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Intelligent Environments for Longevity and Active Aging

The Role of Technology Solutions in Revolutionizing Healthcare

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Abstract. The rapid increase in the aging population has brought about the need for new solutions in healthcare. Intelligent environments offer a promising approach for promoting longevity and active aging through the use of technology solutions. In this paper, following the author's journey in the field, we explore the role of intelligent environments in revolutionizing healthcare, and we discuss their potential to enhance the quality of life for older adults. We also provide an overview of some of the key technological solutions that are being developed to support intelligent environments for longevity and active aging.

Keywords. Longevity, Active Ageing, Sensing, Context-Awareness, Behavioral shift detection

1. Introduction

The aging population is increasing at a rapid pace, which has led to significant challenges in healthcare. There is a growing need for new solutions that can help older adults maintain their independence, health, and well-being. One promising approach is the use of intelligent environments, which leverage technology solutions to promote longevity and active aging.

The pursuit of a longer, healthier life has long been a central goal for researchers and scientists, leading to an ongoing debate between the concepts of longevity and anti-aging. Longevity focuses on delaying the onset of age-related diseases and extending the human lifespan by promoting a healthy lifestyle, while anti-aging aims to reverse or halt the aging process altogether [1]. While these two approaches may seem distinct, they share a common goal: to enhance the quality and length of our lives. However, the growing body of evidence suggests that focusing on longevity may be a more attainable and practical approach to improving human health, as opposed to the more speculative field of anti-aging. In this paper, following the recent finding of the author in the last 10 years of research, we will examine how technological advancements are contributing to the pursuit of longevity and why it is crucial to prioritize this approach over anti-aging.

One area where technological advancements are already demonstrating significant potential for promoting longevity is in the development of digital health tools and pre-

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cision medicine. By leveraging artificial intelligence, wearable devices, and big data analytics, researchers are now better equipped to identify and address the unique health needs of individuals, ultimately leading to more effective prevention and treatment of age-related diseases [2].

Considering the current state of scientific knowledge and the practical implications of available technologies, it is evident that focusing on longevity is a more effective and realistic approach to improving human health. By prioritizing the development and implementation of technologies that promote longevity, we can potentially extend the human lifespan and enhance the quality of life for individuals.

In this paper, we explore the role of intelligent environments in revolutionizing healthcare promoting longevity, and we discuss some of the key technological solutions that are being developed to support this approach.

2. The Role of Intelligent Environments in Revolutionizing Healthcare

Intelligent environments offer a range of benefits for healthcare, particularly for older adults. They can help individuals maintain their independence and improve their quality of life by providing support for daily activities, monitoring health and well-being, and promoting social interaction. In addition, intelligent environments can help to reduce the burden on healthcare systems by providing remote monitoring and support, reducing the need for hospitalization, and enabling earlier intervention in health issues.

One key advantage of intelligent environments is the ability to provide personalized support for individuals. By leveraging data and machine learning algorithms, intelligent environments can adapt to the needs and preferences of each user, providing tailored support for daily activities and health management. This approach has the potential to improve outcomes and reduce the burden on caregivers and healthcare providers.

Another advantage of intelligent environments is their ability to provide a seamless user experience. By integrating various technologies, such as sensors, wearables, and smart home devices, intelligent environments can provide a unified platform for health management and daily activities. This approach can reduce the complexity of managing health and promote more consistent and effective interventions.

There are a range of technological solutions that are being developed to support intelligent environments for longevity and active aging. Some of the key areas of focus can be summarize as follows:

- **Sensing and communication infrastructures.** Sensor-based monitoring and activity tracking. Wearable devices for health monitoring and management. Smart home devices for activity support and environmental control.
- **Context awareness and behavioral shift detection.** Machine learning algorithms for personalized support and health management. Algorithms that leveraging the presence of wearable and environmental sensors can recognize the context of the user and detect behavioral shifts towards possible pathological states.

These technological solutions offer significant potential for enhancing the quality of life for older adults and promoting longevity and active aging.

3. Sensing and communication infrastructure

In the field of Active Ageing, Ambient Assisted Living (AAL) represents a key step to facilitate the process of healthy ageing. In AAL, sensing and communication infrastructures play a crucial role in enhancing the quality of life for older adults by providing responsive and adaptive environments that cater to their individual needs. A comprehensive understanding of these infrastructures can be gleaned from the findings of several groundbreaking studies, which have explored various aspects of AAL systems, ranging from smart metering and IoT integration to human factors and indoor localization.

