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ICT-based solutions for Alzheimer's Disease Care: A systematic review

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ABSTRACT In recent years, there has been a growing recognition of the significant challenges posed by Alzheimer's Disease (AD) and the need for innovative solutions to improve the quality of life for affected individuals. As AD prevalence continues to rise, technological advancements offer promising opportunities to address the multifaceted needs of patients and caregivers. This survey paper thoroughly investigates technological innovations in AD care, offering valuable insights into cutting-edge approaches that have the potential to positively impact the lives of affected individuals. By providing a holistic view of available assistive solutions, we review 2459 papers and select 46 relevant studies published between 2015 and 2023, specifically focusing on healthcare technologies and solutions, and utilized sensing methods. The former will include Telemedicine, E-Health, Smart Environment, Internet of Things (IoT), Ambient Assisted Living (AAL), Internet of Medical Things (IoMT), and Personalized Assistive Solutions (PAS), while the latter encompasses Wearable/Environmental, Radio/Audio, Video/Image, and Digital Platforms. Our comparative assessment of recent survey papers reveals the unique contribution of this study, as it comprehensively examines the intersection of multiple parameters. By summarizing insights from these studies, we identify gaps and recommend future directions for advancements in AD care.

INDEX TERMS Ambient Assisted Living (AAL), Alzheimer's disease (AD), Internet of Medical Things (IoMT), Internet of Things (IoT), Systematic Literature review, Personalized Assistive Solutions.

I. INTRODUCTION

Alzheimer's Disease (AD) is a debilitating neurodegenerative disease that affects millions of people worldwide [1]. As the world's population ages, the prevalence of AD is expected to increase, placing a significant burden on healthcare systems, caregivers, and society as a whole. One of the biggest challenges for caregivers of AD patients is to provide ongoing assistance and support to their loved ones while maintaining their personal well-being [2].

As AD progresses, those affected by the disease become unable to manage daily activities independently, requiring increased care and support in the advanced stages of the disease [3]. This care is both time-consuming and expensive [4], with AD costs expected to increase from $177.2 billion to more than $250 billion in Europe between 2008 and 2030 [4] [5]. Family members currently provide an estimated 18.6 billion hours of care to AD relatives [6], resulting in a significant care burden. Caregivers can also experience physical and psychological issues, such as depression, anxiety, and burnout, which can adversely affect their health and well-being. Therefore, it is crucial that caregivers of patients with AD receive ongoing support, beginning at the time of diagnosis and continuing until the later stages of the disease [4] [7].

Fortunately, there has been a surge of innovative approaches leveraging a wide range of application field technologies combined with advanced sensing methods. These cutting-edge solutions offer a game-changing approach to supporting AD patients and their caregivers, as shown in Figure 1. Embracing technologies from various domains, these approaches include remote monitoring, smart environments, Personalized Assistive Solutions (PAS), and data collection through questionnaires and video/audio analysis. The integration of these novel approaches into AD patient care has garnered significant attention in recent years. By combining diverse application field technologies with advanced sensing

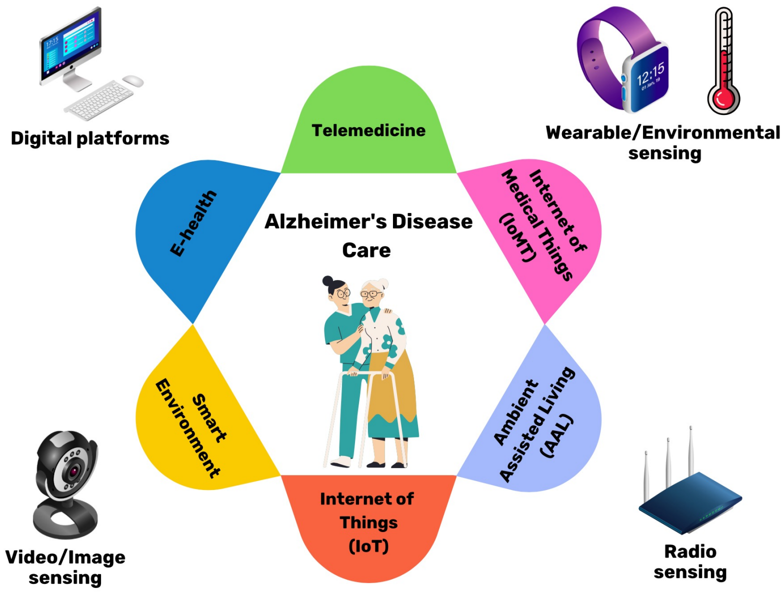

FIGURE 1. Overview on Key Assistive Solutions of Innovative Technologies for AD Care.

methods, these solutions have the potential to improve patient outcomes, enhance the quality of life for caregivers, and reduce healthcare costs.

Such digital health ecosystem for Alzheimer's care is composed of different but interconnected concepts. Telemedicine [8] helps doctors assess and treat patients remotely using technology. E-health [9] uses apps and websites to track patients' health and let them communicate with healthcare providers. Moving from virtual care to the real world, smart environment technologies [10] create homes that adapt to patients' needs. Meanwhile, the IoT [11] gathers real-time information from connected devices, keeping a constant watch. At the same time, AAL [12] systems use smart home tech and IoT devices to make homes safer and increase independence. Alongside, IoMT [13] brings together medical devices and sensors for continuous monitoring. To make care even more precise, PAS [14] uses various sensing technologies to match the special needs of Alzheimer's patients. All these advancements work together to bring innovation to Alzheimer's care in clear and unique ways.

All the aforementioned concepts exploit different sensing technologies to gather data from patients. These technologies include wearable and environmental sensors, radio/audio sensing, video sensing, and digital platform capabilities.

- Wearable and environmental sensors, including inertial and physiological [12] [11] sensors, provide valuable data on vital signs, movement patterns, and environmental conditions of AD patients, enabling continuous monitoring and early detection of potential risks or health deterioration.
- Radio/audio sensing technologies like Wi-Fi sensing, mm-Wave sensing, and Bluetooth Low Energy (BLE) sensing present non-intrusive and privacy-conscious approaches for monitoring various parameters. These technologies have been explored for capturing movement, behavior, and proximity to devices or locations in other contexts.
- Video sensing technologies [15] enable activity monitoring, facial recognition, and emotion detection, providing insights into well-being and cognitive state. These technologies support remote assessment and comprehensive care.
- Finally, digital platforms [16] [17] such as mobile apps, web portals, and questionnaires play a crucial role, offering convenient tracking and management tools, centralized information sharing, and remote cognitive assessments for AD caregivers and patients.

Researchers have exploited these technological concepts and sensing technologies to provide new solutions to enhance the quality of life both for the people suffering AD and their caregivers, as detailed through several survey papers available in the literature [18]–[29]. However, some concepts or technologies are not considered, thus not providing a comprehensive overview of all the existing solutions and techniques. To overcome this shortcoming, this survey explores all the aforementioned healthcare technology solutions and sensing technologies and conducts a meticulous examination of the entire spectrum of essential aspects and technologies linked to Alzheimer's care.

The rest of the paper is organized as shown in Figure 2, which involves outlining the selection criteria in Section II and describing the unique contributions in Section III. The comprehensive coverage of technologies is discussed in Section IV, followed by the discussion of results in Section V, and concluding insights in Section VI.

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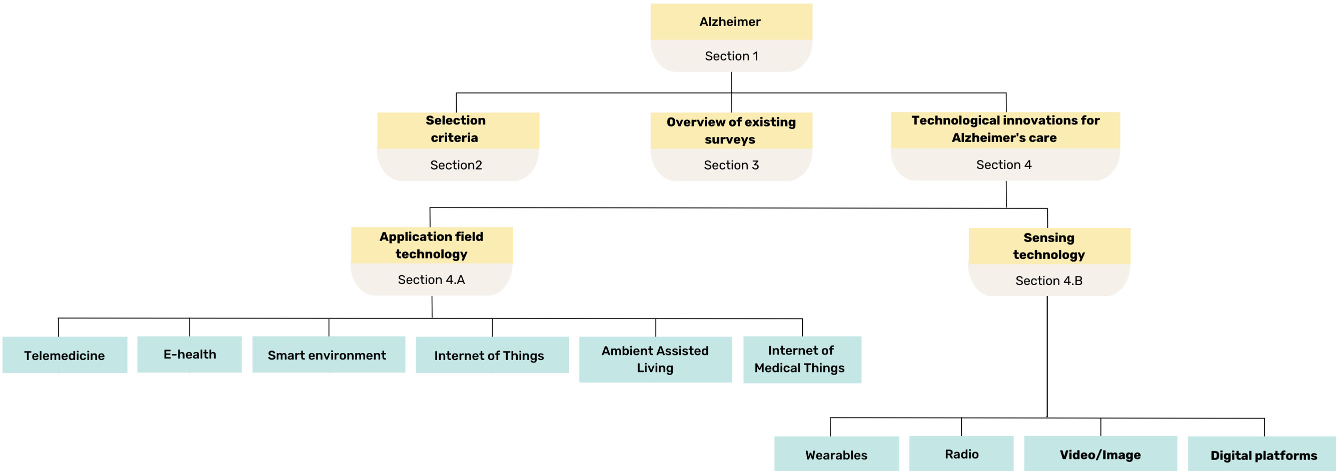

FIGURE 2. Overview of the proposed survey structure on exploring technological innovations in Alzheimer's care.

