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An Empirical Analysis of AI Related Scientific Knowledge and Technologies to Support Elderly Independent Living

Fei Yuan[1], Kumiko Miyazaki[2], and Santiago Ruiz-Navas[2]

[1] *Beijing University of Technology, China*

[2] *Ritsumeikan Asia Pacific University, Japan*

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ABSTRACT

The constant increase of an aging society unveils social and economic problems. Elderly independent living (EIL) is supported by numerous services and technologies that take care of their emotional and physical health. Previous studies have reviewed the potential of Artificial Intelligence (AI) applications to support health care, such as AI robots and intelligent senior well-being support systems. A growing number of scientists and technology companies are working on AI applications to help the EIL. We propose to identify AI technological innovation opportunities when developing AI solutions to help the elderly independent living. The research consists of two steps: 1) Identifying AI solutions to help EIL by implementing scientometric analysis on scientific publications related to AI technologies and the elderly. 2) The review and national-level comparison of the identified AI solutions under the proposed framework of elderly need, supporting function, underlying technologies and scientific knowledge. Based on an analysis of the literature on emerging technology in the third AI Boom, we pinpoint science mapping to grasp the situation of research and development of emerging technologies in various regions, to explore the status of technological and research cooperation, to find out the hot research topics of AI technologies in dealing with the problem of aging, to discover the direction of technological development and innovation opportunities in the future, and to combine with the actual need of EIL for exploring the innovative potential of AI technology. From our analysis we argue that solutions to support EIL require the integration of knowledge from various disciplines, services and products such as machine learning, sensors, data analysis, IoT, wearable devices, sociology and healthcare.

* Corresponding Author.
E-mail: yuan@bjut.edu.cn; kmiyazak@apu.ac.jp, ru21014d@apu.ac.jp

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I. INTRODUCTION

Starting from 2012, the third boom AI technologies promise innovations to improve the quality of life of the elderly population. However, to improve their quality of life, some issues need to be attended such as safety, costs, and user-friendliness; in this context of AI opportunities and challenges. This paper used a bottom-up approach to look into what challenges management of technology researchers could consider to foster innovations emerging from AI. The world's population is aging, and the population aged 65 and over is growing faster than all other age groups globally. By 2050, almost all countries will face severe pressures of population aging, and the independent living care of the elderly has urgently become one of the key issues in economic and social development (Bloom, Canning and Fink, 2010).

The third boom of AI technology is driving the R&D and offering solutions to support the elderly independent living based on various technologies, e.g., sensor networks and cognitive computing, Apps loaded with machine learning algorithms, and social robots. However, these solutions still have a long passage to innovation. Challenges such as achieving a balance between respecting seniors' privacy and monitoring their data to better serve them or serving the seniors without generating dependence to "virtual" rather than human interaction stand in the middle of this path towards innovation.

Management of technology has provided insights on how to exploit opportunities to achieve innovation and create value. Nevertheless, AI technologies to support EIL present a special challenge. 1) AI covers many disciplines, and their innovations can be delivered as AI-powered intangible software or tangible facilities. Therefore, it requires the identification of cross-disciplinary AI solutions to help the EIL. Moreover, 2) it requires the review and comparison of seniors in a different context with special needs that take advantage of the knowledge underlying AI technologies to meet the supporting functions for independent living. Looking into these two points, we propose a scientometric analysis and a framework to focus on developing AI solutions to help the EIL. The scope of the paper is narrowed by answering two research questions: What are the opportunities of AI solutions being disclosed in scientific research of different nations and institutions to help senior adults to live independently? And what are the challenges and issues disclosed in those AI solutions to help the EIL?

II. METHOD

Based on scientometric analysis on AI technology to support EIL, this paper illustrated the national and regional research development, cooperation, and trending topics in the field of emerging AI technology for elderly activities of daily living (ADL).

Moreover, elderly demand for innovation in the technology domains can still drive researchers to advance innovation. To meet the need of elderly in AI technology innovation, a descriptive analysis of knowledge and technology structure examined the knowledge and technical structure of AI and explored the potential AI solutions of product and service innovations supporting elderly independent living.

