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A Systematic Review of Activity Monitoring and Measurement Systems in Elderly People with Dementia over the Last 5 years

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Abstract: This systematic literature review was conducted to explore systems for measuring and monitoring the activity routine of elderly people with dementia. It was identified and analyzed relevant studies evaluating the construction, effectiveness, and usability of these systems to improve the quality of life of this demographic group. This survey covered the exploration of multiple scientific databases, namely B-on, Google Scholar, PubMed, Science Direct and IEEE, covering the period from 2018 to 2023. The methodology of the different scientific studies, along with their results, as well as the characteristics of the study and the characteristics of the technologies were investigated. The final compilation consisted of 22 articles describing different measurement and monitoring tools. Gaps were identified in this final samples, as well as fields that still need to be addressed. Future research efforts should prioritize the development and refinement of robust, safe, and practical tools aimed at improving patients' quality of life and alleviating the responsibilities of their caregivers.

Keywords: Elderly, Dementia, Activities, Monitoring, Measurement, Systematic review.

1. Introduction

Dementia is a broad term including several illnesses that affects millions of individuals worldwide, particularly among the elderly population aged 65 years and older [1]. It is characterized by memory loss, cognitive impairment, behavioral changes, and functional limitations. Such symptoms can compromise and prevent the performance of activities of daily living [2].

In addition, according to the World Health Organization, in 2021 approximately 55 million people were living with dementia [3] and this number is likely to grow more and more with the increase of the elderly population. If the predictions come true, the number of people with dementia could reach the 139 million mark in the next 30 years [4, 5]. In this sense, it is important to find new solutions or strategies that can help these older people to perform their daily activities without requiring continuous attention or help from their relatives and caregivers, or at least to improve their treatment with information provided on their daily activities.

On the other hand, it is important that the people responsible for the care of these patients can also have tools that help them to monitor these activities and facilitate this care. Therefore, recognizing and understanding the specific needs and challenges faced by the target group is crucial for developing adapted interventions and support systems. In this regard, this research sought to study the available systems to monitor the daily activities of elderly people with dementia, and the measured bio signals, as well as their effectiveness in improving the quality of life of these elderly people and their caregivers have been developed.

Through this systematic analysis of existing literature, the review provided an overview of the current state of the art, identifying gaps and limitations of existing studies and highlighted areas for further research and improvement. The results of this review serve as a basis for future evidence-based decision-making in healthcare settings, guiding the development and implementation of more effective and adapted measurement and monitoring systems.

This paper is organized in 5 sections. Section 2 describes the literature review methodology; Section 3 presents the results obtained; Section 4 shows the discussion and the strengths and limitations of the studies; and, finally, Section 5 presents the paper final considerations and remarks.

2. Methodology

2.1. Search Strategy

For the search strategy, it was applied the PICO (Patient/Population, Intervention, Comparison and Outcomes) framework [6-8]. For that, it was selected as demographic focus group elderly individuals affected by dementia. The intervention component concerns the measurement and monitoring systems, designed to supervise, and track the intrinsic aspects of the daily routines of the selected target population.

Concerning the comparison, it was defined all studies that perform comparative analysis, as well as different measurement and monitoring methodologies or that evaluated the effectiveness of available systems against pre-defined standards. Ultimately, regarding the outcome, it was performed a critical analysis focused on the identification of the role of the available devices to improve the quality of life, daily functioning and well-being of older people affected by dementia.

2.2. Databases, Keywords, and Filters

With the aim of an exhaustive exploration of the literature, a selected set of keywords was used. Variations of terms including, but not limited to, "routine measurement", "monitoring systems", "assessment systems", "older people", "dementia", "activities" and "technologies" were included. Through strategic integration with Boolean operators (AND, OR), these keywords were inserted into the search queries. Different scientific databases were used in this data collection, namely B-On, PubMed, Google Scholar, ScienceDirect and IEEE.