II. SELECTION CRITERIA

To ensure that the review was conducted thoroughly and transparently, the researchers followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. These guidelines provide a framework for reporting and conducting systematic reviews.

A. ELIGIBILITY CRITERIA

Inclusion and exclusion criteria for the selection of articles were as follows: (a) articles were excluded if the word "Alzheimer's" did not appear in the title, keywords, or abstract; (b) the studies had to be published in English; (c) articles published before 2015 were excluded; (d) only articles for which the full text was available were considered, and conference proceedings were excluded if only available in abstract form; (e) reviews, editorials, commentaries, and summaries have been excluded; (f) studies conducted on animal models, healthy subjects or specific areas have not been taken into account.

B. SEARCH STRATEGY

To perform an in-depth search for relevant articles, we used various databases such as IEEE Explore, the ACM Digital Libary, Scopus, PubMed, and Web of Science. In Table 1, we provide the specific search query used, aiming to cover a wide range of sources and ensure a comprehensive search. In addition, we reviewed related studies authored by the same researchers to identify the most appropriate ones that fit our purposes.

The search process produced a comprehensive set of references for our systematic review as demonstrated in Table 2. These results were obtained by employing the predefined search strategy tailored for this systematic review.

title (alzheimer) **or** keywords (alzheimer) **or** abstract (alzheimer)	**and**
ambient-assisted **or** assisted living tools **or** AAL **or** AAL tools **or** assisted living technology **or** smart living **or** IoT **or** internet of things **or** IoMT **or** internet of medical things **or** e-health **or** tele-medicine **or** tele medicine **or** telemedicine **or** digital health **or** digital medicine **or** telehealth **or** digital therapeutics **or** tele-assistance **or** tele-monitoring **or** virtual coaching **or** virtual assistance	**and**
wearable **or** sensors **or** sensor **or** body-worn **or** inertial **or** accelerometer **or** gyroscope **or** IMU **or** GPS **or** pulse **or** humidity **or** occupancy **or** magnetometer **or** temperature **or** heartbeat **or** smartphone **or** smartwatch **or** smart glasses **or** physiological sensors **or** environmental sensors **or** video **or** radio **or** wifi sensing **or** radar	

TABLE 1. Executed search query on IEEE Explore, the ACM Digital Libary, Scopus, PubMed, and Web of Science on 01/03/2023.

Publisher	Total
IEEE (link)	1162
ACM (link)	25
Scopus link)	1100
PubMed (link)	28
Web of Science (link)	144
Total	2459

TABLE 2. Search outcome samples per Publisher from 01/01/2015 to 01/03/2023.

C. RESULTS

The search results were entered into the Rayyan software, which is a web-based tool that helps reviewers work together to select studies. If there were any disagreements, we were resolved through discussion and reaching a consensus or by consulting with other authors. We started our literature search by identifying 2459 records from the mentioned sources and applying the defined searching strategy. After removing duplicates, we screened 2180 papers based on their title and abstracts and selected 82 papers for full-text screening. We did not find any additional papers from the gray literature. During the evaluation process, we thoroughly assessed all 82 references and excluded papers that did not study any form of AD or made use of other types of technological solutions. Additionally, if multiple papers with similar content were presented by the same author at conferences, we selected

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the most recent paper. Finally, we included 46 papers in this review, as shown in Figure 3, that met our inclusion criteria.

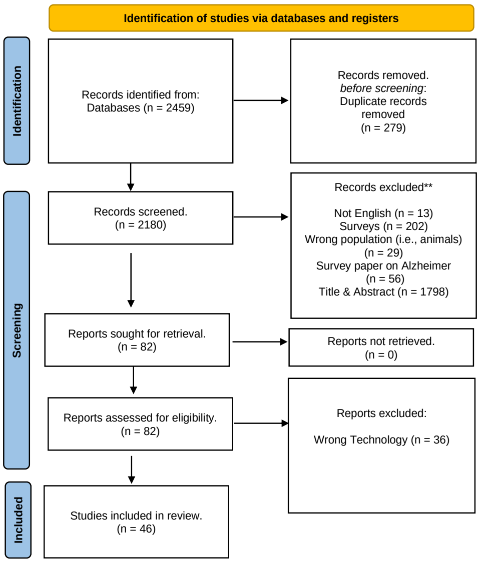

FIGURE 3. PRISMA diagram of the performed search.

III. OVERVIEW OF EXISTING SURVEYS

In this section, we present a comprehensive comparison of different survey studies that explore technological solutions for AD care. To ensure the relevance and consistency of our analysis, we selected the 12 most pertinent survey papers solely focused on AD patients. Out of a vast pool of 2459 articles, these 12 surveys emerged as the most relevant and aligned with the objectives of our study. The comparison presented in Table 3 encompasses a wide array of specific parameters related to application and sensing field technologies. Each cell contains either a "✓" symbol indicating coverage of the specific aspect, or an "✗" symbol denoting the absence of discussion on that aspect within the corresponding survey. This comprehensive comparative analysis aims to discern the extent to which each survey addresses the various parameters, thereby offering invaluable insights into the current landscape of technological innovations within the realm of AD care.

As illustrated by Table 3, four prominent focal points of research and discourse in the surveyed papers are E-health, inertial sensing technology, mobile and web apps, and video-sensing technology. This prominence underscores their significance and relevance in the sphere of technology applications and sensing methods for AD care, providing a deep understanding of prevalent trends and the ongoing research emphasis within the field.

The last row of Table 3 summarizes the topics covered in this survey paper, which fills gaps in existing surveys, offering a comprehensive overview of the state-of-the-art in the digital health ecosystem for Alzheimer's care.

IV. TECHNOLOGICAL INNOVATIONS FOR ALZHEIMER'S CARE

In this section, we will thoroughly discuss 46 papers, examining their contents in detail. Our main focus will be on exploring the application fields of these papers in subsection IV-A. Afterward, in subsection IV-B, we will take a closer look at the sensing technologies covered in these works.

A. APPLICATION FIELD TECHNOLOGY

This subsection focuses on exploring various technology solutions implemented in specific areas within this field. These advanced technologies have had a profound impact on enhancing the quality of care for individuals with AD, while also serving as invaluable support systems for their dedicated caregivers.

Figure 4 illustrates the chronological emergence of transformative technologies in the healthcare domain. Each milestone represents a distinct phase in the evolution of healthcare technologies, showcasing continuous progress and innovation in the field.

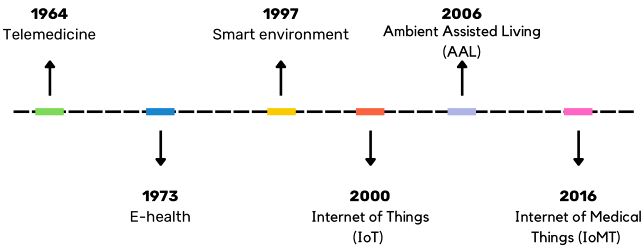

FIGURE 4. Evolution of Technological Innovations in Healthcare: A Chronological Overview.

1) Telemedicine

Telemedicine refers to the use of telecommunications technology to provide remote healthcare services and support for people with AD. Telemedicine has become increasingly relevant in AD care due to its ability to overcome geographic barriers and improve access to specialist care. Of the 46 articles included in this survey, there are notable contributions from the following sources: [8], [30], and [31] that focus specifically on the use and advances in telemedicine technology in the management of AD. Table 4 summarizes key aspects of these articles.

