6], which continuously monitor older adults' daily activities at home. These systems can track various health indicators, identify early signs of cognitive decline or mobility issues, and send timely alerts to individuals and their caregivers. This proactive approach enhances security and encourages seniors to seek medical attention when necessary[7].

Among the promising technologies in this field are LiDAR sensors, which are known for their precision in spatial mapping. While they are widely used in autonomous vehicles, their application in healthcare for indoor activity recognition has yet to be thoroughly explored. LiDAR can effectively track movements and identify patterns that may indicate health issues, offering a more unobtrusive alternative to wearable sensors and cameras. This technology accurately determines a person's location within confined spaces, making it particularly valuable for monitoring patients in settings such as hospitals or assisted living facilities.

Unlike camera-based monitoring, LiDAR technology preserves individual privacy, ensuring that it does not compromise the confidentiality of individuals while still providing valuable health monitoring capabilities[8].

A novel LiDAR-enabled IoT Ubiquitous Health Monitoring System designed specifically for the elderly population. By leveraging the capabilities of LiDAR to track movements and detect anomalies in confined spaces, alongside IoT's ability to provide real-time data connectivity, the proposed system offers a comprehensive solution for monitoring the well-being of older adults and facilitating aging in place. The system is enhanced by deep learning algorithms that analyze the data to identify patterns indicative of potential health issues, enabling timely interventions[9].

In the field of human activity recognition, the integration of LiDAR and IoT technologies offers a transformative approach to health monitoring, particularly for the aging population in Australia. As the elderly demographic rapidly grows, there's an urgent need for advanced health solutions to support seniors' well-being and independence. Monitoring Activities of Daily Living (ADLs), such as self-care and mobility, is crucial for early detection of physical or cognitive decline. Technology-driven ADL monitoring systems using LiDAR and IoT offer a non-intrusive way to track these activities in real-time. These modern solutions significantly enhance elderly care by enabling continuous, automated, and accurate monitoring in indoor environments[10].

Health monitoring technologies have evolved significantly, encompassing various methods and emerging innovations. Traditionally, activities of daily living (ADLs) were monitored through manual methods, including self-reports, interviews, and direct observation by caregivers or healthcare professionals. While informative, these methods are often subjective, limited by the frequency of observation, and prone to inaccuracies due to under-reporting or poor recall by the individuals being observed[11].

In more modern approaches, wearable health monitoring devices like fitness trackers and smartwatches have gained popularity. These devices allow for continuous tracking of vital signs, physical activity, and sleep patterns, proving to be widely accessible. However, their uptake among the elderly is often hindered by usability issues, discomfort during prolonged wear, and the need for regular maintenance[12].

Studies[13] indicate that adherence to wearable technology tends to decline over time, particularly among older users who face usability challenges. Moreover, the data gathered by these devices may lack the necessary granularity and accuracy for detecting subtle health issues, which are particularly crucial in elderly care. Another method employed predominantly in institutional settings is camera-based monitoring systems. These systems provide high accuracy in identifying abnormal behaviors and emergencies, such as falls. Nonetheless, privacy concerns present a major barrier to their widespread adoption. Many elderly individuals perceive continuous video surveillance as intrusive, leading to resistance against using such systems. Furthermore, varying lighting conditions can impact the effectiveness of cameras in continuous monitoring scenarios[14].

In contrast, in-home sensor systems [15]utilize non-invasive technologies, such as motion detectors and pressure sensors, to unobtrusively monitor daily activities within a person's home environment. While these systems offer the advantage of persistent monitoring, their capabilities tend to be limited to detecting gross movements. This can result in false alarms or missed subtle health changes that are critical for early intervention. Additionally, these systems often fail to provide comprehensive health insights due to a lack of integration with other health data sources[16].

