# Trends, Challenges, and Opportunities in Assistive and Robotic Kitchen Technologies for Aging Society: A Scoping Review

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#### Abstract –

The world's population is rapidly aging. According to the United Nations, nearly 10% of the world's population is over 65 years old. The aging population crisis is arguably one of the most pressing challenges to the future well-being of humanity. The kitchen is an essential place for human activities, and cooking holds significant importance for older adults, serving as a key measure of their capacity for independent living. Moreover, it plays a crucial role in ensuring that older individuals receive the necessary nutrition to maintain good health. Naturally, the investigation of assistive kitchen technologies emerges as a compelling and significant field of research. However, there are no existing reviews that specifically address assistive kitchen and cooking technologies designed for vulnerable populations such as older adults or individuals with disabilities. Therefore, this paper provides a scoping review of the trends, challenges, and opportunities in emerging assistive kitchen and cooking technologies for the past decade. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) methodology was adopted for the review. As a result, 100 peerreviewed publications from 29 countries were included in this review. These studies cover six major research topics on assistive and robotic kitchens. As a result, the trends, challenges, and opportunities of the current technologies are analyzed, and a modular and adaptable smart kitchen is proposed. The study will fill the scientific gap and lay the groundwork for future development of assistive kitchen technology.

Keywords -

Activity Recognition; Artificial Intelligence; Disabilities; Cooking; Gerontechnology; Population Aging; PRISMA; Robotics; Sensing; Smart Home

## **1** Introduction

The world's population is aging at an unprecedented pace. According to the United Nations, as of 2022, there are nearly 8 billion individuals living on this planet, of which 9.6% (771 million) are over 65 years old. Globally, the population aged 65 years or over is the fastest-growing age group, whose proportion increased from 6.9% in 2000 to 9.3% (i.e., "aging society") in 2020 and is projected to reach 15.9% (i.e., "aged society") by 2050 and 22.6% (i.e., "super-aged society") by 2100 [1, 2]. The population aging crisis is not only a severe crisis for the developed world, but also an imminent threat to emerging economies. It is arguably one of the most imminent challenges facing the future prosperity of humankind.

Kitchens are one of the places where humans spend the most time while awake. A new poll commissioned by Bosch Home Appliances suggests that the average American spends over an hour per day in the kitchen, adding to more than 400 hours a year [3]. Although the time that the current generation spends in the kitchen is much less than the older generation, potential pandemics like COVID-19 will only likely increase people's time in the kitchen again [4]. More importantly, cooking is a significant activity for older adults, not only because it is a crucial indicator of older adults' ability to maintain independent living, but also because appropriate cooking ensures the nutrition intake of older adults to maintain good health. In fact, previous studies even suggested that frequent cooking may improve the survival rates in older adults [5]. Over time, kitchens have evolved to be more convenient and technological. However, average kitchens are not designed to be inclusive and adaptive, especially for the characteristics and needs of the growing aging population. As a result, the investigation of assistive kitchen technologies becomes a compelling and significant research area.

There have been a number of review studies on the impact of assistive technology on older people. For example, Shishehgar et al. examined how various robots can help older adults [6]. Zhu et al. analyzed the global trends in the study of smart healthcare systems for older adults with a special focus on artificial intelligence (AI) solutions [7]. Ghafurian et al. reviewed smart home devices for supporting older adults [8], while Nthubu reviewed sensors, design, and healthcare technologies in smart homes [9]. In addition, Facchinetti et al. analyzed how smart home technologies can help older adults manage their chronic conditions [10], and Ohneberg et al. identified existing assistive robotic applications in nursing settings in a scoping review [11]. Furthermore, Fasoli et al. made an in-depth online search on emerging technologies in aged care, which went beyond only the literature review [12]. It is worth noting that Singh et al. reviewed automated cooking machines and food service robots [13], but the study focused more on robotic solutions for the food service industry rather than for private homes and individuals.

The studies mentioned above provide insightful knowledge in regard to the impact of emerging technologies on older adults. However, reviews focusing on assistive kitchen and cooking technologies for vulnerable groups such as older adults and disabled individuals are non-existent. Therefore, in order to fill the scientific gap and lay the groundwork for the future development of assistive kitchen technology, this paper provides a scoping review of the trends, challenges, and opportunities in emerging assistive kitchen and cooking technologies for the aging population [14].

## 2 **Research questions**

The review aims to examine the following research questions (RQs):

- RQ1: What smart assistive kitchen and cooking technologies have been developed for older adults or individuals with disabilities in the past decade?
- RQ2: What are the focuses and trends of the reviewed studies on developing smart kitchen devices for older adults?
- RQ3: What are the challenges in the reviewed studies that need to be taken into account as potential considerations for developing smart kitchen technologies for supporting older adults and individuals with disabilities in the future?