Lindauer et al., in [8], Tele-STELLA's (Telehealth-based support for families living with later-stage Alzheimer's disease) feasibility and acceptability were explored across multiple sites. The intervention utilized telehealth services (phone, video-conferencing, mail, email, and/or text) for 124 patients with AD. The study evaluated intervention fidelity, efficacy in reducing dementia symptoms, and caregiver reactivity. Limitations included unclear technological and scheduling challenges, limited discussion on transportation safety and privacy, unknown efficacy of the Constellation component, insufficient evidence on technology access strategies, potential generalizability limitations, and lacking

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Ref. Year	**Application Field Technology**							**Sensing Technology** Wearables/Environmental			Radio sensing			Digital Platforms		Camera-Based
	AAL	Telemedicine	E-health	IoMT	Smart Env.	IoT	Pers. Assist. Sol.	Inertial	Physiological	Environmental	Wi-Fi	BLE	mm-Wave	Mobile App/Web	Questionair	Video/Image
[20] 2022	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
[21] 2022	✓	✓	✗	✗	✓	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✓
[18] 2021	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
[22] 2021	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓
[23] 2021	✗	✓	✓	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓
[24] 2020	✗	✗	✗	✗	✓	✗	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓
[28] 2020	✗	✗	✗	✗	✓	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	✓
[25] 2020	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓
[26] 2020	✗	✗	✓	✗	✗	✗	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓
[19] 2018	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓
[27] 2018	✓	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓
[29] 2017	✓	✗	✓	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗	✓	✗	✓
This Survey	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

TABLE 3. Comparison with previous surveys.

Ref. (Year)	**Objective**	**Methodology/Technology**	**Sensors/Controller**	**Limitations**
[8] (2021)	Establish the feasibility and acceptability of Tele-STELLA, evaluate fidelity to the protocol, and test efficacy in reducing behavioral and psychological symptoms of dementia and caregiver reactivity	Tele-health via phone, videoconferencing, mail, email, and/or text	NA	Lack of specificity regarding technological and scheduling challenges
[30] (2020)	Design and evaluate a live remote assistance system for Alzheimer's patients living alone at home using shared visual representation.	Augmented Reality (AR HMD)	NA	Limited evaluation and scope.
[31] (2015)	Offer real-time information to remote caregivers about the patient's status, focusing on capturing eating history and location history.	BeagleBone Black by BeagleBoard	Reed switch, force sensor, photoelectric sensor, PCB, XBee Series 1 RF module/ATmega328P.	No information provided on cost-effectiveness

TABLE 4. Overview on Telemedicine-based survived papers: Objectives, Technology, Sensors, Limitations.

technological information. Despite these limitations, Tele-STELLA aimed to support families with late-stage dementia through telehealth, providing education and support globally. No specific application or algorithm was used, and no accuracy measures were reported.

Spalla et al., in [30], design and evaluate a live remote assistance system for Alzheimer's patients living alone at home. The system utilizes augmented reality (AR) head-mounted displays (HMDs) to create a shared visual representation, facilitating communication between caregivers and patients. Although the specific sensors/controllers used are not mentioned in the table, the study focuses on the use of Wi-Fi technology for remote assistance. However, the study notes limitations in terms of evaluation and scope. The findings indicate that the system assists patients with Alzheimer's in their daily living activities, enabling them to live more independently.

In [31], O'Brien, et al., offer real-time information to remote caregivers about the patient's status, with a specific focus on capturing eating history and location history. The methodology involved the BeagleBone Black by BeagleBoard, and the sensors/controllers used included a reed switch, force sensor, photoelectric sensor, PCB, and XBee Series 1 RF module/ATmega328P. The study did not provide information on cost-effectiveness. The findings demonstrated that the system enabled primary caregivers to remotely view the patient's status while away from home.

2) E-Health

E-health describes the use of digital technologies, including online platforms, mobile apps, and electronic health records, to give persons with AD access to health services and support. The following sources have made noteworthy contributions to the 46 articles that make up this survey: [9], [32], [33], and [17]. These sources explicitly address the application and developments of e-health technology in the context of AD care. Key points from these articles are compiled in Table 5.

In [9], Qamar, et al., Developed an Android-based assistive healthcare application to support caregivers of Alzheimer's patients. The application aimed to manage daily tasks, medications, and improve patient memory through brain games, utilizing mobile technology without the need for sensors. However, the paper lacked empirical evidence of the app's effectiveness in improving patient outcomes or reducing caregiver burden. Despite this limitation, the application provided a way for stand-in caregivers to manage patients' lives and enable easy communication of patient needs, with the potential to enhance the quality of life for both caregivers and patients.

In [32], Hendawi et al., proposed a knowledge-powered personalized virtual coach aimed at providing diet and nutrition assistance to Alzheimer's patients and their caregivers. The system was built on a cloud-based client-server architecture, and instead of using an algorithm, it utilized a

Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[9] (2022)	Create an Android-based assistive healthcare application for caregivers of Alzheimer's patients to manage daily tasks, medications, and improve patient memory with brain games	Mobile Technology	NA	Lack of empirical evidence on the app's effectiveness in improving patient outcomes or reducing caregiver burden
[32] (2021)	Propose a knowledge-powered personalized virtual coach for diet and nutrition assistance to Alzheimer's patients or caregivers.	Cloud-based architecture	NA	Limited generalizability beyond Alzheimer's population.
[33] (2017)	Enroll technology-enabled caregivers to assess caregiver burden, depression, anxiety, and sleep disturbance.	Technology-enabled caregivers	NA	Reliance on limited assessment tools
[17] (2017)	Provide additional helpful information about scheduled events in a user-friendly and enjoyable manner.	Semantic web application (CAPTAIN MEMO) based on the OntoMemo dynamic ontology.	NA	Limited consideration of ethical issues

TABLE 5. Overview on E-Health-based survived papers: Objectives, Technology, Sensors, Limitations.

SWRL rule set. However, the study acknowledged limitations in terms of generalizability to populations beyond those with Alzheimer's disease, as the personalized virtual diet coach may not be as effective or suitable for other groups. Nonetheless, the system demonstrated the capability to offer useful recommendations specifically tailored to Alzheimer's patients, with potential benefits for their brain health and overall well-being.

In [33], Coffman et al., aimed to enroll a cohort of technology-enabled caregivers to gather basic demographic characteristics and assess the level of caregiver burden, depression, anxiety, and sleep disturbance as part of a larger project delivering caregiver support. The study focused on utilizing a cohort of caregivers who had access to technology. However, the study acknowledged limitations in terms of assessment tools, as it relied on a limited number of measures such as the Zarit Burden Interview, M-3, and PROMIS Sleep Disturbance form. These tools may not capture the full range of mental health outcomes associated with caregiving. Nevertheless, the study highlighted the potential benefits of delivering tailored caregiver support through mobile technology, which is a strategy recognized and strongly supported by caregiver advocates.

In [17], Ghorbel et al., aimed to provide additional helpful information about scheduled events in a user-friendly and enjoyable manner. They utilized a semantic web application called CAPTAIN MEMO based on the OntoMemo dynamic ontology. The study focused on supporting natural language inputs and multilingualism. The findings showed that the approach helped Alzheimer's patients organize their daily lives and provided useful information about scheduled events.

3) Smart Environment

Smart environments leverage a network of interconnected devices and sensors to create an intelligent, responsive setting for patients with AD. These environments are designed to accommodate the changing needs and preferences of people with AD. Among the 46 articles that follow the references [10], [34], [35], [36], [37], [38], [39], [40] and [41], focus on smart environment technology. The main points of these publications are outlined in Table 6.

Liappas et al., in [10], present the design and evaluation of a live remote assistance system for Alzheimer's patients living alone at home. The system utilizes AR head-mounted display (HMD) technology to create a shared visual representation that facilitates communication between caregivers and patients. Although the paper acknowledges limited evaluation and scope, the system proves beneficial in assisting patients with Alzheimer's in their daily living activities, promoting their independence.

In [34], Oskouei et al. designed an IoT-based solution to track activities and monitor the health of Alzheimer's patients. The methodology involves IoT and cloud computing, although the specific sensors and controllers used are not mentioned. Neural networks and Bayesian algorithms are employed, enabling the provision of daily life facilities and medical support for patients.