A total of 281 articles relevant to the scope were initially identified and exported to the Zotero platform [9]. Following a reading of the titles and a review of the inclusion and exclusion criteria, 92 articles were selected for a reading of the abstracts and conclusions. Subsequently, after a thorough review of abstracts and conclusions, the articles were refined in accordance with the criteria outlined in the forthcoming sections.

2.3. Selection Criteria

Concerning the inclusion criteria, only studies between 2018-2023 were considered. One of the main inclusion criteria was the selection of articles that provided specialized research in the field of monitoring and measurement systems for daily activities. At the same time, studies that focused on treatment modalities without patient data acquisition were removed. Articles written in languages other than English and Portuguese language are part of this exclusion list. Systematic reviews, meta-analyses, editorials, journal articles, magazine articles and book chapters were also excluded. All duplicates between databases were also removed.

2.4. Quality Criteria

The selection process for the articles in this study was also based on a set of quality criteria, with the aim of guaranteeing the integrity and credibility of the research results. First, priority was given to studies with a representative sample of elderly people with dementia. However, it was realized that large samples became difficult in some studies, due to the lack of necessary authorization.

In addition, the quality criteria gave priority to studies that incorporated validated and reliable measurement systems. In addition, the evaluation process included studies that employed methodologies capable of minimizing potential bias, both in terms of selection and confounding factors. Strategies such as randomization and pairing were considered.

3. Results

After the research process and considering all the stablished criteria, a collection of 22 articles was selected for final analysis. These carefully selected articles will be presented in the following subsection, organized in Table 1.

3.1. Characteristics of the Selected Studies

This section presents a detailed overview of the selected articles. Table 1 contains vital information, including the authors, the titles of the articles, the main characteristics of the studies and the types of technology used. The articles were also identified in the table for future reference in the review.

Among the articles identified, a trend emerges in which three of them [19, 22, 27] mainly investigate the feasibility of using already available technologies, rather than the details of the systems themselves. Although these studies do not focus precisely on the architecture of each system, they do provide some information on the operational dynamics of such technologies and their potential acceptance by patients.

Table 1. Selected Articles.