Emerging technologies are also making waves in health monitoring. The Internet of Things (IoT) represents a significant advancement by creating smart environments where interconnected devices can collect and share health data in real time. IoT systems facilitate a holistic view of an individual's health status through integrated data sources. However, challenges such as system complexity, high costs, and concerns regarding data security and interoperability hinder their widespread adoption, particularly in rural or less developed areas. Artificial Intelligence (AI) and Machine Learning (ML) technologies are increasingly being utilized in health monitoring systems to analyze large datasets, predict health trends, and personalize care. By enhancing the ability to detect patterns and anomalies, these technologies can offer early warnings of potential health issues. Nevertheless, their effectiveness can depend heavily on the availability of large, high-quality datasets, with ongoing concerns about algorithmic biases posing challenges for equitable care outcomes across diverse populations. Additionally, while ML techniques are powerful, they often require more complexity and resources than traditional methods, making real-time applications difficult in home-based settings[17].

LiDAR technology, well-known for its applications in autonomous vehicles and environmental mapping, uses laser light to measure distances and create detailed three-dimensional maps of physical spaces. Its non-intrusive nature and high precision present promising opportunities for health monitoring. Despite this, LiDAR's application in healthcare remains limited, with few studies exploring its potential for monitoring human activity and health status. These sensors can capture precise spatial data, which is critical for monitoring movement, detecting falls, and analyzing gait, particularly in assessing the health of elderly individuals. Wi-Fi and Radio Frequency (RF): Wi-Fi and Radio Frequency (RF) technologies have gained increasing attention for their potential in activity recognition and health monitoring. These approaches leverage changes in Wi-Fi signals caused by human movement to detect and classify activities. For instance, a novel algorithm has been developed for recognizing low-level micro-activities and predicting walking routes. This algorithm integrates wearable sensing with an inverse beacon fingerprinting scheme, alongside inertial sensors. This method addresses the challenges related to beacon signal stability and the mismatches often found in magnetic field fingerprinting. By combining the results from both techniques, a notable improvement in prediction accuracy is achieved, allowing for centimeter-level positioning accuracy in micro-activities and over 80% classification accuracy for walking routes[18].

Gaps and Challenges: Despite the promising capabilities of Wi-Fi RF approaches, several challenges hinder their widespread adoption. The accuracy of activity recognition using Wi-Fi signals can be influenced by environmental factors such as the placement of furniture, walls, and interference from other electronic devices. Additionally, relying on RF signals raises concerns about data stability and consistency, particularly in dynamic home environments. While these methods offer non-intrusive monitoring, they often rely on complex algorithms and significant computational resources, which may not be feasible for real-time applications, especially in resource-constrained settings. Another notable limitation is their reduced capability to provide context-aware monitoring, which is essential for accurately identifying complex Activities of Daily Living (ADLs) in elderly care[19].

1.1 LiDAR Technology for Recognizing Human Activities in Indoor Environments

Recent studies have delved into the application of LiDAR technology for identifying human activities in indoor settings. For instance, Benedek integrated 3D LiDAR sensors within a 4D surveillance system, enabling the analysis of gait and the identification of activities such as walking, running, and jumping. Similarly, studies focused on using spatio-temporal interest point features for depth-based action recognition by employing 2D LiDAR sensors. Another approach by Jalal introduced a feature termed "depth silhouettes context," which merges depth information from a 2D LiDAR sensor with contextual data to enhance human tracking and activity recognition using embedded Hidden Markov Models (HMMs)[20, 6]. The following figure represents the main categorization of human activities monitoring systems of daily living.