In [35], Francillette et al., presented two approaches for simulating the behavior of individuals with Mild Cognitive Impairment (MCI) and AD using behavior trees and error injection. They utilized artificial intelligence (AI) techniques and motion, light, and RFID sensors/controllers. The study acknowledged limitations in generalizability, sample size, capturing real-world complexities, data collection, measurement accuracy, and ethical considerations. The findings showed that the proposed approaches facilitated the generation of desired errors and enabled the simulation of human activities in intelligent environments.

In [36], Ahmed et al. developed a medical system using IoT to enhance the quality of life for individuals with AD and reduce caregiver burden. The IoT-based system incorporated various sensors/controllers, such as a motion processing unit sensor, GPS module, heart rate sensor, microcontrollers, LCD display, accelerometer/gyroscope, buzzer,

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Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[10] (2022)	Create a computational framework for smart homes that enhances awareness for individuals with AD. Utilize context-aware tools, predict behavior and uncertain events, simulate errors and behaviors, enable interventions, provide realistic activity simulations, and validate with real users	Cognitive Modelling	NA	No distribution of errors among stages or criteria provided
[34] (2020)	Design a novel IoT-based solution for tracking activities and monitoring health of Alzheimer's patients.	IoT, Cloud Computing	NA	Reliability limitations of IoT devices used.
[35] (2020)	Present two approaches for simulating the behavior of individuals with Mild Cognitive Impairment (MCI) and AD using behavior trees and error injection.	AI (behavior trees)	Motion, light/RFID	Limited generalizability, sample size, and real-world complexities. Data collection, measurement accuracy, and ethical considerations.
[36] (2020)	Develop and implement a medical system using IoT to improve the quality of life for individuals with AD and reduce caregiver burden.	IoT	Motion processing unit sensor, GPS module, heart rate sensor, microcontrollers, LCD display, accelerometer/gyroscope, Buzzer, Arduino Nano, Node MCU ESP8266	Ethical concerns about privacy, autonomy, and informed consent.
[37] (2019)	Propose a framework for monitoring patients with Alzheimer's and other dementias in their homes using sensors to gather contextual information.	Conceptual framework	NA	Limited scope, not applicable to other cognitive impairments or disabilities.
[38] (2019)	Develop an assistive system that recognizes the intent of Alzheimer's patients in completing daily tasks and guides them towards successful completion.	AAL technology	RFID sensors, Bluetooth module/Arduino	Limited coverage of day-to-day activities, excludes social interaction and cognitive stimulation.
[39] (2018)	Propose a cost-effective AI-enabled system to enhance the quality of life for Alzheimer's patients.	AI, IoT, Cloud Computing	Light, Bulb, Smartphone	No empirical data on system effectiveness or user-friendliness
[40] (2015)	Develop a Tele-health system based on IoT technology for monitoring elderly individuals with AD remotely.	IoT and RFID	ECG wireless sensor, UHF passive wearable RFID wristband/RFID.	Study conducted on a limited number of participants
[41] (2015)	Support Alzheimer's patients in living independently within their living rooms, providing necessary emergency assistance and support.	Activity tracking and monitoring	Kinect device, NFC readers/Smart Phone	No consideration of implementation and maintenance costs

TABLE 6. Overview on Smart Environment-based survived papers: Objectives, Technology, Sensors, Limitations.

Arduino Nano, and Node MCU ESP8266. The study acknowledged ethical concerns regarding privacy, autonomy, and informed consent. The findings demonstrated that the system provided 24/7 monitoring, location tracking, medication reminders, and an emergency call button, thereby improving the quality of life for patients and easing the caregiver burden.

In [37], Araujo et al., introduce two approaches for simulating the behavior of individuals with Mild Cognitive Impairment (MCI) and AD using behavior trees and error injection. Artificial intelligence techniques are utilized, and motion and light/RFID sensors are employed. The study discusses challenges related to limited generalizability, sample size, capturing real-world complexities, data collection, measurement accuracy, and ethical considerations. An error injection algorithm with a specified range is proposed, facilitating the generation of desired errors and the simulation of human activities in intelligent environments.

In [38], Rashmi et al., focus on developing and implementing a medical system using IoT to enhance the quality of life for individuals with AD and reduce caregiver burden. The system integrates various components such as a motion processing unit sensor, GPS module, heart rate sensor, microcontrollers, LCD display, accelerometer/gyroscope, buzzer, Arduino Nano, and Node MCU ESP8266. Ethical concerns related to privacy, autonomy, and informed consent are discussed. The system provides 24/7 monitoring, location tracking, medication reminders, and an emergency call button, ultimately improving the quality of life for patients and alleviating caregiver burden.

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In [39], Zhang, et al., proposed a cost-effective AI-enabled system to enhance the quality of life for Alzheimer's patients. The system utilized AI, the IoT, and Cloud Computing technologies. The sensors/controllers employed were lights, bulbs, and smartphones. The study did not provide empirical data on system effectiveness or user-friendliness. However, the findings indicated that the system improved the daily functioning and well-being of Alzheimer's patients, offering a cost-effective solution to Alzheimer's care challenges.

In [40], Raad et al., concepts focus was enhancing patient and family support through a real-time AAL system using the IoT and AR. The system employs relay actuators, sensors, and smartphones/glasses to improve the ability of Alzheimer's patients to carry out daily tasks independently. Audio messages are utilized to aid memory difficulties. Key technologies within the IoMT include:

In [41], Lam et al., support Alzheimer's patients in living independently within their living rooms, providing necessary emergency assistance and support. The methodology involved activity tracking and monitoring, and the sensors/controllers used were the Kinect device and NFC readers/smartphone. Similar to [31], no consideration was given to implementation and maintenance costs. The findings highlighted the potential of the system to enable AD patients to handle daily activities, regain confidence, and alleviate burdens on families and caregivers.

4) Internet of Things

The Internet of Things encompasses a network of interconnected physical devices and objects capable of collecting and exchanging data through internet connectivity, all without the need for direct human interaction. In the realm of AD care, IoT has emerged as a potent technology, facilitating the seamless integration of diverse devices and sensors to gather and share data, leading to enhanced monitoring and support for individuals with AD. Several notable studies have explored the use and progress of IoT in the context of AD, [11], [15], [42], citear-8, [44], [45], [46] and [47]. Table 7 summarizes key aspects of these articles.

Chokri et al., in [11], developed a secure IoT assistant-based system prototype for AD. It aimed to provide psychological support services and ensure secure information sharing among family members. The system utilized IoT technology, a CNN, steganography, and the S/MIME protocol. Challenges included privacy concerns, IoT device limitations, and ethical considerations. The system featured facial recognition, easy-to-wear collar, voice conversations, person tracking with safety alerts, and secure information handling. Steganography was employed to hide identities and provide relationship information for non-registered individuals.

Patil et al., in [15], introduce a wearable camera-aided device and a Bluetooth ear-complementary device prototype integrated with AI technology. The objective is to improve awareness for Alzheimer's patients and reduce caregivers' burden. The methodology incorporates AI, IoT, and the HAAR cascades algorithm. The sensors/controllers used include an ESP32 camera and a smartphone. However, the study mentions technical issues with the smart specs technology, which may impact intervention effectiveness and data reliability. The Haar cascades algorithm is utilized for detecting faces and face recognition. The findings indicate that the prototype effectively enhances awareness and reduces caregiver burden for Alzheimer's patients, as evaluated through user satisfaction surveys.

In [42], Lee et al., developed a nursing system with IoT devices for communication, location tracking, fall detection, and early warning services for aging and dementia patients. The methodology involved IoT technology, recurrent neural networks (RNN), and long short-term memory (LSTM). The sensors/controllers used included IMU (inertial measurement unit), accelerometer, gyroscope, GPS positioning chip, and MCU (microcontroller unit). The study noted potential limitations in addressing ethical considerations related to data privacy, security, and informed consent. The findings indicated that the nursing system provided safety care services for nursing homes and elderly residences, as well as improved remote healthcare management for chronic patients.

In [43], Leri et al., presented the development of an IoT-enabled global tracking system and mobile application for individuals with AD. The system utilized IoT, wireless networks, and GPS technology. A wearable tracking device incorporating a Neo-6m GPS module and SIM800L Mini GSM/GPRS module was created and integrated with an internet-connected system for real-time access. The solution aimed to address wandering and getting lost cases in Alzheimer's patients by providing accurate location data. However, the paper may have overlooked the temporal aspects of the system, such as its long-term sustainability, scalability, and adaptability to future technological advancements. No specific algorithm was mentioned. The paper highlighted the development of a wearable tracking device, the comprehensive solution it offered, and the potential benefits of extensive monitoring for Alzheimer's patients in terms of safety, security, and caregiver support.