Index	Authors	Year	Title	Type of Technology	Characteristics
A1	Shao et al. [10]	2018	A Fuzzy Spiking Neural Network for Behavior Estimation by Multiple Environmental Sensors	Daily life monitoring system with environment sensor network.	The survey used a Partner robot, a guardian's smartphone, and various environmental sensors. The Fuzzy spiking neural network was also used to find sensor information that best reflects human behavior. An experiment was made in a house of four.
A2	Su et al. [11]	2018	Activity Recognition System for Dementia in Smart Homes based on Wearable Sensor Data	Wearable sensors and ambient sensors.	Study proposes augmented reality (AR) system in smart homes. Integrates internal positioning, hand movements using Random Forest and Dirichlet Process Mixture Model. Uses tri-grams for feature extraction.
A3	Obaid et al. [12]	2018	Automatic Food-Intake Monitoring System for Persons Living with Alzheimer's-Vision-Based Embedded System	Real-time vision-based device using raspberry pi 3 Plus and a 7-inch display with USB webcam.	The system employs innovative image processing techniques for hand and face detection designed to monitor food intake. It uses skin color detection through the HSV model, ensuring accurate tracking of hand movements. Experimental testing demonstrated an 89% accuracy in real-time scenarios.
A4	Yao et al. [13]	2018	Compressive Representation for Device-Free Activity Recognition with Passive RFID Signal Strength	Radio Frequency Identification (RFID)-based Compressive Sensing System for Unobtrusive Activity Recognition.	Focus on RFID and RSSI technology for activity tracking, without wearable devices. Applies dictionary learning and canonical correlation analysis. Validated in real-world experiments.
A5	Chun-Fang et al. [14]	2018	Indoor Positioning for Dementia in Smart Homes Based on Wearable Device	Bluetooth indoor positioning with the usage of accelerometer sensor and a gyroscope sensor.	The study integrates Bluetooth, accelerometer and gyroscope into a smart bracelet for indoor positioning. A Random Forest classification model processes the Bluetooth data for accurate positioning. Online tests adjust the results dynamically, taking real-time data into account.
A6	Yang et al. [15]	2019	Assistive and Monitoring Multifunctional Smart Crutch for Elderly	Multifunctional smart crutch.	The study proposes a multifunctional smart crutch using an Internet of Things (IoT) platform which enables GPS location, fall detection using a gyroscope and heart rate monitoring with the MAX30102 (integrated pulse oximetry and heart rate monitoring module). An assistance light feature adjusts the brightness based on the intensity of the ambient light.
A7	Takahashi et al. [16]	2019	Battery-less Shoe-Type Wearable Location Sensor System for Monitoring People with Dementia	Indoor location shoe sensor with battery independence.	The study presents a battery-free shoe sensor that uses the movement of walking to obtain energy. It achieved a 94.3% success rate in estimating indoor locations, with a successful 130-day trial in a nursing home.
A8	Thorpe et al. [17]	2019	Development of a Sensor-Based Behavioral Monitoring Solution to Support Dementia Care	Wearable sensor technology.	Study carried out with 5 healthy people, using a smartwatch and a smartphone with google APIS. The research focused on obtaining location, step count and activity recognition data.
A9	Huang et al. [18]	2019	Development of Health Care System Based on Wearable Devices	Smart clothes, body tag, and healthy watch.	The study involves integrating IoT with wearable devices, such as smart clothes and watches and body tags. The devices collect physiological signals from users, which are transmitted to a service server via Bluetooth. Includes care notification that enables real-time monitoring.
A10	Maiden et al. [19]	2019	Evaluating the Use of Daily Care Notes Software for Older People with Dementia	Daily notes system via mobile devices and desktops.	The survey was carried out using the Yammer Software application, with 18 caregivers, 2 team leaders and 13 patients of a residential home, as well as other health professionals who also had access to the notes.
A11	Kolakowski & Blachucki [20]	2019	Monitoring Wandering Behavior of Persons Suffering from Dementia Using BLE Based Localization System	Bluetooth Low Energy (BLE) based positioning system.	The system employs an Extended Kalman Filter algorithm to calculate user positions based on signals received from anchors distributed in a monitored area. The experiments involved tracking four dementia patients for three days.
A12	Lousado & Antunes [21]	2019	PRO2S – System for the Protection and Monitoring of the Elderly and Mentally Ill in Outdoor	Application integrated with sensor system.	The study looks at a system called PRO2S that uses the Internet of Things and ubiquitous computing for real-time monitoring. It incorporates an accelerometer, temperature, humidity, and pulse sensors into a bracelet. It provides immediate alerts in the event of abnormal situations.

Table 1. Continued.

