Assistive Cooking Technology and Needed Future System Components: An Overview

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***Abstract* — This paper provides an overview of the state-of-the-art in cooking robots. The goal is to provide the context and background of how assistive robots can provide help to people with disabilities in preparing meals. In addition to presenting various current techniques, the paper covers and analyzes the trends, capabilities, and patterns that have appeared. At the same time, this paper identifies malpractices and outdated concepts that may help reshape the current progression path of this field. The paper examines cooking systems and their outdated and exclusive modalities as well as the components that would help the user benefit extensively to create a system that was all-encompassing as possible. The study also identifies the growing population of elderly people in the world population, and with that, a growing need for caregivers and assistance in homes. It also highlights the awareness of the barriers faced by people with disabilities -and demonstrates how their lives could benefit from the popularization and mainstream production of cooking assistive technologies. One of the salient conclusions is that research in assistive technology is imperative for household chores, such as cooking, to relieve the strain on people with disabilities, including the elderly, to ensure independence in the home with the benefit of aid. The paper also describes additional avenues of research in this area and sheds some light on what the future of assistive cooking robots may entail.**

***Keywords*— cooking, robot, assistive technology, differently-abled independence, assistive meal prep, recipe planning methodologies, motion planning methodologies**

I. Introduction

Aging, a disease that whittles the fortunate, is considered one of the most prominent conditions due to the ever-growing restrictions and limitations of performing specific activities that only increase with age. According to the UN, the percentage of the global population aged 60 years or older rose from 8.5 percent in 1980 to 12.3 percent in 2015, with that number projected to rise past 21.5 percent by 2050, which can be seen in Fig. 1 [1]. With the population of older adults growing exponentially, the demand for assistive robots has progressed alongside it. As a new wave of older adults starts shying away from nursing homes, studies have increased to create robots with specific parameters to operate within the average household. As of now, there are eight main obstacles to face for those who want to age in place or suffer from disabilities: social isolation, dependent living, physical or cognitive impairment, mobility problems, inadequate health monitoring, lack of recreation, reminding problems, and fall problems [2].

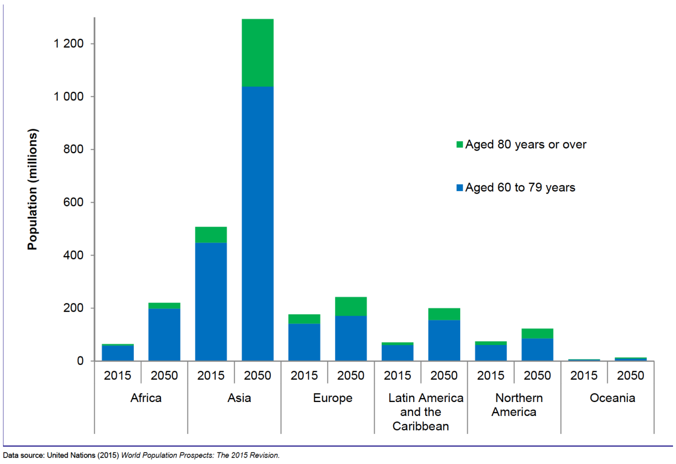

Fig. 1 A simple bar graph showing the population of older persons, estimated for 2015 and projected for 2050 [1].

II. Cooking robot systems

Currently, there is a wide range of cooking robots that have been produced, with a few explicitly made with disabilities in mind. However, generally, these assistive machines are made to support one type of disability only. By broadening the capabilities of these current systems through analysis and modification, it could allow a single device to be mass manufactured and used by most types of differently-abled people.

A. Robots for Elders - China

In China, a complete kitchen robot was previously made for people with disabilities that had the following four main functions: automatic loading of ingredients, automatic cooking, automatic sending of dishes, and self-cleaning [3]. In addition to automatic loading, ingredients are also delivered pre-portioned and pre-cut in a box component to lessen the strain on the cooking process. When the customer wants a specific meal, the following will run: A telescope and RFID transceiver will read an RFID tag to determine whether the components for that meal are present, available, and within the specific ingredients expiration date. The grabbing manipulator loads the ingredients into the cooking modulate after its prep. Sadly, this article never specified any information pertaining to its automated cooking; however, it can perform basic Chinese cooking techniques (such as the toss, stir, and flip), automatically put raw ingredients into the wok, and cook the food equally.

Fig. 2 A picture of the chinese cooking robot for elders [3].