# 3 Methodology

In order to conduct a thorough scoping review, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) methodology was adopted [14]. The details of the application of the PRISMA-ScR methodology, including the selection criteria, publication search strategy, and data screening process, are reported as follows.

## 3.1 Study selection and eligibility criteria

Peer-reviewed articles published in journals, books, and conference proceedings were included. When a conference proceeding and a journal article are based on the same research conducted by the same team, only the journal articles are kept.

The main reason for the defined time period for selecting the publications (i.e., articles that were published in the past 10 years) is that earlier studies may contain technologies that are already outdated or obsolete. In fact, even some early studies included in this research already have this problem. For example, the use of Adobe Flash is noticed in Blasco et al. [15], which has been an obsolete technology for many years [16].

Sociological articles that do not involve any emerging assistive technologies or novel designs are not included in this study since they are outside the scope of this study.

Articles that are written in languages other than English are excluded altogether due to the limited language skills of the authors as well as the pursuit of impartiality.

Articles that are not relevant to the RQs are also excluded. This could be papers featuring technologies that are meant to be applied outside of the kitchen or cooking context, such as the living room or bedroom.

Articles that are not yet fully peer-reviewed, such as preprints that are under review at the time of the analysis, are also excluded to achieve high reliability.

Articles with target groups that do not include older adults or individuals with disabilities are not included. For instance, several identified studies only focus on adolescents or children whose physiological and psychological characteristics are vastly different from older adults.

Table 1 summarizes the inclusion and exclusion criteria of this review.

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
<ul> <li>Peer-reviewed articles published in journal and conference proceedings</li> <li>Articles published in the past 10 years (from 2013 to 2023)</li> </ul>	<ul> <li>Articles with no emerging technologies or novel designs involved</li> <li>Articles that are written in languages other than English</li> <li>Articles that are essentially different versions of the same research</li> <li>Articles that are not relevant to the RQs</li> <li>Articles that are not yet peer-reviewed</li> <li>Articles' target users do not include older adults or individuals with disabilities</li> </ul>

## **3.2** Databases for publication search

Popular research databases for science and engineering, including Scopus, Web of Science, and IEEE Xplore were utilized, which should cover the vast majority of the relevant literature. Google Scholar was not considered due to its limitations, such as limited functionality, opacity, and inaccuracy [17]. Keio University Library and the Technical University of Munich Library synergistically provided a full-access database for the literature items.

The search protocol was defined based on the RQs as well as the inclusion and exclusion criteria. The following search query was adapted and applied to each database:

(TITLE-ABS-KEY (kitchen OR cooking) AND TITLE-ABS-KEY (sensor OR sensing OR smart OR intelligent OR assistive OR gerontechnology) AND TITLE-ABS-KEY (old OR elderly OR older OR aging OR ageing OR senior OR disabled OR disability OR impairment)) AND PUBYEAR > 2012 AND PUBYEAR < 2024.

The final search was performed on August 22, 2023, covering all publications that have been included in these databases until that date.

### **3.3 Data screening process**

In total, 794 items were identified in the initial data search. After removing duplicate records, 576 unique records were kept for abstract screening. In this step, a total of 433 records were excluded due to their irrelevance. Next, the records were sought for retrieval,

and the full text of 10 reports could not be retrieved. Finally, the full texts of the remaining 133 records were fully assessed, and 33 publications were further excluded based on the exclusion criteria. This resulted in 100 publications eventually being included in the scoping review.

Figure 1 shows the identification and screening processes of this study based on the PRISMA flowchart.



Figure 1. The PRISMA flowchart for this study

## 4 **Results**

In this section, the collective characteristics of the included studies are analyzed and visualized as follows.

#### 4.1 Sources of the publications

The study finally included 100 publications for the scoping review, including 26 scholarly journal articles and 74 book chapters or conference proceedings, which suggests a good timeliness of the included studies (Figure 2).



Figure 2. Sources of the publications

## 4.2 High-frequency keywords

A word cloud based on the titles of the included studies was generated using Free Word Cloud Generator [18] (Figure 3). The larger the word size, the more frequently these words appear in the titles. The word cloud largely goes in line with the data search protocol with a few exceptions such as activity recognition, which turns out to be one of the major topics in the assistive smart kitchen research but was not expected in the data search process.



Figure 3. Word cloud representing the frequency of the words used in the titles of the analyzed publications

## 4.3 Countries or regions of authors

The countries or regions of the authors were counted. Authors who contributed to multiple articles were counted multiple times. It can be observed that Canada is the strongest country in terms of smart kitchen research, followed by the UK, Italy, Germany, Japan, USA, Greater China, India, Greece, and France. The top 10 countries on the list indicate a combination of advanced countries in gerontechnology and countries with great culinary cultures (Figure 4).