Index	Authors	Year	Title	Type of Technology	Characteristics
A13	Dolatabadi et al. [22]	2019	The Feasibility of a Vision-Based Sensor for Longitudinal Monitoring of Mobility in Older Adults with Dementia	Vision-based sensor for tracking.	Study with 18 institutionalized elderly people. The setup included a Microsoft Kinect, a laptop computer, a radio frequency identification reader and two circularly polarized UHF antennas. Walking sequences were recorded, analyzed, and gait parameters extracted.
A14	Mibu & Shinomiya [23]	2020	Activity Recognition and Anomaly Detection for the Elderly with Dementia by using Passive RFID Sensor Tags	Passive radio frequency identification sensor tags.	The study employs passive radio frequency identification tags on everyday objects like trash boxes for unobtrusive monitoring. The system aims for easy installation, requiring no active cooperation from the elderly, and alerts caregivers or family members of meaningful anomalies.
A15	Pratama et al. [24]	2020	Geofencing Technology in Monitoring of Geriatric Patients Suffering from Dementia and Alzheimer	Geofencing surveillance system.	Patient monitored by a GPS device. If the monitored area is exceeded, the distance between the elderly person and the nearest caregiver is calculated using the Haversine method.
A16	Favela et al. [25]	2020	Monitoring Behavioral Symptoms of Dementia using Activity Trackers	Personalized behavioral symptom monitoring with activity trackers.	9 elderly people and 8 caregivers participated in the study. Two smartwatch models were used to collect data on steps per minute, heartbeats per minute and minutes of sleep. The data sought to evaluate behavioral changes related to dementia in participants in Cognitive Stimulation Therapy using the Eva robot.
A17	Raad et al. [26]	2021	An RFID-Based Monitoring and Localization System for Dementia Patients	Sirit radio frequency identification robust reader.	The study is based on RFID to track and monitor the elderly in a smart environment. The system uses battery-free RFID wearable tags. The system enables real-time tracking, issuing alerts in the event of potentially dangerous wandering outside predefined zones.
A18	Pu et al. [27]	2021	Portable EEG monitoring for older adults with dementia and chronic pain – A feasibility study	Pain monitoring through a portable EEG device.	Use of a portable headband for EEG measurement. Sample of 5 elderly people in an institution. The device is connected to a smartphone or other device capable of receiving data. The device was placed on different days, monitoring the level of pain perceived by the subjects.
A19	Basuki et al. [28]	2022	Audio Based Action Recognition for Monitoring Elderly Dementia Patients	Audio capture and action recognition with deep learning.	Usage of two hardware devices (Raspberry Pi 4B and ReSpeaker sensor). Usage of a Convolutional Neural Network. Usage of MQTT protocol to transmit the data to the backend platform.
A20	Au-Yeung et al. [29]	2022	Monitoring Behaviors of Patients with Late-stage Dementia Using Passive Environmental Sensing Approaches: A Case Series	Unobtrusive activity-sensing technologies to track behavioral markers.	Platform gathered participant data, including sensors under mattresses, movement sensors and actigraphy devices; other participants used Emerald sensors. Data correlated with medication, assessed by caregivers and doctors.
A21	Megalingam et al. [30]	2022	Indoor Tracking of Dementia Patients without GPS	Real time location systems.	The technology studied is a real-time localization system based on wireless sensor networks and NodeMCU microcontrollers. It uses proximity sensors, actuators, and an alert node to locate and monitor patients.
A22	Garcia-Requejo et al. [31]	2022	Indoor-Outdoor Tracking and Activity Monitoring System for Dementia Patients	Infrared-based positioning system.	A wearable device that integrates a Global Navigation Satellite Systems (GNSS) module, an accelerometer, and an infrared-based indoor positioning system. It communicates via LoRaWAN. The system includes The Things Stack cloud platform and Grafana. The wearable is equipped with an environmental sensor. The Lorix-One 868 MHz serves as a LoRaWAN gateway.

Studies A2, A5, A8, A9, A11, A12, A16, A18, A20 and A22 used devices directly linked to patients, such as smart watches and tags. Study A9 introduces for the first-time smart clothing. Study A10 was unique in its use of a technology managed solely by caregivers. Additionally, the other studies (A1, A3, A4, A6, A7, A13, A14, A15, A17, A19, A21) implemented remote monitoring technologies, eliminating the necessity for the elderly to carry a device.

In terms of monitoring methodologies, the research landscape reveals different aspects. Study A19 is the only one to propose audio capture and subsequent recognition for activity assessment. Studies A5, A6, A7, A8, A11, A13, A15, A17, A21, and A22 converge on geolocation strategies adapted to elderly people with dementia. With similar objectives, A8 and A16 used pedometer technology to assess ambulatory activity. Expanding the research repertoire, A8

emerged as a singular effort to delineate activities through sensor-activated inference. Study A6, on the other hand, brings a unique and innovative idea within the research carried out, since it promotes a monitoring system with both geolocation and failing detection functionalities.

Instead of automated processes, A10 introduced an annotation system mediated by the caregiver, facilitated by a smartphone app. Both A8 and A20 focused on the acquisition of sleep patterns, while A16 studied into heart rate monitoring. A20 and A13 used motion sensors to obtain data, although A13's study attempted to monitor each patient's gait. It is interesting to note that the A18 study used a portable EEG device to identify pain levels, the only study to look at pain in dementia patients.