The robot can cook over three hundred Chinese dishes “typical for the aged” [3], giving users familiarity and comfort with their meals. To automatically deliver cooked dishes, a rotary table is attached to the robot. This table is raised and can hold multiple dishes simultaneously without causing extra strains on the user by allowing rotation through a centrifugal motor. After the cooking process is complete, the robot will then begin the automatic cleaning process. The wok, the stirring tool, the wok cover, and the sink will all clean themselves. For a robot to perform these tasks, it needs plenty of space to do so. One of the major cons to this system is its overwhelming size. The dimensions of the robot, excluding the fume treatment module and the touch screen system, are 2.295 m (length), 0.770 m (width), and 2.000 m (height) [3]. For someone with a smaller kitchen or a larger wheelchair, the robot’s size can create mobility issues for the user. In the conclusion of their article, the author states that its size was too cumbersome for most kitchens.

The abilities of this cooking robot are essential for people with disabilities but allow very little independence in the cooking process. For older adults who prefer to age in place, independence is essential, and customization in the amount of help the robot provides is vital to allow accessibility for people with all ranges of disabilities [4].

B. Augmented Reality Supported Induction Cooker

In Switzerland, an AR-Supported induction (AR-SI) cooker prototype has been created to aid the user within the cooking process while still allowing independence [5]. The AR-SI cooker promotes healthier gastronomy by creating and assisting the user with a simplified, healthy recipe. It provides three main advantages: helping regular people who lack culinary skills to make a meal quickly, training cooking candidates within a culinary school, and upgrading AR-SI into a food robot by enriching the solution with automatic cutting and stirring systems. A virtual assistant is built on AR with AR support to give detailed steps and instructions on following the recipe step by step. It also takes into account weight control and presents a 3D visualization of the cooker and pan. This assistance can help people with minor disabilities with the cooking process by leading the user while still allowing the satisfaction of creating their meal.

The AR-SI cooker has a primary weight sensor and monitors the ingredients' weight to ensure each ingredient is appropriately proportioned. With the use of the weight sensor, users can cut down on food waste, know the exact measurements needed, and modify the number of meals on a day-to-day basis. The AR-SI relies on induction technology to provide energy efficiency, hygienic cooking, which is safer to use and leads to less heat propagation in closed environments. The invention of this cooker assisted in promoting accessible and efficient healthy eating. It stores data like nutrition information through an IoT (Internet of Things) network. Due to this, it can keep up with data like consumed power, food temperature, and food amount. The cooker can adapt to the weight of the ingredients and adjust the power as the weight decreases. If the weight decreases, the power is reduced and prevents additional energy consumption. The authors of this article conclude that their prototype of the AR-SI is only just a preliminary step; however, with time, the integration with food robots by adding automatic cutting systems will allow for even more efficient systems.

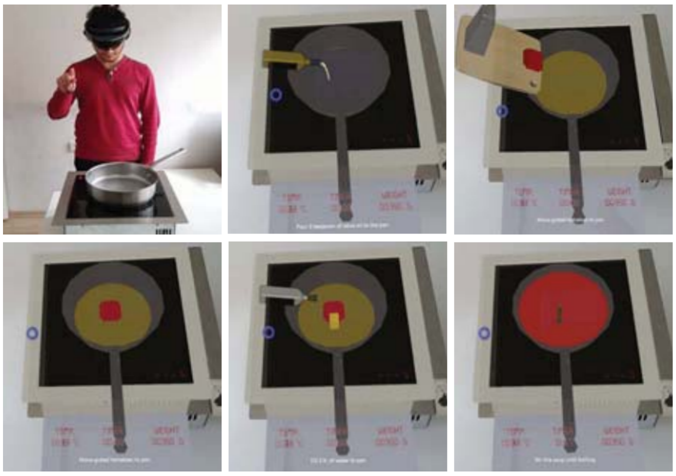

Fig. 3 A collage of pictures demonstrating the process of cooking tomato soup by AR-SI cooker [5].