III. AI TO SUPPORT ELDERLY INDEPENDENT LIVING

A. Elderly independent living (EIL) care

To help the elderly live independently at home, the new challenges and changes that come with aging require flexibility, openness to change, and acceptance of a new way of life. Indeed, the ability to stay in one's home in older years instead of a nursing home is a positive and empowering concept, and, currently, it is becoming more and more of a preferred and achievable lifestyle choice. Home modifications, myriad caregiving services, and products driven by technology advances make aging at home a realistic goal for many. It is important to see what assistive technologies, such as AI, can do and what is currently available for helping the elderly so they can live their best lives at home. AI technologies improve the independence of the elderly and maintain the quality of life seniors deserve while living in their own homes. Emergency situations such as a simple slip and fall can trigger a series

of medical conditions in geriatric patients. A bit of getting extra in-home care assistance by AI technologies can ensure that the activities of daily living (ADL) are met efficiently and safely for the elderly who needs long-term care.

B. AI-enabled solutions to support elderly independent living

Given the rapidly aging demographic situation, healthcare providers are starting to shift parts of their care-pathways to artificial intelligence (AI) based automatization (Sanya, 2018). AI-enabled solutions for telemedicine and telecare, such as those connected to Ambient Assisted Living solutions (Siegel, Hochgatterer, and Dorner, 2014), will have the biggest positive impact on caregiving services. Also, simple technical aids can be beneficial for the elderly to enhance the quality of life (QOL) by enabling autonomy in their familiar surroundings.

AI-enabled devices and research are helping in every step of the independent living care-pathway and revolutionizing elder care. Companies like Apple and Fitbit have made smart wearable biometric trackers available to elderly and geriatric patients. The elderly can use this device's built-in AI-powered functionality to check inconsistencies in their biometric data, as well as to detect a significant or hard fall and sound an alarm (Sanya, 2018). AiCare claims to use machine learning analytics and wearable sensors to personalize individual security, safety, and care to empower an independent lifestyle for senior citizens. Xsens, Kardian, and Qventus have built AI-powered fall detectors. Starkey has integrated AI-powered fall detectors within its hearing aid Livio AI.

One of the biggest impacts of AI is in helping anti-aging researchers understand the very process of aging and thereby develop methods to delay the process, such as Calico (AiCare, 2020), Insilico Medicine (InSilico, 2020), and Nuritas (Nuritas, 2018).

Driven by a shortage of human caregivers in developed nations, AI are assisting decisions about elderly care in independent living for home care and nursing facilities. At the same time, AI-empowered digital innovations are guiding the elderly in developing countries to improve their quality of life. Kwai, an AI-based short video platform, enables a new business model impact on inclusive development for elderly in rural areas in China and Bangladesh. Trials are taking place in Japan to provide mobility for the elderly living in rural areas through self-driven vehicles.

IV. SCIENTOMETRIC ANALYSIS OF AI TECHNOLOGIES TO SUPPORT ELDERLY INDEPENDENT LIVING

A. Scientific output on AI to support Aging

Based on an analysis of the literature on emerging technology in the third AI Boom (Miyazaki, Satou, and Ruiz-Navas, 2019), we pinpointed scientific mapping (Chen, 2017) to grasp the situation of research and development of emerging technologies in various regions, to explore the status of technology cooperation, to find out the hot research topics of AI technology in dealing with the problem of aging, to discover the direction of technological development and innovation opportunity in the future, and to combine with the actual need of EIL for exploring the innovative potential of AI technology. In this paper, the SCI-EXPANDED and SSCI databases in the core collection of Web of Science were searched for the literature related to AI and aging from 2012 to 2019. The keywords are divided into two parts: AI technology and aging-related terms. 3683 documents were finally obtained. Figure 1 shows the number of publications of interdisciplinary research on AI technology and aging.