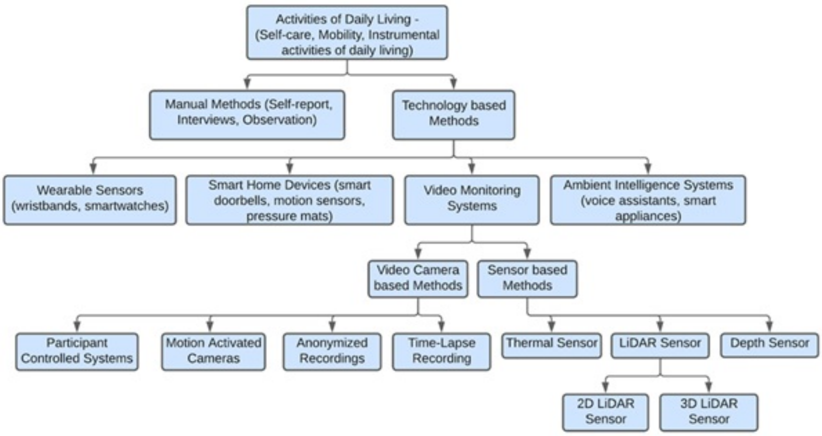

Fig. 1. Human activities of daily living monitoring systems

However, many of these techniques necessitate intricate processing algorithms, which can limit their suitability for real-time applications. To navigate this challenge, researchers have proposed leveraging machine learning techniques to boost both the accuracy and efficiency of LiDAR-based human activity recognition systems. For example, Benedek utilized a support vector machine (SVM) classifier to distinguish between various activities using features extracted from 3D LiDAR data[21]. Additionally, Jalal and Kamal suggested a machine learning approach that combines 2D LiDAR data with RGB-D data to improve the accuracy of human activity recognition, especially in cluttered environments. Despite their effectiveness in enhancing accuracy, these machine learning methods can introduce complexities and increased resource demands, which may hinder their deployment in real-time or resource-constrained contexts[22].

1.2 Scene Recognition and ADL Identification Using LiDAR

LiDAR technology also shows potential for scene recognition, which can aid in identifying Activities of Daily Living (ADLs) through the examination of spatial configurations and movement patterns within monitored areas. By analyzing the 3D point cloud data produced by LiDAR sensors, systems can detect not only the presence and movement of individuals but also the surrounding context of these movements. For example, differentiating between various rooms or zones within a home—such as the kitchen, bathroom, or bedroom—enables the system to infer likely activities being performed, like cooking, bathing, or sleeping[23]. This capability for scene recognition enhances the system's context-aware monitoring, facilitating the detection of deviations from normal routines that may signal health concerns or emergencies. The integration of scene recognition with ADL identification has the potential to significantly elevate the accuracy and relevance of health monitoring systems, particularly for ensuring that elderly individuals are safely managing their daily activities without the need for constant intervention.

1.3 Key Challenges in the Adoption of Existing Technologies among the Elderly

Despite the availability of various health monitoring technologies, their adoption among the elderly remains low due to key barriers such as complexity, discomfort, and privacy concerns. Many elderly individuals find wearable devices and camera-based systems intrusive or difficult to use, underscoring the need for intuitive and minimally invasive solutions that provide reliable health data while respecting privacy. 1) Geographic and Workforce Challenges: Australia's vast geography and a shortage of healthcare professionals, especially in rural areas, hinder consistent in-person care for the elderly. Remote monitoring solutions, like LiDAR systems, can mitigate these challenges by offering continuous health surveillance and reducing reliance on healthcare workers. 2) Privacy and Ethical Concerns: Privacy issues related to camera-based systems significantly deter elderly individuals from adopting health monitoring technologies. Non-invasive, privacy-preserving alternatives are urgently needed to enable comprehensive monitoring without compromising autonomy and security. 3) Insufficient Integration and Interoperability: The lack of seamless integration between health monitoring systems limits effective healthcare delivery. Solutions that unify data from various sources—such as LiDAR, wearables, and IoT sensors—are needed to enhance accurate health assessments and improve care for the elderly.

1.4 LiDAR as a Viable Indoor Healthcare Technology

The present research introduces the innovative use of LiDAR technology for monitoring the health of elderly individuals, effectively addressing the shortcomings of existing technologies by offering a precise and non-invasive solution and respecting privacy. The capacity of LiDAR to monitor movements and identify anomalies within confined spaces marks a significant advancement in remote health monitoring. In contrast to camera-based systems, LiDAR does not capture images that can reveal a person's identity. The system primarily collects 3D point cloud data, representing the shape and movement of objects in the environment. This approach significantly enhances privacy and promotes user acceptance, positioning LiDAR as a promising technology for widespread adoption in elderly care.