C. RAMCIP: Advanced Social Robot for Elderly People

The EU funded RAMCIP project, targets and combats the increasing need for elderly care services at home [6]. The creation of the RAMCIP robot or Robotic Assistant for patients with Mild Cognitive Impairments resulted from this initiative to share responsibilities with human caregivers. The project focused mainly on developing high-level cognitive functions to enable proactive robotic behavior. RAMCIP was not made with only the ability to cook in mind; it can support assistance provision for daily activities, including cooking, eating, medication supply, and securing safe handovers. Researchers also developed methods for unobtrusive human activity recognition to identify intricate human actions and the behavior of multiple personals within the user's home. The resulting conclusions of this method aid the robot's performance in cooking, housekeeping, detecting forgotten actions by the user, and emergencies such as falls. Users can effectively communicate with the system through an interactable touchscreen, speech, and gestural modalities. The assistive robot can also fetch and grasp an assortment of objects that cannot be reached by the user safely, from small items to dishes and cooking utensils. RAMCIP can interact with other home environments such as doors, light switches, and ovens. Live demonstrations of RAMCIP continue while looking into ways to commercialize the service robot. Project Coordinator Dimitrios Tzovaras stated that this project helps reduce the dependence on a human caregiver for elders and time spent in hospitals and institutionalization. Although RAMCIP is not primarily considered a cooking robot, its versatility through a combination of methods to assist is vital to allow relief and service for a wide range of disabilities.

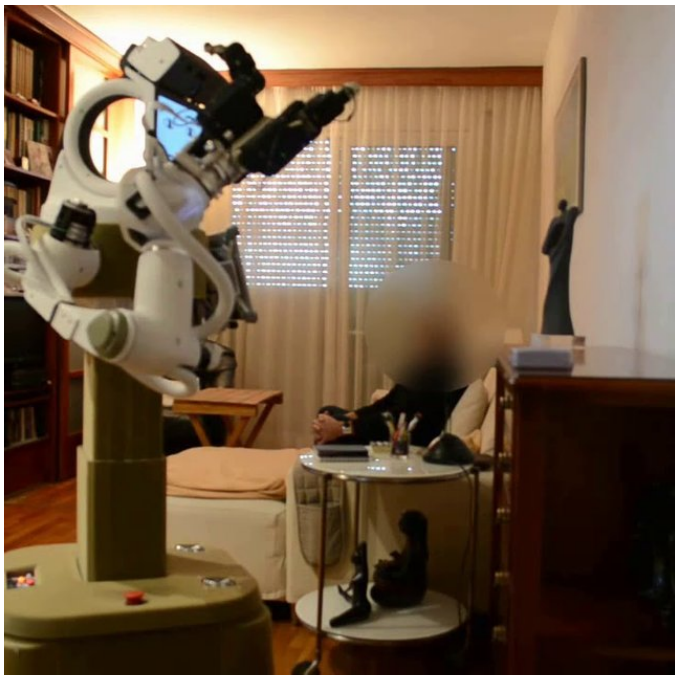

Fig. 4 A picture of the RAMCIP robot. User’s face was blurred for privacy reasons [7].

III. Components to the systems

After analyzing the previously mentioned robots, the following section pertains to different components of a “perfect” cooking system.

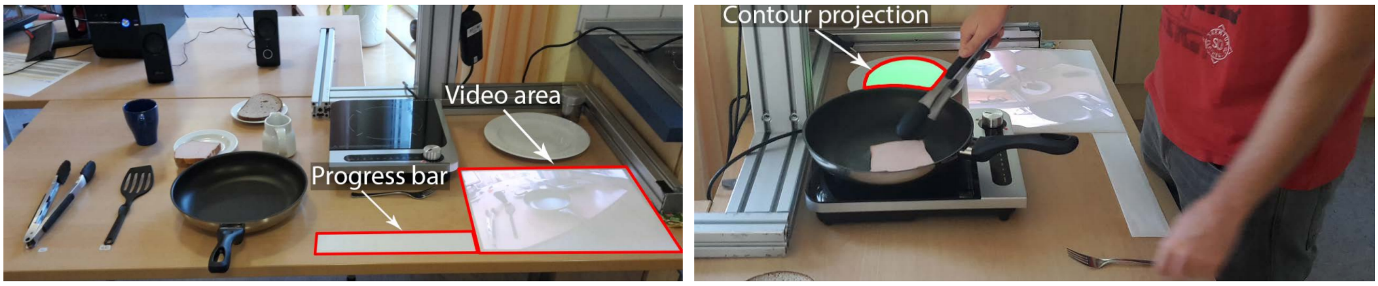

Figure 5. A picture of the visual output modalities of the cooking instruction system [14]