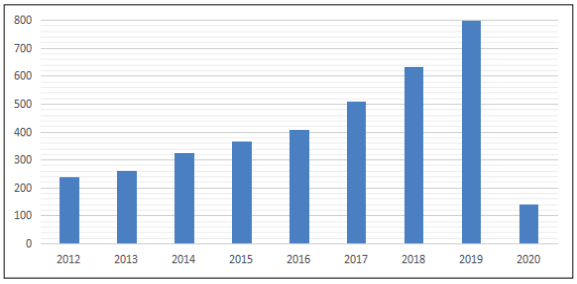

Figure 1. Number of papers on AI to support Aging 2012-2019

B. Mapping the regional research of AI technology for Elderly independent living care

We analyzed the affiliations of retrieved publications and obtained the rankings of research institutions publishing papers on AI technology to support aging issues in Table 1.

Table 1 shows that the top-ranked research institutions were mostly top universities in the world. They had relatively high subject rankings in computing science, namely AI and machine learning, and aging-related medicine, brain science. It showed that institutions with interdisciplinary capabilities had the research and innovation potential to meet the interdisciplinary issue of elderly independent living.

Moreover, newly joined institutions had published many papers in the interdisciplinary area since 2012. It is noted that the great majority of institutions are US institutions, indicating that the US had a leading position for AI technology to deal with aging issues. In recent years, many research institutions outside the United States have emerged, mainly in Europe and Asia, indicating that with the development of AI technology and the intensification of population aging, more and more countries were concerned with AI technology to solve the aging issues.

We utilized CiteSpace to analyze the node of the regional cooperation network. Table II showed the top 15 regions in terms of publication frequency.

In this paper, nations with a score greater than 0.05 were defined as the core position in the research of AI technology to support elderly independent living. Seven countries in Table 2 were the core players, namely the United States, the United Kingdom, Canada, Australia, France, Japan, and South Korea, and these countries had the highest number of published scientific research literature contributing to AI technology to support ADLs. Considering the centrality scores, the United Kingdom and Canada were in a leading position in the research field with more international influence in the cooperative network.

However, not all countries with high volume publications were at the forefront. For example, Australia has only 205 articles since 2012, but its centrality is 0.12 (higher influence), while Italy has 246 articles more than Australia with centrality at 0.03. It may reflect that the research

Table 1.
Top 20 Research Institutions by the Number of Publications

Rank	Organizations	Number
1	University of California System	118
2	Harvard University	102
3	University of London	87
4	University of Toronto	85
5	Pennsylvania Commonwealth System of Higher Education Pcshe	74
6	University of Texas System	74
7	State University System of Florida	68
8	University of Pittsburgh	53
9	Centre National De La Recherche Scientifique Cnrs	52
10	Institut National De La Sante Et De La Recherche Medicale Inserm	52
11	Harvard Medical School	51
12	Columbia University	47
13	University of Pennsylvania	44
14	Chinese Academy of Sciences	43
15	Karolinska Institutet	41
16	King S College London	41
17	Mayo Clinic	40
18	University of California San Francisco	39
19	Northwestern University	38
20	University College London	38

impact of the scientific outcome on emerging AI technological domain was associated with the international cooperative network and whether it met the societal expectation and demand supporting elderly ADLs.

Japan, Italy, Germany, France, etc., with a high degree of aging, were all increasing their research in this field so that the related articles were in the forefront, and their cooperation with other countries also relatively close. According to the centrality scores, Japan and France were the core countries of a cooperative research network, which showed their influence. While Italy and Germany were not highly centralized in the network, it showed that their research differed from the main focus of global researchers, and the research results had not attracted the attention of others. The increasing frequency showed that more and more researchers paid attention to AI technology to solve the aging problem. The low centrality showed that the quality and theme of related AI technology research had not been highly recognized and valued by other researchers.

Although France, Japan, and South Korea had not published many articles, their research results had a greater impact. It means that their research output induced innovation closer to solving problems caused by population aging. China's publication ranks second with 455, but the centrality is only 0.04, indicating that its attention on using AI technology to deal with the aging problem is emerging and many researchers had explored AI technologies to support aging, but the outputs of technological innovation did not match with the actual needs of an aging society, and the development of related AI technologies had not effectively solved the main problems caused by the population aging.