Study A1 also innovates by using a partner robot that interacts with the elderly, providing a companion for conversations, as well as sensors that not only detect anomalies and activities, but also recognize drownings in the bathroom. Differently, study A3 proposes a vision-based system that monitors patients' food intake.

Finally, there are a notable number of studies on the use of radio frequency identification for different functions. Studies A4 and A17 propose the identification of activities through tags, with A4 presenting a dictionary and canonical correlation to detect such activities and A17 proposing the construction of an Android application to track and alert on location and suspicious activities. Study A14 implements tags on different objects, such as garbage cans, to check for anomalies in garbage disposal and thus be able to infer that something is wrong. Article A13 also features the use of radio frequency identification to locate patients.

The following subsection takes an in-depth look at the conclusions and results of these studies.

3.2. Presentation of Results

The selected studies cover a diverse range of approaches already used in the state-of-the-art for the development of monitoring systems, providing an insight into the current landscape of research dedicated to supporting individuals with dementia. In this section, a detailed analysis of each selected article is provided.

The first proposed system [10] integrates information, network, and robot technology, creating an Information Structure Space (ISS) to collect, store, transform and provide information. The sensor network for monitoring is composed of a daily life monitoring system, a partner robot system, and a behavior visualization system. The article introduces a Fuzzy Spiking Neural Network (FSNN) as a method for estimating behavior. The experiment involved four individuals, and the results showed an accuracy of 94.03 % in estimating behavior. Finally, the authors identified relevant challenges, such as delays in sensor data, and express future goals of optimizing the system, reducing costs, and considering external factors such as seasonality.

Article A2 presents an Augmented Reality (AR) system for monitoring elderly people with dementia in smart homes. The system integrates data from on-body sensors (e.g., smartwatches with Bluetooth) and environmental sensors to monitor indoor positions and hand movements. The authors used machine learning algorithms such as Random Forest for indoor positioning and Dynamic Bayesian Network with Dirichlet Process Mixture Model for activity recognition. Here, the main feature is the use of a non-parametric grouping approach to categorize hand movements and integrate position information to distinguish similar activities. The proposed system achieved an accuracy rate of 99.1 % in recognizing complex activities related to "taking a medicine" and "eating a meal".

The third article [12] presented a real-time vision-based system designed to monitor food intake. Using the microcomputer Raspberry Pi 3 and a 7-inch screen, the system employed image processing techniques to detect hands and faces. It also uses skin color detection, ensuring accurate tracking of hand movements. The proposed structure defines an approach for tracking food intake activities, as well as engaging patients through video instructions. Experimental tests showed 89 % accuracy in real-time scenarios, demonstrating the system's potential to provide timely and independent support. Although the system is functional, it raised considerations related to the ethical implications of using images.

The study A4 presented a device-free, unobtrusive human activity recognition system based on RFID transmission signals. The proposed approach, which used a sparse representation based on a dictionary, demonstrated good results in detecting and classifying 23 postures and actions with an average accuracy of > 96 %. As a conclusion of the study, the results demonstrated the potential of the proposed approach for real applications in monitoring and assisting the elderly in their daily activities.

In the study A5, the authors developed an indoor positioning system for elderly people with dementia using smart bracelets equipped with Bluetooth sensors, an accelerometer, and a gyroscope. Considering the limitations of GPS, the authors also thought about the inconvenience of carrying smartphones. By combining Bluetooth-based positioning with data from motion sensors, the proposed method improved accuracy. The use of a median filter effectively reduced noise in the Bluetooth signal caused by environmental factors and body movements. The system demonstrated successful indoor localization, taking advantage of a finite state machine to refine the position results. The results suggested a promising approach to accurately locating the elderly in smart homes.

The A6 study introduced a different idea of a multifunctional smart crutch designed for elderly location monitoring, heart rate monitoring, fall

detection and supportive lighting for dark environments. Connected to the Internet of Things (IoT) platform, specifically using the China Mobile ONE-NET platform, the smart crutch enables real-time data transmission and accessibility for family members.