Figure 4. Countries or regions of the authors

#### 4.4 Years of publications

Figure 5 shows the number of analyzed publications per year in the past 10 years. The year 2023 was not included since only publications until August 2023 were available when performing the data search. There is a general upward trend in the number of publications each year in the past 10 years, which indicates that the topic of smart and assistive kitchen technology is gaining popularity.



Figure 5. Numbers of publications per year from 2013 to 2022

#### 4.5 Categories of study purposes

Regarding the functionality of the studies, the plurality of analyzed studies (n = 28) focus on human activity recognition in the home environment, including the kitchen. Such studies are often not about assistive kitchen technologies per se, but these endeavors provide unique insights into older adults' activities in the kitchen, which may serve as a guide for future research and development of assistive kitchen technology. The second largest category of studies is kitchen assistance, followed by safety monitoring, cooking instruction, and inclusive design. Only one study is about improving comfort level (i.e., room temperature) in the kitchen environment (Figure 6).



Figure 6. Categories of study purposes

## 4.6 Technologies applied

Based on the comprehensive analysis of the selected studies, the following categories of technologies were utilized:

- 1) Stationary / ambulant sensors
  - Cameras (e.g., RGB cameras, depth cameras, infrared cameras, etc.)
  - Audio sensors
  - Temperature sensors
  - Gas and smoke sensors
  - Vibration sensors
  - Load sensors
  - Wireless sensor nodes
- 2) Wearable sensors
  - Biometric sensors
  - Motion sensors
  - Smart glasses
- 3) Robotics
  - Mobile service robots
  - Robotic arms
  - Humanoid robots
- 4) Extended reality
  - Augmented reality
  - Mixed reality
- 5) Interactive user interface
  - Mobile apps
    - Websites
    - Physical buttons
    - Optical scanners
    - Ambient lighting
    - Smart speakers
- 6) Ergonomics
  - Inclusive design
  - Mechatronics

Many studies utilized more than one category of technologies. On top of these technologies, a majority of the selected studies were powered by AI solutions, including machine learning and neural networks, to realize the target smart functions (Figure 7).



Figure 7. Mapping the key featured technologies applied in the studies (created by MindMup 2)

## 4.7 Study design

In the total examined studies, 64 employed at least one study design with voluntary test participants, while 36 proposed systems were only tested by the authors and researchers with no test participants as end users (Figure 8). This is relevant because one of the main aims of this paper is to reveal research trends in smart assistive kitchen technologies rather than the soundness of these systems.



Figure 8. Percentage of publications with or without a study design

# 5 Discussion

In this section, the trends, challenges, and opportunities in Assistive and Robotic Kitchen Technologies for older adults and people with disabilities will be discussed, which answers the RQs of this literature review.

## 5.1 Trends

As defined in the inclusion and exclusion criteria, the target users of all selected studies included older adults, with the largest number of studies targeting older adults in general. Other noticeable target users include older adults who live alone, older adults with cognitive decline (e.g., dementia), and older adults with physical disabilities. In short, the vast majority of systems attempt to improve the quality of life for a wide variety of seniors by allowing them to use the kitchen and cook more independently.

A kitchen seems to be an ideal environment to create a dataset for machine learning of human activity recognition due to the complexity and uniqueness of human activities that occur in that space. A large number of studies focus on human activity recognition in kitchens, which may not directly assist older adults in cooking but will be helpful in understanding the behavior patterns of older adults in the kitchen and may serve as prerequisites to develop assistive products to help older adults cook.

Many studies focus on using external add-on technologies to assist existing kitchen facilities rather than redesigning and redeveloping kitchens to assist older adults, with a few exceptions.

Stationary sensors, which in some cases can be regarded as ambulant sensors (e.g., sensors embedded in wheelchairs and kitchen utensils), are the most commonly used technologies in the analyzed studies. They were chosen due to various reasons such as low cost and non-intrusiveness.

On the contrary, wearable sensors are only employed by a few studies (n = 3) due to their limitations, such as intrusiveness and limited battery life.

Robotics is another important technology that many studies employed (n = 13). Robotics has many advantages, such as good flexibility, high efficiency, and high mobility, but it also has obvious disadvantages, such as high complexity and high cost, which leads to a low level of willingness to adopt among older adults. In this study, those robotic solutions were only applied by authors from developed countries. However, it is foreseeable that as robotics becomes more widespread and the price of robots becomes more affordable, more assistive smart kitchens will integrate this technology.

Extended reality is also a promising category of assistive kitchen technologies (n = 4). However, it seems that only augmented reality and mixed reality are useful in the kitchen context. Virtual reality was not employed by any of the selected studies as its immersive experience isolates its users from the real environment.