Table 2.
Publications Frequency of Countries/Regions

	Frequency	Centrality	Nation/region
1	1342	0.10	USA
2	455	0.04	China
3	332	0.23	England
4	279	0.20	Canada
5	246	0.03	Italy
6	237	0.05	Germany
7	205	0.12	Australia
8	178	0.04	Spain
9	175	0.06	France
10	173	0.12	Japan
11	142	0.06	South Korea
12	139	0.02	Netherlands
13	128	0.00	Taiwan
14	98	0.03	Sweden
15	87	0.01	Switzerland

C. Visualizing the trending foci of AI supporting elderly ADLs

By exploring keywords of literature, we understand the research hotspot and the development frontier for future research and discover opportunities for later technological innovation.

A total of 978 keywords appeared more than five times were selected to visualize the research foci of AI to support aging. By dint of VOSviewer, the 978 keywords were divided into 7 clusters, each of which was marked with a different color in Figure 2. In particular, the bigger the node in the network, the greater the frequency of the keyword, which represented the hot research content.

In Figure 2, the closer the node was to the center, the more important the keyword is, which was the research focus in the field; nodes of the same color represented the same research topic. We reviewed these seven clusters and keywords, then examined the related technological application for elderly ADLs. The result is shown in Table 3.

The keywords in Table 3 are associated with ADLs needs about information supplement, cognitive ability, Neurodegenerative disorders, disease diagnosis and prognosis, caregiving, behavior recognition, and surveillance. The first and fourth clusters both had a keyword which frequently appeared in the literature. The keywords were dementia and machine learning that occupies the major position, which meant that in the field of AI technology to assist EIL, using machine learning technology to deal with Neurodegenerative diseases, such as Alzheimer's disease, played an important role with an opportunity for innovation.