The seventh study [16] presented a battery-free location sensor included in a shoe to monitor the movement of elderly people with dementia. To address the challenges posed by battery-dependent portable sensors, the proposed system takes advantage of energy harvesting, specifically from the natural movement of walking, to power the transmitter built into the shoe. The experiment demonstrated that location estimation was successful, achieving a high success rate of 94.3 % in a controlled laboratory environment. In addition, the system was implemented and monitored in a real nursing home, where it successfully tracked the movement of an elderly woman with dementia for more than 130 days. These promising results suggest that the sensor developed can offer a reliable and maintenance-free solution.

The A8 [17] study, although successful in tracking behavior at home and identifying patterns, aiding predictive models and personalized interventions for dementia care, still needs to return this data to the health system to prove the real effectiveness of each of them in improving the quality of life of individuals. Furthermore, the success of studies carried out on healthy people may still run into several problems if carried out on people who have all the difficulties that dementia can offer.

The study A9 presented an IoT-based system that uses portable devices, including smart clothing, a health watch and body tags. The devices collect physiological data, such as electrocardiography signals and changes in attitude, which are transmitted to a service server. The system includes a Bluetooth to Wi-Fi gateway for data transmission and a care notification system for proactive health management. The results of the field implementation in a long-term care facility showed successful monitoring of the health status of residents, both for those suffering from chronic diseases and dementia. The system effectively detected abnormal events, provides immediate emergency notifications, and offers personalized health insights and questionnaires.

The A10 study [19], although not giving details of the system adopted, shows the successful adoption of the software by care providers. Positive results include an increase in the volume of daily care notes, improved readability, greater accessibility, and better preparation for activities. Usability considerations are highlighted, with the versatility of the software being crucial to overcoming barriers. Furthermore, the alignment of policies and technologies remains a challenge. Finally, as this is a study that relies on manual data input, it still needs research and evaluation of the best ways to maintain the reliability of the information collected.

The A11 [20] study is directly concerned with wandering behavior in individuals with dementia, and for this it uses a location system based on Bluetooth Low Energy. The system consisted of a tag worn by the user, an infrastructure that includes a set of anchors distributed in the monitored area and a system controller. The system also employed an Extended Kalman Filter algorithm to calculate the users' positions based on the signals received from the anchors. The experiments, carried out in a long-term care center, involved monitoring four dementia patients for three days. The Bluetooth system demonstrated moderate accuracy in locating users, successfully detecting, and diagnosing some wandering incidents. However, monitoring is not yet automatic, preventing a more immediate response.

The study A12 presented a model called PRO2S (Protection and Security System). Taking advantage of the IoT and portable sensors, the system incorporates devices such as accelerometers, GPS, temperature, humidity, and pulse sensors, all integrated into a discreet wristband for the user's comfort. The system allows for real-time monitoring, guaranteeing the safety of users within predefined zones. Functional and non-functional requirements are discussed, as well as the systems architecture. The interface allows administrators to monitor users' outdoor activities, triggering alerts for anomalous situations. Future work includes refining the system based on the proof of concept presented, addressing energy sources, and customizing the technology for individual users.

The A13 study [22] demonstrated the feasibility of using the vision-based tool to longitudinally monitor gait in people with dementia. The tool successfully collected and analyzed gait data, providing information on walking patterns and gait measurements. This approach offers potential to improve falls risk assessment in long-term care by detecting changes in mobility patterns that may precede health events. Although portable sensors have limitations, vision-based systems such as AMBIENT are promising. Opportunities for improvement presented include refining participant identification methods, improving sensor placement and automating data processing.

Study number fourteen [23] proposed a non-intrusive monitoring system for elderly people living alone, using passive RFID sensor tags on everyday objects. The system aimed to detect anomalies in daily activities, such as leaving garbage or neglecting meals. Experiments focusing on garbage can monitoring revealed that changes in Received Signal Strength Indication (RSSI) values were correlated with the amount of garbage, enabling the detection of unattended garbage. In addition, temperature measurements on tableware indicated the potential to detect neglected meals. The results highlight the feasibility and effectiveness of the proposed RFID-based monitoring system.