One such study [3] proposed a smart meter-led probe for appliance use recognition, which enables the monitoring of individual appliances and helps create an energy-aware AAL environment. This approach not only optimizes energy consumption but also provides insights into the daily activities of older adults, supporting the development of personalized care plans. The integration of the Internet of Things (IoT) with AAL systems has also been explored, as demonstrated in [4] that introduced the ASIP programming model for Arduino devices. This model facilitates the seamless integration of IoT-enabled sensors and actuators into AAL environments, thereby enhancing their adaptability and responsiveness to the needs of older adults.

In the context of reliability and human factors, the DOREMI case study [5] highlighted the importance of considering user-centered design and usability principles in AAL environments. By addressing these factors, the study demonstrated how AAL systems can be tailored to accommodate the unique preferences, capabilities, and limitations of older adults, ultimately improving their overall experience. Also the NESTORE project [6] showcased the design of an integrated IoT system for personalized coaching for healthy aging. This holistic system, comprising wearable and environmental sensors, offers tailored recommendations and interventions to promote physical activity, cognitive stimulation, social engagement, and healthy nutrition. Complementing the NESTORE project, we explored the potential of BLE (Bluetooth Low Energy) beacons to enhance the monitoring capabilities of AAL environments [7]. By leveraging these beacons, the study demonstrated the feasibility of implementing unobtrusive, accurate, and energy-efficient indoor localization and tracking solutions for older adults.

An important piece of information to monitor sedentariness at home is represented by indoor localization. In [8] we proposed a unified approach for heterogeneous indoor localization systems, which enables the discovery of location-based services in AAL environments. This approach simplifies the integration and management of various localization technologies, thereby enhancing the overall efficiency and usability of AAL systems.

To support the characterization of older adults' status and behavior, in [9] we introduced a multi-domain ontology on healthy aging. This comprehensive framework enables the modeling and analysis of various factors that influence healthy aging, from physical and cognitive aspects to emotional and social dimensions. Lastly, the sensing platform proposed in [10] aims to monitor sleep efficiency in AAL environments. By employing unobtrusive sensing technologies, this platform provides valuable insights into the sleep patterns of older adults, which can then be used to develop personalized interventions to improve sleep quality.

In summary, sensing and communication infrastructures are instrumental in the development and implementation of effective AAL environments. By leveraging the ad-

vancements showcased in these studies, AAL systems can be designed to offer personalized, adaptive, and responsive solutions that cater to the unique needs of older adults, ultimately promoting their health, well-being, and independence.

4. Context awareness and behavioral shift detection

To ensure the well-being, independence, and quality of life of older adults in their ageing process, it is vital to develop innovative technologies that enable continuous monitoring and personalized interventions. Context-awareness and behavioral shift detection play a critical role in achieving these goals. In this regard, several studies have explored the potential of smart environments, mobile and e-health services, and personalized coaching systems for older adults.

In [11], we emphasized the importance of smart environments and context-awareness in a healthy active ageing framework. We proposed a system for lifestyle management in older adults, leveraging the power of intelligent environments to monitor and assess the users' daily activities. The potential of mobile and e-health services to improve the quality of life in long-term care settings [12] underlined the importance of technology in supporting older adults, especially those with mild cognitive impairments (MCI). These systems can exploit the presence of Decision Support Systems (DSS) for personalizing coaching, aimed at promoting active ageing [13,14]. We proposed innovative approaches for designing coaching plans tailored to the individual needs and preferences of older adults. Furthermore, we conducted experiments with frail MCI older adults to evaluate the effectiveness of mobile and e-health services, providing valuable insights into the practical applications of such technologies in real-life scenarios [15]. These aspects have been taken into account in the design of the NESTORE e-Coach [16], a multi-domain pathway to well-being in older age. This comprehensive system integrates various aspects, including physical, cognitive, social, and nutritional dimensions, to deliver personalized coaching interventions for older adults. The NESTORE e-Coach exemplifies the potential of combining context-awareness and behavioral shift detection to promote healthy aging.

Active ageing is a holistic approach that aims to promote the well-being and independence of older adults by addressing various aspects of their lives. Three main areas of intervention that significantly impact the health and quality of life of older adults are sedentariness, nutrition and sleep, and cognitive and social interactions. By targeting these domains, active ageing interventions can help older adults maintain their physical and mental health, fostering a more vibrant and fulfilling life in their later years.

4.1. Sedentariness

Sedentariness is a major concern in older adults, as it contributes to the decline in physical fitness, increased risk of chronic diseases, and reduced functional independence. Active ageing interventions that promote physical activity and reduce sedentary behaviors can greatly enhance older adults' mobility, strength, and overall health, enabling them to remain active and engaged in their daily lives.

Monitoring sedentariness in older adults is crucial for promoting active ageing and maintaining their overall well-being. Indoor localization techniques offer an effective

means of tracking older adults' movements and activities within their home environment. Several studies have explored various approaches to indoor localization for monitoring sedentariness and evaluating older adults' activity levels.