In [44], Machado et al., propose the DCARE model, utilizing ambient intelligence and IoT technologies with wearable sensors, specifically a smartwatch. The study evaluates the prototype using synthetic data and employs PLSRegression machine learning algorithms for risk prediction. The findings indicate that DCARE enables real-time monitoring of vital signs and location data, supporting personalized care for Alzheimer's patients.

In [45], Sharma et al., proposed an architecture for an Internet of Health (IoH) ecosystem, including Alzheimer's prediction using movement data and tracking abnormal behaviors. The methodology involved IoT, deep learning, fog computing, and cloud technologies. The sensors/controllers used in the study included gait sensors and Bluetooth board sensors. The study acknowledged limitations in evaluation, limited access, and ethical considerations. The findings highlighted the improvement in the quality of life for patients after the detection of Alzheimer's disease.

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Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[11] (2022)	Develop a secure IoT assistant-based system for Alzheimer's Disease providing psychological support and secure info sharing.	IoT, CNN, steganography, S/MIME protocol	Microphone, buzzer, earpiece, NEO 6MV2 GPS module, Raspberry Pi 3	Privacy/security concerns, accuracy and reliability limitations, ethical considerations
[15] (2022)	Develop a wearable camera-aided device and Bluetooth ear-complementary device prototype integrated with AI technology. Improve awareness for Alzheimer's patients and reduce caregivers' burden	AI, IoT, HAAR cascades algorithm	ESP32 camera, Smart Phone	Technical issues with the smart specs technology used. Impact on intervention effectiveness and data reliability
[42] (2021)	Develop a nursing system with IoT devices that includes communication, location tracking, fall detection, and early warning services for aging and dementia patients	IoT, RNN, LSTMs	IMU, accelerometer, gyroscope, GPS positioning chip, MCU	Ethical considerations related to data privacy, security, and informed consent may not be adequately addressed
[43] (2021)	Build an IoT-enabled global tracking system and mobile app for people with Alzheimer's Disease. Create a wearable tracking device using GPS technology and integrate it with an internet-connected system for real-time access	IoT, Wireless Network, GPS technology	Neo-6m GPS module, SIM800L Mini GSM/GPRS module, Arduino	May not address the long-term sustainability, scalability, or adaptability of the system
[44] (2021)	Propose the DCARE model for monitoring Alzheimer's patients, develop a prototype, and evaluate it using the DCARE Dataset Simulator Tool.	Ambient Intelligence, IoT	Wearable sensors, Smart Watch	Limited caregivers and patients used the prototype. Insufficient time to collect insights on engagement and effectiveness. synthetic data instead of real sensor data.
[45] (2020)	Propose an architecture for an Internet of Health ecosystem, including Alzheimer's prediction using movement data and tracking abnormal behaviors.	IoT, deep learning, fog computing, cloud	Gait sensors, Bluetooth board sensors	Limited evaluation, limited access, ethical considerations.
[46] (2018)	Develop an RFID-based localization system for patients with memory loss.	IoT, RFID	Mat Pressure Sensor, RFID Reader, RFID Tags	Privacy concerns, limited scope
[47] (2018)	Use IoT and a mobile application to support Alzheimer's caregiving and prevent caregiver burnout.	IoT	Smartwatch	Limited consideration of ethical issues

TABLE 7. Overview on IoT-based survived papers: Objectives, Technology, Sensors, Limitations.

In [46], Raad et al., proposed an RFID-based localization system to enhance the health and safety of patients with short-term memory loss. The system utilized IoT and Radio Frequency Identification (RFID) technology, along with components such as a Mat Pressure Sensor, Reader and Antennas, and RFID Tags integrated with Arduino. The algorithm presented in the project simplified the detection of motion between rooms for elderly individuals, allowing monitoring of daily activities and triggering alerts in case of emergencies without extensive sensor usage. The paper acknowledged potential privacy concerns and limitations in scope. The project's goal was to improve access to care, enhance care quality, and reduce the cost of care for Alzheimer's patients. The indoor localization system aimed to ensure patient safety and provide convenience for caregivers.

In [47], Aljehani et al., initiated a project to support Alzheimer's caregiving and prevent caregiver burnout using the IoT concept and a mobile application. The project involved an Apple Smartwatch as a wearable IoT device for Alzheimer's patients and an iOS application on the caregiver's iPhone to access and store patient data. The application allowed caregivers to track and locate their loved ones, monitor patient heart rates, create task reminders, and provide AD information. However, the study lacked consideration of important ethical issues such as patient privacy, data security, and informed consent. It aimed to enable patients to live a more independent life and assist caregivers in providing optimal care to Alzheimer's patients.

5) Ambient Assisted Living

Ambient Assisted Living refers to the integration of technology into the living environment to facilitate independent living and improve the well-being of patients with AD. The following sources have contributed significantly to the 46 articles in this survey: [12], [48], [49], [50], [51], and [52], [53], and [54]. These sources specifically address the application and developments of AAL technology against the backdrop of AD concerns. Key points from these articles are compiled in Table 8.

In [12], Patil et al., propose an innovative system for

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Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[12] (2022)	Address senior health deterioration, propose an Alzheimer's IoT solution, and evaluate accuracy using sensors in patients' homes. Enhance security with AES and assist patients and families	ML, IoT, CNN	Motion sensor, pressure, moisture sensors, Arduino, Raspberry Pi, RFID, Zigbee	Limitations in accuracy, reliability, or security of the IoT technology used. Limited generalizability
[48] (2019)	Develop a system for reminding patients of daily tasks and medication, monitoring falls, and sending location coordinates.	Assistive Technology	GPS module, GSM module, LCD, buzzer, accelerometer module, ADC converter/Arduino Mega	Sample size, privacy, and security concerns.
[49] (2019)	Create a tool to evaluate the well-being of patients and support healthcare decision-making.	iBeacon technology, ICT, Localization Algorithm	Raspberry pi3 (Antenna)	Potential bias, limited generalizability, subjective assessments, ethical considerations.
[50] (2019)	Enhance patient and family support through a real-time Ambient Assisted Living (AAL) system using Internet of Things (IoT) and Augmented Reality (AR) concepts.	IoT and Augmented Reality (AR)	Relay actuators, sensors, smartphones/glasses	Small sample size, limited generalizability.
[51] (2019)	Detect location of misplaced objects, display names of friends/relatives on AR display, monitor navigation, and send location to caregiver.	Augmented Reality (AR)	Switch, camera, accelerometer/gyroscope, display, microcontroller, Bluetooth module/glasses	Cost and accessibility concerns
[52] (2018)	Develop a mobile application using AR to assist individuals with early-stage Alzheimer's disease.	Mobile Technology, Augmented Reality	NA	Limited generalizability due to small sample size
[53] (2018)	Develop a system to address wandering episodes and falling risks for dementia patients using deep learning and a smartwatch.	Deep Learning	Smartwatch	Limited coverage due to reliance on smartwatch
[54] (2017)	Enable Alzheimer's patients to live independently within their living rooms while providing necessary emergency assistance and support.	Machine learning technologies	Kinect device, NFC readers/Smartphone	Lack of consideration for implementation and maintenance costs

TABLE 8. Overview on AAL-based survived papers: Objectives, Technology, Sensors, Limitations.

monitoring Alzheimer's patients, incorporating features such as location tracking, heart rate monitoring, and assistance in the self-administration of drugs. The technology utilized includes GPS and GSM modules, heart rate module, accelerometer module, and an Arduino Mega with an LCD display. The study emphasizes validation and cost considerations and highlights the benefits of assisting patients in self-administering drugs, enhancing their independence, and providing security for caregivers.

In [48], Fuior et al., proposed a system focused on leveraging assistive technology to enhance patient safety and well-being in AD. The system aimed to perform various tasks, including reminding patients of daily tasks and medication schedules, monitoring for falls and triggering alarms in emergencies, and automatically sharing location coordinates with family members. The technology utilized included a GPS module, GSM module, LCD, buzzer, accelerometer module, ADC converter, and power supply integrated with an Arduino Mega. The paper acknowledged limitations such as the sample size and privacy and security concerns associated with monitoring devices in AD. No specific algorithm was mentioned. The system aimed to assist patients in their daily lives, promoting self-care, maintaining independence, and ensuring safety and active engagement.