A. Interface

Most robots can now function to the point of autonomy due to their "integrating, perception, action, planning, and learning capabilities" [8]. One issue that is still apparent is their inability to explain or demonstrate their internal process. Researchers from Carnegie Mellon University "propose a three-layered model to represent robot experience which doubles as a retrievable episodic memory."
This episodic memory functions as an internal memory bank, allowing the robot to give the same narration if unchanged parameters. A learning algorithm stores information and recalls the necessary parts to fit the user's specifications. This verbalization system is limited to the current task but can include higher-level thinking if required, such as grasping the tool most effectively to execute the task. The researchers hope to add a neural network to the verbalization system to automatically analyze conversations between the robot and user, allowing the robot to modify its speech syntax to fit the user's qualifications. Additionally, they hope to conceive a learning algorithm that intakes a natural language corpus to refine the current verbalization models to sound more natural and have more range and options for the verbal specifications.

By effectively narrating the steps taken, users could build more trust in intelligent systems, allowing them to sneak peek into the overall system's thought and action processing [9]. In doing so, patients who work alongside it can practice their dictation, memory retention, and active listening skills. The process could significantly help patients with cognitive issues, such as dementia or Alzheimer's. For those who may not need constant caretaker, sometimes the elderly are often left unaccompanied for times, especially if they are within the lower economic brackets. Adding a verbalization system can help simulate conversing, which could lead to lower depression and loneliness, drastically altering the user's health for the better [10]. Additionally, the robot could potentially be modified in time to be multipurpose by utilizing the builtin speakers and microphone to access commercially used communication software to broaden the users point of contact.[1]
Currently, approximately 20 percent of the world population is affected by cognitive deficiency [11]. Deficiencies can cause difficulties in learning, remembering information, and decision-making due to genetic conditions, injuries, or age-related effects [12]. The "United Nations Convention on the Rights of Persons with Disabilities" expresses that the fundamental human rights of people with cognitive disabilities need preserving, and that includes their right to independent living [13]. Living facilities have started to foster and train independent living skills to protect those rights, including cooking. A study compared the time it took for cognitively impaired users to prepare a meal and their cooking performances between regular caretaker assistance and in-situ assistance. Caretaker assistance was strictly auditory. The in-situ assistance included auditory instructions, looped videos with how to complete each recipe task, and contour projections displayed on or around objects of interest in the current cooking step [14], visible in Fig. 5. Additionally, a progress bar is made available by projecting the overlay onto

[1] Examples of this would be using Zoom to host doctorate check-ups or lead the user through simple physical therapy exercises.

the hot plate. After a two-week-long trial, the study measured longer meal preparation times using in-situ assistance compared to caretaker assistance. However, the cooking times with the caretaker assistance in the second week using the same recipe improved significantly after employing in-situ assistance the week before. With typical cooking instructions lacking multi-sensory use, visual feedback generated by in-situ assistance seemed to complement the cognitive processing of instructions, proving that simultaneous feedback from a robot can assist users greatly during the cooking process.

B. Mechanics

Even though the number of cooking robots has exponentially increased in the past few years, they still must be programmed beforehand with a set number of recipes. These recipes often take a considerable amount of effort, time, dedication, and resources to code. To counteract this issue, Masahiro Inagawa, Toshinobu Takei, and Etsujiro Imanishi have developed a recipe analysis program that can effectively analyze recipes online and then convert them into data for automated cooking. The program will not only be able to devise the ingredient and cooking specifications, but it will also be able to interpret and analyze the text for clues on how to motion plan the entire procedure. By separating recipe data and motion code from the recipe, it allows the system to more effectively break down the collected metadata and allow for better procedural generation within the robots-assisted simulation program, which tests the likelihood of success beforehand and then sends the approved instructions to the physical copy, after some minor modifications if necessary, as shown in Fig. 6 [15].

What truly is exemplary about this algorithm is its capability to analyze different Japanese dialects and syntax and still manage to interpret most of the recipe (Japanese frequently have different verbs that mean the same or different things based entirely on the word's context). The overall process starts from first obtaining the input recipe online, applying the data format to the recipe, converting it to recipe data, extracting motion code, sort the motion code, plan robot motion, pseudo-execution code, modify the simulation a bit, output the operation code, then finally, the robot is now able to execute the recipe. The result was a 50% success rate on 50 randomly chosen recipes, with most errors that it ran into due to the recipe's textual content (40%) and lack of content in the database (33%). "Nearly 70% of the failures were due to a lack of unique expressions and proper nouns in the database" [15].