In [17] we proposed a method for monitoring user position in the GiraffPlus Ambient Assisted Living (AAL) environment. The study highlighted the importance of accurately determining the user's position for effective monitoring of sedentariness and other activities. We also presented a stigmergic approach to indoor localization using Bluetooth Low Energy (BLE) beacons [18]. This method enabled efficient and cost-effective monitoring of older adults' movements within their homes. The work presented in [17] focused on monitoring elderly behavior via indoor position-based stigmergy. This approach allowed for the observation of older adults' activities and patterns of movement, which could be used to infer their levels of sedentariness. Potortì et al. [19] introduced the CEO (Context Event Only) indoor localization technique for AAL, providing a robust and effective solution for monitoring older adults' activities and sedentariness at home. These techniques can be made more robust and efficient exploiting the presence of public datasets for testing and development before the actual deploy in real houses [20]. In this regards, we presented a multisource and multivariate dataset for indoor localization methods based on WLAN and geo-magnetic field fingerprinting [21]. This dataset facilitated the development and evaluation of various localization approaches for monitoring older adults' movements and activities. In the context of the DOREMI project, we explored a stigmergy-based approach for long-term monitoring of indoor users' mobility in AAL environments [22]. This method demonstrated its effectiveness in tracking older adults' movements and identifying sedentary behaviors. For indoor scenarios, sometimes it is enough for monitoring sedentariness the possibility to detect occupancy instead of a fine grained position [23]. This approach allowed for accurate and efficient monitoring of older adults' presence in specific areas of their homes, providing valuable insights into their activity levels and sedentariness. For the sake of ease of installation, we also developed a robust device-free localization method that required only a few anchors, demonstrating its potential for cost-effective and reliable monitoring of older adults' movements within their homes [24].

Indoor localization methods have shown great promise for monitoring sedentariness in older adults within their home environment. The various approaches presented in these studies offer efficient and cost-effective means for tracking older adults' movements, providing valuable insights into their activity levels and identifying sedentary behaviors. By leveraging indoor localization techniques, it is possible to promote active ageing and enhance the overall well-being of older adults.

4.2. Nutrition and sleep

Nutrition and sleep play a critical role in maintaining the health and well-being of older adults. Adequate nutrition is essential for sustaining energy levels, preserving muscle mass, and preventing malnutrition-related health issues. Meanwhile, good sleep hygiene contributes to mental and emotional well-being, cognitive function, and immune system health. Active ageing interventions that address these aspects can significantly improve older adults' quality of life and well-being. Advances in technology have enabled the development of innovative solutions to monitor nutrition and sleep for older adults in the comfort of their homes. These unobtrusive systems are critical in promoting healthy lifestyles and improving the quality of life among the elderly population.

Sleep monitoring has been a subject of extensive research, leading to the development of various systems that can assess and analyze sleep behavior in an unobtrusive manner. One such system leverages a set of force sensors placed under the mattress of the user to understand human sleep behavior [25]. This approach allows for continuous monitoring without disturbing the user's sleep, making it ideal for home use. Another study explores the use of smartwatches and stigmergic receptive fields for assessing sleep behavior [26]. By capturing data from the smartwatch's built-in sensors, the system can provide insights into sleep quality and duration. Machine learning techniques have also been applied to understand human sleep behavior [27]. By analyzing data collected from various sources, these algorithms can detect patterns and anomalies, leading to a more comprehensive understanding of sleep quality. A survey of available technologies reveals a diverse range of tools and methods for assessing sleep quality [28]. These include contactless sensors, wearable devices, and mobile applications, each offering unique advantages and limitations. By selecting the most appropriate technology, tailored sleep monitoring solutions can be designed to meet the specific needs of older adults.

Nutrition monitoring has also gained attention, with remote coaching approaches showing promising results in promoting nutritional and physical improvements among older adults [29]. In a real-world study, a remote coaching system facilitated the monitoring of dietary habits, physical activity, and cognitive training, resulting in significant improvements in the participants' nutritional status and physical performance. This approach demonstrates the potential of technology-assisted interventions in promoting healthy eating and active lifestyles among older adults.

The ability to monitor nutrition and sleep at home for older adults has significantly advanced, thanks to the development of unobtrusive monitoring systems, wearable devices, and remote coaching approaches. By harnessing these technologies, older adults can benefit from personalized interventions that promote better sleep quality, improved nutritional habits, and enhanced overall well-being.

4.3. Cognitive and social interactions

Cognitive and social interactions are fundamental to active ageing, as they help maintain cognitive function, emotional health, and social connectedness. Interventions that encourage older adults to engage in cognitively stimulating activities and foster social connections can help counteract cognitive decline and feelings of isolation, which are common in older age. By nurturing these aspects, older adults can enjoy a more meaningful and fulfilling life. Monitoring these aspects can help detect early signs of cognitive decline and social isolation, allowing timely interventions to support older adults' mental and emotional health. Several studies have explored different approaches to monitoring cognitive and social interactions using various technologies, such as sensorized shoes, wearable devices, and environmental monitoring systems.