In [49], Masciadri et al., present an application acting as a personal assistant for Alzheimer's patients, offering functionalities such as face recognition, detection of wandering and fainting, assistance in finding the way home, reminders for daily chores and past life, and organizing and planning tasks. Machine learning algorithms are employed with accelerometer and gyroscope sensors integrated into a smartwatch. The paper focuses on personalized assistance, practical implementation, and a wander detection algorithm for tracking and caregiver notification. The system is specifically designed for patients in the early stages of the disease, aiding in recognizing people and overcoming difficulties.

In [50], Ghorbanir et al., focus on the design and implementation of a wearable device for accurately determining the 2D location of Alzheimer's patients using a backpropagation-based artificial neural network (BP-ANN). The study employs deep learning techniques, specifically the BP-ANN algorithm, and utilizes ZigBee-based XBee

S2C anchor nodes and a mobile node/ZigBee-based XBEE S2C anchor nodes for data collection. The paper highlights challenges such as a time-consuming strategy, limited optimization techniques, and movement during experimentation. However, the proposed BP-ANN algorithm shows promise in achieving satisfactory localization error for effectively tracking Alzheimer's patients in indoor environments.

In [51], Gacem et al., detect the location of misplaced objects, display names of friends/relatives on an AR display, monitor navigation, and send the location to caregivers. The methodology involved augmented reality technology and various sensors/controllers, including a sensitive switch, camera, accelerometer/gyroscope sensor, display, microcontroller, and Bluetooth module/glasses. The study mentioned concerns related to cost and accessibility. The findings highlighted the potential benefits of the smart assistive glasses prototype in aiding early-stage Alzheimer's patients by increasing independence and reducing caregiving costs.

In [52], Kanno et al., developed a mobile application using augmented reality techniques to assist individuals diagnosed with early-stage AD in object and people identification and location tracking. The application leveraged mobile technology and an augmented reality interface as part of assistive technology. However, the experiment involved a small sample size consisting of only two older individuals, one former caregiver, and one family member. This limited sample size may not be representative of the broader population of individuals with AD or their caregivers, and the findings may not be easily generalized to a larger population. The application did not involve the use of any specific algorithm. The system aimed to improve daily living activities for Alzheimer's patients and enhance the quality of life for both individuals with Alzheimer's and their caregivers.

In [53], Rodrigues et al., provide support for dementia patients, specifically those with AD, by developing a system that addresses two major challenges: wandering episodes and the risk of falling. The system utilized deep learning techniques and relied on a smartwatch as the primary device. However, there is a limitation in terms of coverage as the system's effectiveness depends on the patient consistently wearing the smartwatch and having a reliable network connection. This may result in limited coverage of the patient's activities and potentially missed alerts. The system employed artificial neural networks, which are inspired by biological neural networks, for information processing. The primary objectives were to improve safety and security for Alzheimer's patients and other older adults at risk of falls and wandering, while also enhancing the quality of life for patients and their families by reducing the need for constant supervision.

In [54], Lam et al., enable Alzheimer's patients to live independently within their living rooms while providing necessary emergency assistance and support. The methodology involved machine learning technologies, and the sensors/controllers utilized were the Kinect device and NFC readers/smartphone. The study identified a lack of consideration for implementation and maintenance costs as a limitation. The findings showed that the proposed system allowed AD patients to handle daily activities, regain confidence, and alleviate burdens on families and caregivers.

6) Internet of Medical Things

Internet of Medical Things refers to the network of medical devices, sensors, and applications that collect and exchange healthcare-related data. In the context of the management of AD, the IoMT enables real-time monitoring, data analysis, and remote interventions. There are notable contributions from the following sources among the 46 articles included in this survey: [13], [55], [56], [57], [58], [59], [60], and [61], which specifically focus on the use and advancement of IoMT technology in the context of AD care. The Table 9 summarises major points from these publications.

B. Elvas et al., in [13], conducted a design and evaluate a live remote assistance system for Alzheimer's patients living alone at home. The system utilizes (AR HMD) technology to facilitate communication between caregivers and patients, enhancing daily living activities and promoting independent living.

From Yadav et al., in [55], an architecture for an IoH ecosystem was proposed, incorporating IoT, deep learning, fog computing, and cloud technologies. The system aims to predict AD using movement data and track abnormal behaviors, ultimately improving the quality of life for detected AD patients.

Siri et al., in [56], reviewed an article focused on early clinical manifestations of AD and explored the use of sensors and mobile/wearable devices for digital phenotyping. Various technologies such as IMU, geopositioning, touch screen, microphone, camera, and more were discussed, highlighting the opportunity for early detection of neurodegenerative diseases using these technologies.

In [57], Al-Naami et al., developed system to remind Alzheimer's patients of daily tasks and medication, monitor falls, and provide location coordinates. The system incorporates Assistive Technology and utilizes components such as GPS and GSM modules, accelerometer modules, and Arduino Mega. Its purpose is to assist patients with AD in their daily lives and help maintain their independence.

In [58], Omar et al., Saw the development of a tool to assess Alzheimer's patients' quality of life and aid in medical decision-making. This tool aims to improve clinical knowledge, enhance safety, and reduce carer stress by utilising ICT, localization algorithms, and iBeacon technologies.

In [59], Cazangiu et al., suggested an IoT-based aid for people with AD and their carers. The system uses parts including an OLED display, a pulse sensor, a Esp8266 12e, and more to monitor and help with health. It benefits both patients and carers by providing round-the-clock support and monitoring.

In [60], Jiménez et al., suggested a theoretical framework for keeping an eye on people with dementia and Alzheimer's in their homes. By using sensors to collect contextual data, the framework allows for flexible and personalised moni-

Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[13] (2022)	Create a remote monitor system for AD using Health Remote Monitoring Systems (HRMS) to triage and follow-up with people living with dementia. Reduce burden on staff and unnecessary hospital visits.	ML, AI, IoT, Logistic Regression Algorithm	Heart rate, Arterial oxygen, Body temperature, GSR, Smart Watch	Technical limitations of the remote monitoring system could affect effectiveness
[55] (2021)	Offer a continuous mechanism using IoT-based sensors to monitor various parameters of Alzheimer's patients and enhance their quality of life	IoT, Cloud Computing	Esp8266, LM35, Pulse sensor, gyroscope, LCD, buzzer, resistor, LEDs, Atmega 328 Micro-Controller	The system has technical limits and cannot guarantee the complete normal routine
[56] (2021)	Develop a cost-effective and user-friendly smart wearable device integrated with a software application for Alzheimer's patients.	IoT, cloud computing (Ubidots)	GPS module, pulse sensor, temperature sensor, OLED Display, Help Button/Node MCU	Small sample size limits generalizability. Focuses on specific population (mild to moderate AD).
[57] (2021)	Propose a wireless-sensing smart wearable medical device (SWMD) for Alzheimer's patients, monitor vital biomarkers, falls, and provide GPS location.	Cloud Computing	ESP32, Maz30100, buzzer, LCD, gyro sensor, oximeter sensor, temperature sensor, SIM800L, battery 2000mA/Smart Watch	Prototype tested with limited number of patients/caregivers.
[58] (2019)	Propose an IoT-based assistive tool for Alzheimer's patients and caregivers, providing health monitoring and assistance.	IoT	Esp8266 12e, Pulse sensor, OLED display, Battery, Servo Motor, Piezo buzzer, Hc-05 Bluetooth module, Neo 6m GPS tracker/Arduino Uno	Prototype system, dependency on Wi-Fi connection.
[59] (2018)	Design a device to monitor health parameters in Alzheimer's patients.	IoT	Pressure Sensor, Heart Rate Sensor, Temperature Sensor, Arduino Nano	Limited generalizability due to sample size not specified
[60] (2018)	Develop a portable device resembling a clock to aid elderly individuals in daily activities.	IoT	Pulse Sensor, Temperature Sensor, GPS, NodeMCU ESP8266	Effectiveness not supported by evidence

TABLE 9. Overview on IoMT-based survived papers: Objectives, Technology, Sensors, Limitations.

toring. Modules for anomaly detection notify carers of odd behaviour.

In [61], Tabakis et al., developed an assistive system that recognizes the intent of Alzheimer's patients in completing daily tasks and guides them toward successful completion. This system utilizes AAL technology, incorporating RFID sensors and Bluetooth module/Arduino. It improves the quality of life for Alzheimer's patients by assisting with day-to-day tasks and enhancing independence and healthcare monitoring.