Interactive user interfaces (e.g., graphical user interfaces, physical buttons, optical scanners, ambient lighting, etc.) are another noteworthy area of research because they are typically inexpensive, tangible, intuitive, highly versatile, and can be seamlessly embedded into inhabited environments, thus creating a technological environment that is appropriate for the characteristics of older adults.

The technologies proposed, especially in developing countries, are primarily focusing on practical solutions with local characteristics. Because cooking is a highly regional activity in different countries, many technologies developed may not be widely applicable or demanded in other countries, such as smart LPG cylinders for India and smart rice cookers for China.

## 5.2 Challenges

Reliability and usefulness: As mentioned in Section 4.7, less than two-thirds of the studies employed a study design with test participants. As a result, a major issue is that many proposed technologies were tested only by the authors or engineers, or in some cases by students or healthy volunteers, not by real target users of these studies who are older adults or people with disabilities. Therefore, the reliability and usefulness of these developed technologies for their actual target groups were largely unknown; thus, their acceptance could not be guaranteed.

Accuracy: The accuracy (i.e., the "intelligence") of many AI-powered monitoring systems needs to be improved. For example, the fire detection system proposed by Mukhiddinov et al. can sometimes falsely identify sunsets, sunshine, lighting, and electric lamps as fires [19].

Compatibility: In some cases, robotic solutions become highly complex and difficult to achieve due to their incompatibility with the environment and target objects. For example, in the study conducted by Odabasi et al. [20], the detection rate of the water bottles is low due to their transparency, which indicates that the concept of robot-oriented design (ROD) should be implemented already in the process of configuring the compliant environment to reduce the difficulties in robot development [21].

Usability: Ease of use is one of the most important attributes of these kitchen technologies for older adults. In many studies, older adults complained that the proposed technologies were too difficult to use. The simpler the operability of the proposed systems, the easier they will be accepted by older adults.

Affordability: Affordability is a main concern not only for emerging economies but also for developed countries as well. Therefore, improving the affordability of the technologies is another key to increasing user acceptance.

# 5.3 **Opportunities**

According to the findings of this literature review, some of the studies proposed adaptable designs, but they

were centered around cabinets rather than the cooking area. When people age, their physical characteristics will also undergo a series of changes, especially their height and posture. Some people may even rely on wheelchairs. Meanwhile, older adults and young people with different physical characteristics may share a kitchen. However, the ergonomics of these existing assistive kitchen designs optimized for the physical characteristics of older adults and individuals with disabilities and scenarios of kitchens shared by people with drastically different physical characteristics were seldom considered.

Therefore, modular smart kitchens that can be adapted to the physical characteristics of older adults and individuals with disabilities (e.g., people using wheelchairs) may be a promising future research direction. As a follow-up of this study, the authors aim to propose a modular adaptable kitchen to improve the quality of life for older adults and people with physical impairment.

The modular adaptable smart kitchen features key functions such as adaptable modular lifting cupboards, an interactive media center, ambient cueing signs, an Azure Kinect motion capture sensor, barrier-free lifting operating platform for cooking. A preliminary design of a modular and adaptable kitchen system is shown in Figure 9.



Figure 9. Preliminary design of the modular adaptable smart kitchen proposed by the authors' team

Currently, a low-fidelity prototype of the proposed kitchen is being built in the Architecture-Human Interaction System Lab at Keio University. Furthermore, approximately 10 student volunteers will be recruited from Keio University to carry out an initial usability test as a proof of concept. After the initial test, high-fidelity prototypes will be built and tested by more older adults in a real-world setting as a key step toward the marketization of the proposed modular and adaptable smart kitchen system.

# 5.4 Limitations of the study

There are several limitations in this study. The analyzed items are only in English, which is potentially biased against many studies in non-English-speaking countries. In the next step, research items in native languages in non-English speaking gerontechnological stronghold countries such as Italy, Germany, and Japan need to be further examined.

In this study, only research articles, rather than products on the market, are analyzed. Many research articles are experimental, and are far from marketization. Patents were not considered, either.

Also, the quality of the included studies is uneven because the sources are inclusive of journals, book chapters, and conferences, which, on the other hand indicates high timeliness and new trends.

In addition, due to page limitations, each reference to the included studies, as well as many details, cannot be fully revealed in this paper. However, an extended report of this research will soon be revealed in detail in an upcoming publication in a scholarly journal.

# 5.5 Conclusion

In this paper, a scoping review on assistive kitchen and cooking technologies for aging society in the past decade was performed following the PRISMA guideline. By analyzing the included publications, insights regarding the trends, challenges, and opportunities of these technologies were discussed. This work fills the scientific gap and lays the groundwork for future development of assistive kitchen technology. The paper will be a trusted reference for students, researchers, and practicing engineers who are interested in developing assistive kitchen and cooking technologies for vulnerable groups and beyond.

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