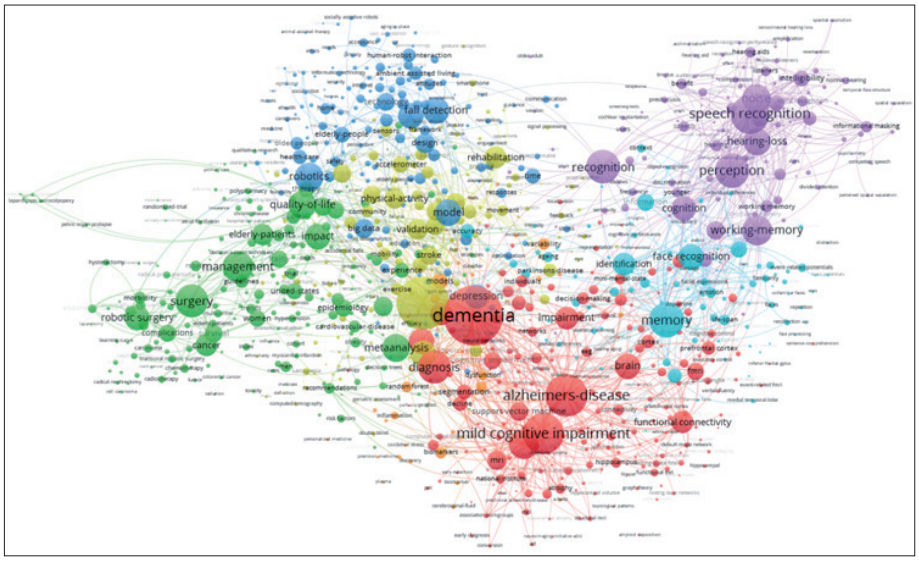

Figure 2. Visualizing the research foci of AI to support aging

Table 3.
Clustering the Research Foci of AI to Support Elderly ADLs

Classifications	Keywords	Technology Application
Cluster 1(red): brain functions of the elderly	Dementia, Alzheimer' s-disease, mild cognitive impairment, brain, fMRI, neural network, cortex, hippocampus, atrophy, prefrontal cortex	AI Detect Alzheimer's Disease in Brain Scans Six Years Before a Diagnosis (Ding et al, 2020); AI help address mental issues such as dementia.
Cluster 2(green): Diagnosis and treatment of disease	Surgery, management, meta-analysis, quality-of-life, morbidity, hysterectomy, carcinoma, polypharmacy, cardiovascular-disease, robotic surgery	AI improve the accuracy of surgical procedures (Hashimoto, et al., 2018); use AI to detect early signs of lung diseases
Cluster 3(blue): Behavior Surveillance	Robotics, fall detection, model, depression, ambient assisted living, ethics, behavior, big data analysis, detection system, human activity recognition	Artificial Intelligence Detect and Prevent Senior Falls (VA2CS, "VA2CS," VA2CS Watch, 2020); Automated Conversational Agent (Woebot) appear to be a feasible, engaging, and effective way to deliver CBT (Fitzpatrick,Darcy, and Vierhile, 2017).
Cluster 4(yellow): Disease prediction and assessment	machine learning, prediction, rehabilitation, physical-activity, bone mineral density, osteoporosis, risk assessment, wearable sensor, randomized controlled, postural control	Prediction of fatty liver disease using machine learning algorithms6; AI assist the elderly in disease rehabilitation training (Zhang, et al, 2017).
Cluster 5(purple): Speech recognition and hearing-aid	speech recognition, working-memory, noise, cochlear implant, hearing aid, hearing-loss, reception threshold, speech perception, word recognition	Use AI to Program Cochlear Implants (Waltzman, and Kelsall, 2020); autonomous cochlear implant (Meeuws, et al., 2020)
Cluster 6(Aqua): facial recognition	face recognition, memory, identification, event-related potentials, eye-movements, emotion recognition, face perception, sex difference, facial expressions	Face recognition assists the cognitive function of the elderly
Cluster 7(orange): Algorithm application	Biomarkers, random forest, body mass, diagnosis, image processing, PCA, segmentation, oxidative stress, marker	Random forest algorithm assists biomarkers or diagnosis of diseases (Gray, et al., 2013).

Dementia, Alzheimer's-disease, mild cognitive impairment, and speech recognition are the research hotspots of AI technology to support elderly ADLs. The senior behavioral ability had attracted the attention of researchers. Together with the observation of all the larger and clearly visible nodes in Figure 2, current research focused on diagnosis and prognosis technologies, assisted Nursing Care of brain function and behavior disorders, and improvement of the quality-of-life by using AI technology.

We also used the CiteSpace clustering function to visualize the co-citation network of literature on AI to support aging. Eight clusters related to elderly ADLs were extracted in Figure 3, which included fall detection, behavior recognition, cochlear implants, auditory and motor function, mild cognitive impairment, gait, health monitoring, and long-term care. It indicated that researchers mainly focus on hearing-aid, behavior-assist, cognitive enhancement, using AI technology to solve the elderly independent living difficulties, to a certain extent, to replace the simple human caregiving.

V. DESCRIPTIVE ANALYSIS OF THE KNOWLEDGE AND TECHNOLOGY STRUCTURE OF AI SOLUTIONS TO SUPPORT ELDERLY INDEPENDENT LIVING

We proposed six steps that provided a descriptive analysis of the knowledge and technology structure of AI solutions to help the elderly independent living scientific publications:

- Retrieving the scientific publications related to AI solutions to help the elderly independent living;
- Author keyword preprocessing;