7) Personalized Assistive Solutions

Personalized Assistive Solutions are key to meeting the unique needs of people with AD, offering tailored systems that integrate multiple sensing technologies without falling into a specific application area. In this survey, we have identified significant contributions from a variety of sources that examine the use and progress of PAS for AD care. Notable studies include by [14], [62], [16], [63], [64] and [65]. Table 10 summarizes key aspects of these articles.

In [14], Le Xin et al., developed a simple mobile application named AlzBot to provide a chatbot for Alzheimer's patients, aiming to enhance socialization and track their location, thereby reducing the burden on caregivers. The application did not rely on specific technologies but utilized a chatbot implementation to create an assistive toolkit for patients and caregivers. However, the paper acknowledged a limitation in terms of the lack of clinical validation regarding the app's efficacy in treating or managing AD, as scientific evidence may be insufficient. No specific algorithm was mentioned. The proposed system showed potential in meeting the expectations of patients and caregivers, improving their quality of life, and reducing caregiver burden. It facilitated communication between Alzheimer's patients and the chatbot agent, particularly during periods of boredom.

In [62], Luca et al., offers a cutting-edge medication monitoring system that includes heart rate monitoring, location tracking, and help with medicine self-administration for people with Alzheimer's. Numerous modules, including GPS, GSM, heart rate, accelerometer, buzzer, LCD, and Arduino Mega, are part of the IoT system. The study emphasises the advantages of using medication administration support to increase patient independence and carer security.

Devi et al., in [16], focused on creating a personal assistant application for Alzheimer's patients. The application utilized machine learning techniques and accelerometer and gyroscope sensors integrated into a smartwatch. The study emphasized personalized assistance and practical implemen-

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Ref. (Year)	Objective	Methodology/Technology	Sensors/Controller	Limitations
[14] (2021)	Develop a chatbot named AlzBot for Alzheimer's patients, enhance socialization and location tracking to reduce caregiver burden.	Mobile app with Chatbot	Motion sensor, Smart Phone	Lack of clinical validation of the app's efficacy.
[62] (2020)	Design an innovative system for monitoring Alzheimer's patients, including location tracking, heart rate monitoring, and assistance in self-administration of drugs.	IoT	GPS module, GSM module, heart rate module, buzzer, accelerometer module, power supply, LCD/Arduino Mega	Validation and cost considerations.
[16] (2020)	Create an application acting as a personal assistant for Alzheimer's patients, including features like face recognition, wandering and fainting detection, assistance in finding a way home, reminders for daily chores and past life, and organizing and planning jobs.	Machine Learning	Accelerometer and gyroscope sensors, Smart Watch	Personalized assistance and practical implementation.
[63] (2020)	Design and implement a wearable device for accurately determining the 2D location of Alzheimer's patients using a BP-ANN.	Deep Learning - BP-ANN	ZigBee-based XBee S2C anchor nodes, mobile node/ZigBee-based XBEE S2C anchor Nodes	Time-consuming strategy, limited optimization, and movement during experimentation.
[64] (2018)	Ensure safety and well-being of Alzheimer's patients by tracking their position during daily activities and social interactions.	iBeacon technology	iBeacon devices, Raspberry Pi3	Limited scope and resources
[65] (2016)	Detect AD using EEG data and classify it using support vector machines. Monitor patients using GPS and GSM technology.	Support Vector Machine	GSM, ARM cortex M3 LPC 1768, GPS antenna, power supply, LCD display, GSM and GPS module, PC and RS 232 kit/ARM cortex M3 LPC 1768.	Use of a single biomarker (EEG signal) and limited scope of monitoring system

TABLE 10. Overview on PAS-based survived papers: Objectives, Technology, Sensors, Limitations.

tation. The findings highlighted the effectiveness of the application in recognizing people and assisting Alzheimer's patients in daily activities, such as wandering detection, finding a way home, and organizing and planning tasks. It was specifically designed for patients in the initial stage of the disease.

In [63], Munadhil et al., designed and implemented a wearable device that accurately determined the 2D location of Alzheimer's patients using a backpropagation-based artificial neural network (BP-ANN). The methodology involved deep learning techniques, and the sensors/controllers utilized were ZigBee-based XBee S2C anchor nodes and a mobile node/ZigBee-based XBEE S2C anchor nodes. The study identified time-consuming strategies, limited optimization techniques, and movement during experimentation as potential limitations. However, the findings indicated that the proposed wearable device yielded satisfactory localization error for tracking patients in indoor environments.

Salice et al., in [64], Published in 2018, ensure the safety and well-being of Alzheimer's patients by tracking their position during daily activities and social interactions. The proposed methodology utilizes iBeacon technology, with iBeacon devices and Raspberry Pi 3 serving as the sensors/controllers. The study acknowledges limitations in terms of scope and resources. To address the tracking challenge, a localization algorithm is implemented to constrain transitions between antennas. The findings highlight the development of a novel indoor localization system specifically designed to support residential care for Alzheimer's patients, ultimately enhancing their well-being. This system demonstrates potential for improving patient safety and facilitating better care in Alzheimer's care facilities.

In [65], Thakare et al., proposed a detection and monitoring system for AD. In the detection phase, the paper applied filtering techniques to EEG data, removing noise and artifacts using independent component analysis. Wavelet transform was then used to extract four features, and a support vector machine was employed for classification. In the monitoring system, Alzheimer's patients were tracked using GPS and GSM technology. The system utilized components such as GSM, ARM Cortex M3 LPC 1768, GPS antenna, power supply, LCD display, GSM and GPS modules, and a PC with an RS 232 kit/ARM Cortex M3 LPC 1768. However, the study had limitations, including the use of a single biomarker (EEG signal) for detection, which may benefit from using a combination of biomarkers for improved accuracy. Additionally, the scope and effectiveness of the monitoring system in ensuring the safety of Alzheimer's patients traveling without caregivers were not adequately addressed. The system aimed to help patients maintain independence and reduce caregiver

Sensing Technology	Involved Sensors	Application Field Technology						
		Telemedicine	E-health	IoT	Smart Environment	IoMT	AAL	PAS
Inertial	Accelerometer, Gyroscope, Magnetometer	[31]		[42] [45]	[35] [36] [37] [38] [40] [41]	[59]	[12] [48] [50] [54]	[62]
Physiological	Heart rate, Oxygen, Blood pressure			[11] [44] [47]	[34] [36] [40]	[13] [55] [56] [57] [58] [59] [60] [61]	[49]	[62]
Environmental	Pressure, Temperature, Light, Gas, GPS	[8] [31]	[32]	[11] [42] [43] [44] [45] [46] [47]	[10] [34] [35] [36] [37] [39] [40] [41]	[13] [57] [59] [56]	[12] [48] [49] [51] [53] [54]	[14] [62] [16] [63] [64] [65]
Radio Signals	Wi-Fi, BLE, mm-Wave							
Video	Video, Image	[30]		[11] [15] [45]				[16]
Digital Platforms	Mobile App, Web Portal, Questionair		[9] [33] [17]	[47]			[52]	[14] [16]

TABLE 11. Categorization of Application Field Technologies based on Sensing Technologies and Data Collection sensor.

burden.

B. CLASSIFICATION BASED ON EMPLOYED SENSING DEVICE

As the previous sections have made clear, sensing devices are essential to the field of AD treatment. As a result, we take on the responsibility of categorising the reviewed methods in this area, considering the unique sensing devices used in these creative solutions.

Table 11 categorizes application field technologies based on sensing technologies and data collection sensors for AD care. The most extensively utilized sensing technology is environmental sensing, which is utilized in a variety of application areas such as telemedicine, e-health, IoT, smart environments, IoMT, AAL, and PAS. The sensors in this field such as light, gas, pressure, temperature, GPS, and light are essential for tracking and evaluating the external environment. By giving Alzheimer's patients and their carers insightful information and support, these sensors improve patient safety and quality of care. The unwillingness of AD patients to employ wearables or sensors that penetrate their bodies is a crucial factor in the widespread acceptance of these technologies. Environmental sensors are a better option for data collection and monitoring because they are non-intrusive, which is why people with AD generally favour them over invasive technologies.

The physiological sensing field ranks as the second most utilized sensing technology. Employing sensors like Heart Rate, Oxygen levels, and Blood Pressure, this field finds application in IoT, Smart Environment, IoMT, AAL, and PAS. By continuously tracking vital signs and health parameters, these physiological sensors facilitate early detection of health issues and ensure comprehensive health monitoring for individuals with Alzheimer's.