Cognitive decline is a major concern in older adults, as it can significantly impact their quality of life, independence, and overall well-being. Among the various factors that can be used to assess cognitive function, the analysis of postural control and gait has emerged as a valuable approach. There is a growing body of evidence suggesting a strong relationship between cognitive decline and changes in postural stability and gait patterns [30,31]. Postural control is essential for maintaining balance and preventing falls, which are common issues faced by older adults. Cognitive decline can affect the neural mech-

anisms responsible for postural stability, leading to impaired balance and increased fall risk [30]. Gait analysis, on the other hand, provides insights into an individual's walking patterns, which can also be influenced by cognitive decline. Research has shown that gait characteristics, such as gait speed, stride length, and variability, can be associated with cognitive impairment and decline in older adults [31].

The relationship between cognitive decline and postural/gait analysis has important implications for early detection, intervention, and prevention strategies. By monitoring changes in postural stability and gait patterns, healthcare professionals can identify early signs of cognitive decline, allowing for timely interventions and personalized care plans to support older adults' cognitive health and overall well-being [32].

One approach to unobtrusively perform gait analysis is through commercial devices that can be used at home like scales or sensorized shoes. For instance, the research presented in [33] used a learning system for automatic Berg Balance Scale score estimation, which can provide valuable insights into older adults' cognitive and physical health. Similarly, the study in [34] used sensorized shoes and stigmergic perceptrons to detect user behavior shifts, which can be indicative of changes in cognitive and social engagement.

The relationship between cognitive decline and social interaction is an important aspect to consider when addressing the well-being and overall health of older adults. Research has demonstrated that social interaction plays a vital role in maintaining cognitive function and preventing cognitive decline in aging populations [35,36]. Socially engaged individuals are more likely to experience cognitive stimulation, which helps maintain cognitive reserve and reduce the risk of developing dementia and other cognitive impairments [35]. On the other hand, social isolation and a lack of social engagement can exacerbate cognitive decline, as individuals may experience reduced cognitive stimulation and increased stress, both of which negatively impact cognitive health [36]. Consequently, promoting social interaction and engagement is essential for preventing cognitive decline and supporting the overall mental health and well-being of older adults.

We can monitoring social interactions through the detection of socialization events. The research presented in [37] explored this idea in the context of the DOReMI project, which aimed to assess the frequency and nature of socialization events in older adults. Another study [38] used energy and environmental monitoring to detect occupancy and social interactions, highlighting the potential of leveraging existing infrastructure for this purpose. Bluetooth Low Energy (BLE) beacons have also been employed for remote detection of human proximity and social interactions in indoor environments [39,40]. These studies demonstrated the potential of BLE beacons as an unobtrusive and cost-effective solution for monitoring social interactions among older adults. Moreover, the research presented in [41] analyzed human posture using wearable devices to detect social interactions, showcasing the feasibility of using posture data as a proxy for social engagement.

These approaches offer promising solutions to support the early detection of cognitive decline and social isolation, allowing for timely interventions to promote the mental and emotional well-being of older adults.

5. Conclusions

The aging population presents significant challenges for healthcare systems worldwide. To ensure the well-being, independence, and quality of life of older adults, it is crucial

to develop innovative technologies and interventions that address various aspects of their lives. In this context, we discussed the importance of context-awareness and behavioral shift detection in smart environments, mobile and e-health services, and personalized coaching systems to promote healthy aging.

Key areas of intervention in active ageing include reducing sedentariness, promoting proper nutrition and sleep, and fostering cognitive and social interactions. Monitoring these aspects can provide valuable insights into the health and well-being of older adults, allowing for timely interventions and personalized care plans. Technologies such as sensorized shoes, wearable devices, environmental monitoring systems, and Bluetooth Low Energy beacons have shown promising results in monitoring cognitive and social interactions in older adults, enabling early detection of cognitive decline and social isolation.

Moreover, the relationship between cognitive decline and postural/gait analysis demonstrates the potential of using motor function assessments for early detection and intervention strategies. Furthermore, the connection between cognitive decline and social interaction highlights the importance of promoting social engagement to maintain cognitive function and overall mental health in older adults.

In conclusion, addressing the various aspects of older adults' lives, leveraging innovative technologies, and understanding the relationships between cognitive decline, motor function, and social interaction are essential for promoting active ageing. These approaches can significantly improve the well-being, independence, and quality of life of older adults, enabling them to thrive in their later years.

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