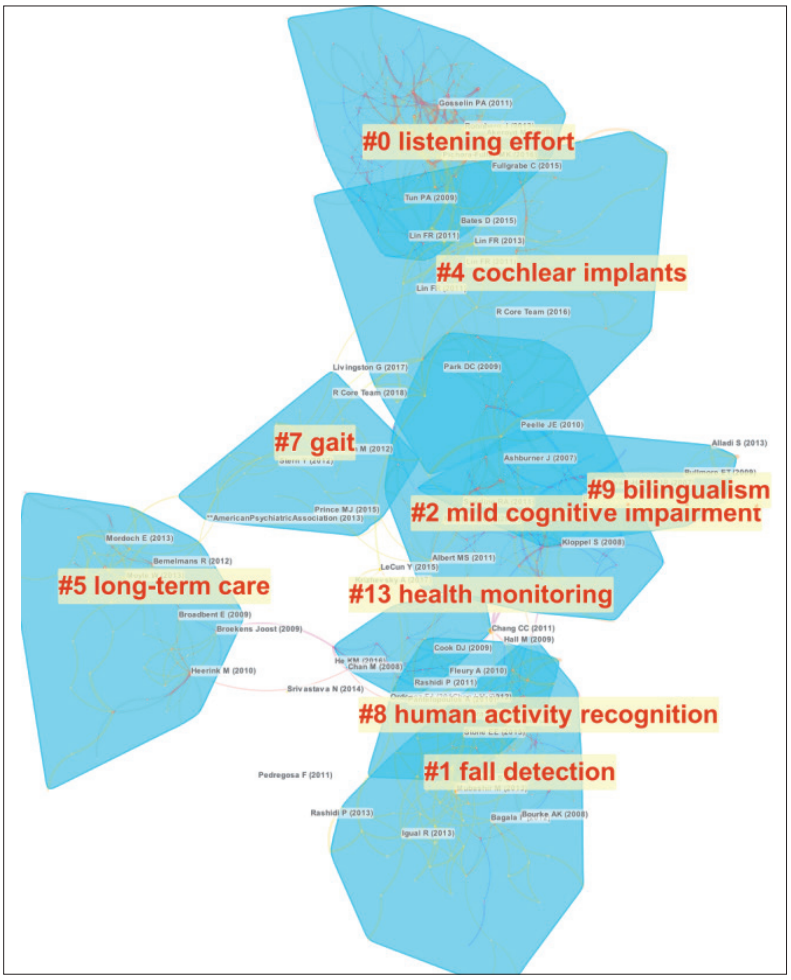

Figure 3. Visualizing the co-citation of literature on AI to support aging

- Enhancing keyword metadata using DBpedia and Wikipedia;
- Classifying technology and knowledge keywords;
- Creating keyword co-occurrence network; and
- Analysis of knowledge and technology structure for 2019.

In this step, we analyzed the keyword co-occurrence network created for the documents published in 2020 using the classification of keywords into knowledge and technology created from the metadata obtained from Wikipedia and DBpedia, for more information about this step see (Ruiz-Navasand, Miyazaki, 2018). The analysis consisted of a descriptive observation of the topological measures for the keywords published in the year 2020, focused on answering the question of what opportunities might be open to developing innovative AI solutions to support elderly living. The following premises guided the descriptive analysis.

- In a context of convergence, knowledge and technologies are the foundation for services and products and services and products are a component of industries (Hacklin, 2008).
- The betweenness centrality of a node in a network represents its connection or influence over other nodes of the network (Newman, 2003).
- Degree of a node in a network represents how often a node is linked to other nodes (Young, et al., 2018).

VI. RESULTS OF DESCRIPTIVE ANALYSIS

A. Analysis of knowledge and technology structure for 2020

We presented the analysis of the top three central clusters for the year 2020.

Notes for the analysis: we expected to find only technology or disciplines among the keywords on a cluster. However, we found that the keywords had mixed classifications such as discipline and industry such as data mining or discipline, industry, and service/product such as biomedical monitoring. Therefore, we decided to classify as a discipline all keywords with only the discipline category and any other combination of categories as technology.

Tables 4, 5 and 6 showed the top ten betweenness central keywords of clusters 12, 14, and 4 (the three most average betweenness central). The columns BS stands for keyword betweenness centrality in the table, D for node degree, RD % node relative degree, AK for author keyword, and C category.

Table 4 showed that the keywords categorized as discipline described challenges for EIL such as sleep quality, stroke, quality of life, atrial fibrillation, e-health and neural networks, and machine learning that described technical knowledge to solve these issues. On the other hand, the words with the technology category described sensors such as gyroscope and accelerometer; and services, e.g., personalized medicine, risk management, and computer vision. In summary,

Table 4.
Cluster 12. Machine learning and sensors to solve quality of sleep and life and strokes.

BC	D	RD %	AK	C
0.387	142	4.578	Machine learning	Discipline
0.028	31	0.999	Data mining	Technology
0.013	23	0.741	Convolutional neural networks	Technology
0.006	31	0.999	Accelerometer	Technology
0.006	13	0.419	Neural networks	Discipline
0.006	4	0.129	Sleep quality	Discipline
0.006	28	0.903	Wearable sensors	Technology
0.005	16	0.516	Risk management	Technology
0.005	13	0.419	Stroke	Discipline
0.003	19	0.613	Convolutional neural network	Technology

researchers used machine learning techniques and a variety of sensors to solve aged person problems such as quality of sleep, stroke, quality of life.