Furthermore, the inertial sensing field, which ranks third in terms of usage, incorporates sensors such as accelerometers, gyroscopes, and magnetometers in Telemedicine, IoT, Smart Environment, IoMT, AAL, and PAS. These inertial sensors, which track movement, gait patterns, and physical activities, provide critical data for monitoring the well-being and safety of people with Alzheimer's.

Video sensing, which includes both video and image sensors, aids in Telemedicine, IoT, and PAS by allowing remote monitoring and visual communication. The sensing field of digital platforms, which includes mobile Apps, Web portals, and questionnaire sensors, enables interactive data collecting and personalized care delivery in E-health, IoT, AAL, and PAS.

Combining various sensing technologies results in amazing advancements in Alzheimer's care, increasing patient well-being, lowering carer obligations, and supporting a holistic approach to addressing the disease's problems.

In addition to the well-discussed sensing fields mentioned earlier, Table 11 provides insights into other valuable sensing technologies used in AD care. For example, the rising popularity of the radio signals sensing field, which includes Wi-Fi, BLE, and mm-Wave sensors, has not been extensively utilized for AD care. This suggests significant potential for innovation and future research in this area.

V. DISCUSSION

The analysis of selected research articles provides valuable insights into the dynamic evolution of the research landscape in Alzheimer's care technology. Since 2015, we have observed a gradual surge in research activity with intermittent fluctuations. Notably, there have been distinct peaks in 2018 and 2021, signifying periods of heightened interest and potential advancements. Conversely, a decline in 2022, along with the absence of pertinent papers in early 2023, could imply shifts in research priorities or a need for renewed exploration. Furthermore, the temporal distribution of publications, as shown in Figure 6, serves as a visual representation of the research community's focal points. The concentration of relevant studies in 2018 and 2021 suggests pivotal breakthroughs or technological strides during those periods.

A particularly noteworthy phenomenon within the landscape of Alzheimer's care technology realm is the swift rise

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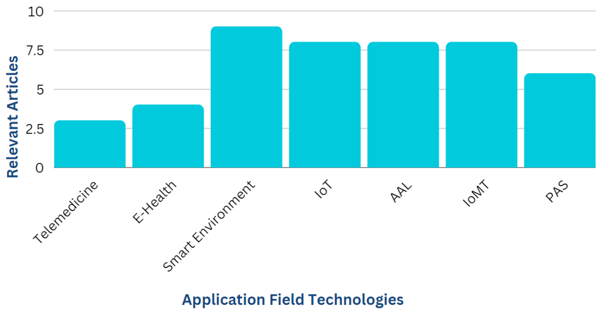
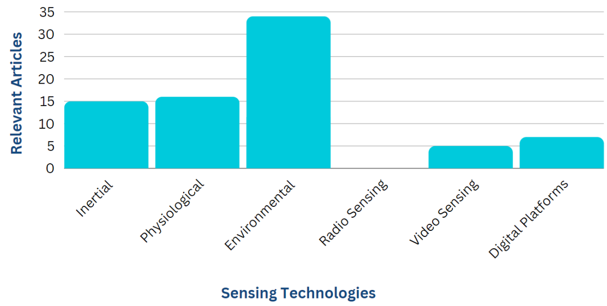


(a) Distribution of Research Papers on Application Field Technology Parameters.



(b) Distribution of Research Papers on Sensing Technology Parameters.

FIGURE 5. Distribution of Research Papers on Alzheimer's Research.

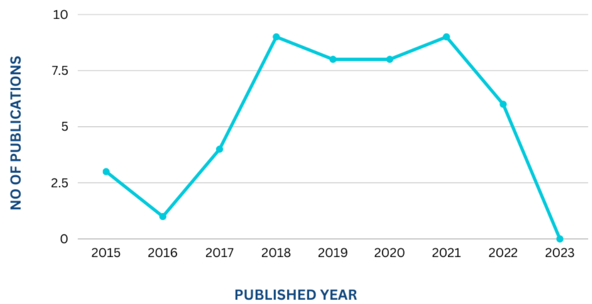


FIGURE 6. Distribution of the studies in terms of publication year.

of the smart environment, capturing substantial attention and driving focused research endeavors. This strategic emphasis gains even more validity from the surge in research activities centered around IoT, IoMT, and AAL technologies, further solidifying their pivotal roles. Equally important is the rise of PAS, showing a shift towards personalized care. With Alzheimer's affecting people differently, PAS has gained attention for its tailored approach to providing individualized support and solutions. Additionally, the domains of E-Health and Telemedicine have gained prominence due to their crucial roles in delivering remote care and essential medical support, sparking increased interest.

Figure 5a depicts the distribution of research activities across multiple technological aspects, capturing the evolving patterns in research. The smart environment's importance stems from its ability to seamlessly integrate technologies, providing comprehensive care solutions. Aside from real-time monitoring, it also enables personalized interventions.

Considering the trends observed over the years shown in Figure 4, it becomes apparent why telemedicine and E-Health are receiving comparatively less focus than other domains. Telemedicine, which dates back to 1964, and E-Health, introduced in 1973, have already experienced longer periods of exploration and development compared to the more recent advancements. The relatively newer concepts, such as the smart environment, IoT, AAL, and IoMT, which emerged from 1997 onwards, have likely captured more attention due to their novelty and the promise of addressing contemporary challenges. This shift in focus could also signify the evolving nature of healthcare technology, where newer and more integrated approaches are gaining traction as they align with modern needs and opportunities.

Moreover, with respect to sensing technologies, they have demonstrated substantial potential in monitoring the well-being and cognitive condition of individuals with AD. Notably, environmental sensors have emerged as the most prevalent technology in this field, underscoring their critical importance in Alzheimer's research. Their non-invasive nature contributes to their widespread adoption, ultimately enhancing the quality of life for individuals grappling with Alzheimer's. Physiological and inertial sensors have also garnered significant attention, further highlighting their relevance. Additionally, considerable interest has been directed toward video/image analysis and mobile app/web portal technologies, while questionnaire-based assessments have received comparatively less exploration. Interestingly, among the selected papers, no contributions were found related to Wi-Fi, BLE, and mm-wave sensing technologies. Such radio signal technologies focus on designing positioning systems that revolve around wearable devices designed for person positioning detection [49], [63], [64] rather than the classical radio sensing systems we are currently discussing.

A. FUTURE OPPORTUNITIES

There are promising areas for future research and development. Under Radio/Audio sensing, the key technologies are Wi-Fi, BLE, and mm-Wave sensing. Wi-Fi sensing has shown relevance in other domains such as smart homes, eldercare facilities, and healthcare monitoring [66]–[68]. It can provide valuable insights into the daily routines and behavior of individuals with Alzheimer's, aiding in early detection and personalized care. On the other hand, mm-Wave sensing, with its precise and non-intrusive monitoring capabilities, can offer valuable information about vital signs, facilitating proactive interventions [69]–[71].

Furthermore, incorporating Digital Twin (DT) technology holds promise in Alzheimer's care. DT technology enables continuous monitoring and analysis, providing comprehensive preventive strategies. By simulating care scenarios and facilitating remote monitoring, DTs enable personalized interventions and support systems. As research in DT technology progresses, it offers transformative potential in Alzheimer's care, providing invaluable insights into cognitive and behavioral patterns and improving the overall quality of life for affected individuals and their caregivers [72].

VI. CONCLUSION

This survey paper presents an in-depth exploration of technological advancements in the realm of Alzheimer's care, concentrating on both application fields and sensing technologies. Through the examination of 46 (from an initial set of 2459 articles) pertinent studies, has significantly contributed to our comprehension of the potential advantages and constraints of these pioneering approaches. The outcomes underscore the critical role played by telemedicine, e-health, smart environment, IoT, AAL, IoMT, and PAS technologies in enhancing the well-being of individuals grappling with AD. Furthermore, wearable and environmental sensors, radio/audio sensing, video/image analysis, and digital platforms display promising capabilities for monitoring cognitive status and overall well-being. Future opportunities lie in the utilization of Wi-Fi, mm-wave, and BLE sensing technologies, integration of technologies, and the use of digital twin concepts in the Alzheimer's healthcare sector.

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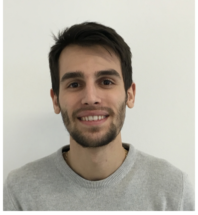

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