The study A15 [24] used the Haversine distance calculation and a notification system to manage proximity between the care provider and the patient. Although generally successful, two trials failed due to

inaccuracies in the distance calculation. The dependence of the mobile device system on GPS signals led to lower accuracy. A further disadvantage emerged: the system does not monitor immobile patients. Future research was suggested that could include alerts of dangerous areas and notifications of patient immobility, as well as improving the effectiveness of GPS.

The A16 study [25] demonstrated the successful adoption of activity monitors by patients and caregivers for the assessment of dementia-related symptoms. Activity monitors provide valuable data on behavioral symptoms such as depression and apathy. Incorporating new sensors or raw data could improve the monitoring of other symptoms. Challenges include accuracy due to the limitations of the devices. Future research could explore advanced sensors and environmental data. Accelerometer raw data could estimate physical agitation and spatio-temporal gait parameters related to the risk of depression and dementia. The raw data would also allow for better monitoring of mobility and sedentary activity. The article also suggests incorporating microphones to assess socialization and including waterproof devices that are easier to use.

The study A17 presented a framework that uses low-cost, battery-free RFID wearable tags for the intelligent tracking of multiple people in a smart home environment. The proposed system employed a proximity-based indoor localization technique, using RFID antennas strategically placed in the living environment. The experiment demonstrated accurate, real-time monitoring of the elderly, detecting wandering behavior and triggering alerts via an Android application. The systems success lies in its ability to track up to three elderly people simultaneously, offering a promising solution for increasing the safety and well-being of people living alone.

A18 study [27] suggested that changes in pain-related brain regions are associated with changes in spontaneous brain activity, which may indicate pain processing. Portable EEG devices, such as the one used in the study, could serve as a low-cost, non-invasive tool for assessing pain in people with dementia. However, the small sample size and technical limitations of the study warrant further research for robust clinical applications. The feasibility of obtaining EEG data from residents with dementia was demonstrated, opening the possibility of EEG being a biomarker of pain for those who are unable to communicate. Finally, the article indicates that larger studies are needed to validate these results and compare portable EEG with medical-grade EEG for pain assessment.

While limited in scope, the study A19 [28] achieved a noteworthy 98 % accuracy in the audio capture, forwarding data to discern basic activities. Ongoing enhancements are warranted, including broadening recognized activities, and minimizing sensor dimensions.

The twentieth article selected [29] is a case series demonstrating the potential of discrete activity detection technology for monitoring people with dementia in their natural living environments. The technology implemented offered continuous, privacy-preserving data with the appropriate clinical implications, including the identification of behavioral changes and medication effects. The study also identified the need for further research to validate behavioral markers, guarantee privacy and establish transparency.

The proposed system by the penultimate article [30] uses a network of NodeMCU devices placed at exit points and on the patient, facilitating real-time monitoring in confined spaces such as homes or care centers. This system mitigated the limitations associated with GPS in smaller areas. The test showed favorable results, with minimal delay observed in the locally configured network. The cost-effectiveness of the system, with an estimated manufacturing cost significantly lower than that of alternatives on the market, increases its potential for widespread adoption. Future work aims to refine the design of the system so that it can be used incorporating low power consumption features, user-friendly interfaces, and additional functionalities such as voice processing.

Finally, the focus of the latest study [31] is on a wearable device based on a commercial tablet, incorporated with a GNSS module for outdoor location, an accelerometer for step detection and a LoRaWAN communications module. In addition, an infrared detector for indoor positioning enables symbolic indoor location using an infrared beacon system. The use of the communications module guarantees low power consumption and wide coverage in areas with limited access to the mobile network. Data on the patients position and steps are stored in a database, accessible via a web application. The system aims to help caregivers while promoting patient independence. Future efforts will involve integrating a fall detector, developing an Android application for alerts, and carrying out experimental tests with volunteers.

Following this exploration, in the next section (Discussion) it will be evaluated the strengths and weaknesses identified, aiming to provide a critical understanding of the state of the art of dementia monitoring systems and relevant challenges to be addressed in the future.