The integration of LiDAR with the Internet of Things (IoT) and Machine Learning (ML) technologies result in a robust, real-time health monitoring system. This system can provide personalised health insights and enable early detection of potential health concerns. The combined strengths of these technologies enhance the system's accuracy, reliability, and ability to scale, offering a comprehensive solution that effectively addresses the unique challenges associated with elderly care. The research also introduces the innovative application of LiDAR for scene recognition, which improves the system's ability to identify Activities of Daily Living (ADLs). By analysing the spatial arrangement and movement patterns within a living space, the system can infer the activities, such as cooking, bathing, or sleeping. This context-aware Monitoring enhances the precision of ADL identification, allowing for detecting deviations from everyday routines that might signal health problems or emergencies. This feature is particularly valuable in the context of elderly care, where monitoring the capacity to perform ADLs is crucial for maintaining independence and identifying early signs of health deterioration. The proposed system is particularly well-suited to address the specific challenges of the Australian healthcare sector, including geographical disparities and work-force shortages. By facilitating effective remote monitoring, the system lessens the workload on healthcare professionals and improves access to care for elderly individuals residing in remote or underserved areas. Furthermore, the system's privacy-preserving features align with the cultural and ethical concerns commonly held by Australia's elderly population, increasing the likelihood of its acceptance and adoption. The system's design prioritises scalability, cost-effectiveness, and ease of implementation, making it a practical solution suitable for widespread adoption across various settings. This research contributes to the advancement of health monitoring and holds significant promise for enhancing elderly care throughout Australia and potentially on a global scale. Integrating LiDAR with IoT and ML establishes a versatile platform that can be adapted to diverse healthcare environments, ensuring that elderly individuals receive the necessary care and attention to maintain their independence and overall quality of life.

2 Conclusion

The subsequent nine chapters compile the proceedings of the workshop in the form of structured book chapters with the aim of improving comprehension, readability, and scholarly coherence.
Chapter 2(Participatory Medicine and Reshaping Healthcare Technology) explores the transformation of the healthcare sector through the convergence of technological advancements and a growing emphasis on patient-centered care. The importance and role of participatory medicine is presented not only in clinical practice but also in medical education.
Chapter 3(PaJR as the Foundation for Next-Generation Telemedicine), provides an in depth explanation of one of our pioneering telemedicine models, Patient Journey Records (PaJR).The concept behind PaJR, utilization of its data and its workflow along with real-world scenarios are discussed here.
Chapter 4(Promoting Socio-economic Right to Health Using Web 2.0 and Web 3.0 in Participatory Medical Cognition), presents the Socio-economic Right to Health as a quintessential phenomenon, having huge impact on to the lives of the people enabling humans to live with dignity and is a significant component of Human Rights.
Chapter 5(Basics of Human Gait) The fundamental ideas and language needed to comprehend human gait are covered in this chapter.
Chapter 6(Gait Analysis Approaches) This chapter describes the utilization of IoT along with the application of Artificial Intelligence and Machine Learning techniques that can be realized to monitor the human gait analysis.
Chapter 7(Human Gait and Science) This chapter presents the science and technological methods that enable the detailed observation of movement dynamics, allowing for the identification of abnormalities, variations, and overall physical health.
Chapter 8(AI-Powered Real-Time Gait Detection Using LiDAR for Healthcare Monitoring) The importance and features of LiDAR technology for the health care applications are described in this chapter.
Chapter 9(Human Gait Anomaly Detection Using LiDAR for Healthcare Monitoring) The experimental setup and the steps performed to collect the LiDAR sensor data for empirical evaluation of the gait analysis are depicted in this chapter.
Chapter 10:(Enabling Multimodal Understanding Lidar Data Meets VQA), This chapter explores the integration of Light Detection and Ranging (LiDAR) data with multimodal systems such as Visual Question Answering (VQA) to enable

robust contextual understanding.

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