From Table 5, we saw that this cluster was focused on technologies. The keywords with the discipline category describe a control technique fuzzy logic and two challenges for elderly independent living, healthy aging, and prostate cancer. In terms of technology, the more betweenness central keywords, IoT and Smart home, give a clue of how these issues were solved. In summary, this cluster described applications based on the Internet of Things, Smart houses, Wearables, and machine learning techniques such as fuzzy logic and deep convolutional networks to provide healthy aging and monitor illnesses such as prostate cancer.

From Table 6, it is possible to see that among the discipline words, most describe issues such as aging, physical activity, traumatic brain injury, chronic kidney disease, except health economics. On the other hand, the words under the technology category described services such as fall risk, vaccination, elderly health, and products such as hearing aids. In summary, this cluster represented applications based on machine learning, health economics, and physical activity in synergy with services such as vaccination and elderly health to solve conditions such as carcinoma, brain injury, and chronic kidney disease.

Table 5.
Cluster 14, Machine learning, IoT, Smart house and wearables to solve healthy aging

BC	D	RD %	AK	C
0.010	22	0.709	IoT	Technology
0.008	23	0.741	Smart home	Technology
0.004	13	0.419	Health care	Technology
0.003	10	0.322	Fuzzy logic	Discipline
0.001	6	0.193	Elderly care	Technology
0.001	9	0.290	Wearable technology	Technology
0.001	6	0.193	Patient monitoring	Technology
0.001	4	0.129	Three-axis accelerometer	Technology
0.000	5	0.161	Healthy aging	Discipline
0.000	6	0.193	CNN	Technology

Table 6.
Cluster 4. Machine learning, health economics, physical activity, vaccination and hearing aids to solve conditions such as carcinoma, brain injury and chronic kidney disease.

BC	D	RD %	AK	C
0.009	5	0.161	Ageing	Discipline
0.005	5	0.161	Fall risk	Technology
0.001	6	0.193	Carcinoma	Discipline
0.001	7	0.226	China	Technology
0.001	2	0.064	Physical activity	Discipline
0.000	3	0.097	Elderly health	Technology
0.000	3	0.097	Traumatic brain injury	Discipline
0.000	5	0.161	Chronic kidney disease	Discipline
0.000	6	0.193	Vaccination	Technology
0.000	3	0.097	Health economics	Discipline

VII. CONCLUSION

Scientometric analysis on AI technology to support EIL in this paper had illustrated the national and regional research development, cooperation, and trending topics in the field of emerging AI technology for elderly ADLs. We, as second part of the paper, analyzed scientific documents related to AI solutions to support aged adults' independent living and provided a descriptive analysis of the more central solutions identified for the year 2020. The analysis resulted in the identification of solutions based on technical and healthcare disciplines to attend elderly living issues such as illness, quality of sleep and life.

In the 3rd boom of AI technology, researchers had paid a lot of attention to some keywords, such as emotion, education, and so on. But these keywords were not highlighted in the scientific mapping, and the relevant literature was not highly cited. With the co-evolution of elderly demand and AI technology, some aging issues had attracted less attention to developing related technology innovation.

Based on scientometric analysis on AI technology to support EIL, we illustrated the national and regional research development, cooperation, and trending topics in the field of emerging AI technology for elderly ADLs. In particular, the combined examination showed that cognitive function, assisted care, and recognition techniques were among the most prominent keywords that have remained the focus of scientist research in the 3rd boom of AI.

The descriptive analysis on the documents published in 2020 led us to identifying solutions using as base knowledge machine learning, healthcare and sociology disciplines, making synergy with products and services such as vaccination, sensors, risk assessment, smart houses, IoT to solve elderly independent living issues such as diseases, quality of sleep and life, brain injury and cancer. From this analysis, we suggested actors interested in developing solutions for supporting elderly independent living to pay attention to foster interdisciplinary work and what it entails. From our analysis we argued that solutions to support elderly independent living require the integration of knowledge from various disciplines, services and products such as machine learning, sensors, data analysis and sociology and healthcare.

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