4. Discussion

Emerging technologies designed to measure and monitor activities hold great promise for improving care for older people with dementia, offering relevant improvements in standard care approaches and alleviating difficulties for caregivers.

According to our analysis, most of the available studies identified as challenging the recognition on anomalies in the activities of the elderly that could be

an indicator of dementia. Therefore, and to achieve a satisfactory performance in this task, most studies focus on a multiparameter evaluation strategy. Here, the fusion of various technologies as evidenced by the studies in this systematic review, reflects a broader movement towards innovative approaches. These encompass IoT, RFID, AR, and vision-based tools, each offering unique advantages on improving care for individuals with dementia.

It is important to note that the direct comparison between selected studies is not straightforward, due to the variables target group (i.e., different target group characteristics between studies), and a multitude of different goals, different scenarios and studied parameters (including different diseases).

Finally, while individual studies present laudable achievements, issues such as ethical implications, user acceptance and the practicality of implementation in various care settings emerge as recurring themes. For this reason, the main points of strength and weakness found in the studies will be presented below.

4.1. Strengths and Limitations of the Studies Included

At first, during the presentation of the results, it was possible to see that in the different technological scenarios described in the different studies, there is a common aspiration for real-time monitoring, evident in solutions such as AR systems [A2], smart crutches [15] and location sensors in shoes [16]. While the potential of these technologies is evident, a comprehensive discussion focuses on critical factors that influence their general adoption is still missing. Ethical considerations, long-term user acceptance and the practicality of implementation in various care settings emerge as critical points for the development of new technologies for detecting dementia.

The studies presenting vision-based tools for monitoring, exemplified by A3 and A13, demonstrated promising performances for improving falls risk assessment or problems with eating. However, a well-founded discussion should cover the limitations inherent in the methods of identifying participants, the need for automated data processing and the practicality of deploying such systems on a larger scale.

The exploration of IoT integration with portable sensors, exemplified in studies such as A9, A12 and A19, underlines the potential for efficient health monitoring. However, critical evaluation is essential to understand potential biases, scalability challenges and the adaptability of these systems in various care settings.

Considering the wearables (A2, A5, A8, A9, A11, A12, A16, A18, A20 and A22), despite being a practical, fast and reliable approach of obtaining patient information, it also presents several limitations, namely uncomfortable to wear, incorrect positioning can result in an incorrect measure and can be easily forgotten.

Lastly, it is also important to highlight that one of the studies under review focused in particular on the dyadic relationship between people with dementia and their caregivers [10], highlighting the key role of caregiver involvement [32]. This underlines the emphasis of research on the need to adequately prepare and integrate caregivers in the assessment and training of these technologies, helping them to obtain information, but also not helping that much on the burden of their work.

5. Final Remarks

The integration of technologies presents a promising avenue for improving the well-being of the geriatric population affected by dementia. Technological implementations show favorable results by providing auxiliary support to the elderly and their caregivers in the field of daily activities, while facilitating the assessment and optimization of medical interventions. Given the rapid pace of demographic ageing, the increasing prevalence of dementia and the expected treatment costs, monitoring technologies are set to play a key role in the daily lives of older people with dementia and their caregivers.

Empirical evidence underlines the satisfactory implications of monitoring paradigms, while at the same time highlighting the need for improvement. The use of pre-existing devices that interact seamlessly with common smartphones and smartwatches is clearly an economical and effective resource. However, the emergence of more sophisticated modalities, such as audio recognition systems, requires greater investment in research to discern their effectiveness. Given the lack of experimental research with substantial cohorts of participants and recognizing the profound implications for older people affected by dementia and their caregivers, further exploration in this field is clearly appropriate and it still a scientific challenge.

Therefore, based on our results, the way forward involves collaborative efforts between researchers, caregivers, and technology developers. Interdisciplinary dialogues, informed by both the successes and shortcomings highlighted in this analysis, could be critical in defining the next generation of technologies to monitor patients with dementia. By addressing the challenges identified and building on the strengths of existing systems, we can aspire to solutions that are not only technically efficient, but also ethically sound and life-changing for people affected by dementia.

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