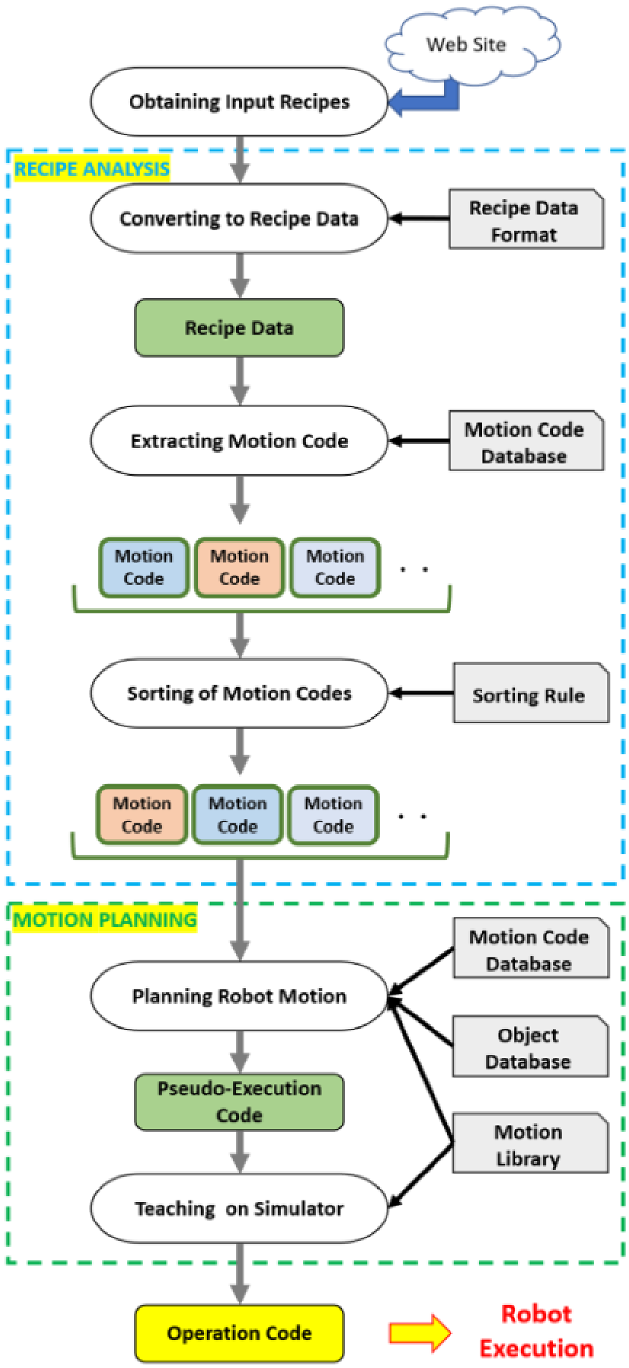

Fig. 6 A picture of the automated conversion process of natural language recipes to recipe data and motion planning [15].

For recipes to be effectively followed and meals made without mistake, it is crucial for the audio-visual scene understanding of the autonomous assistive technology to be implemented with scene understanding capabilities. “Scene understanding is defined by extracting six-W information such as What, When, Where, Who, Why, and hoW on the surrounding environment” [16]. The most important and demanding to extract of the six-Ws is “how.” Researchers from Tokyo extracts “how” from a cooking scene by breaking down the process into two different modules: the first recognizes actions, such as “sliced bread,” and the second module extracts and plans a motion map based on the first layer of action. These two factors are considered as “Audio-visual multimodal recognition & Utilizing cooking knowledge from websites.”

TABLE I[2]
RECIPE : STIR-FRIED VEGETABLE

Category	Stir-fried Vegetable
Ingredients	pork, onion, cabbage, green-pepper
Step	
1	Cut cabbage, carrot, and green-pepper into bite-sized pieces.Season the pork with pepper and cut it.
2	Put the oil in a wok and stir-fry the ingredients for a few minutes. Serve.

The most common method to collect and analyze visual data is through cameras, but often leaves the robot lacking required information due to dead angles and object-passing in front of the camera. Due to this, the robot must intake audio-based information as well to compensate. However, due to the noisy nature of a kitchen and its tools, special cooking devices with separate built-in mics must be used, giving the system multiple audio mapping of the same cooking scene. For the visual scene to be understood, a convolution neural network (CNN) approach provides the system necessary occlusion-robustness. “A CNN is a Deep Learning algorithm which can take in an input image, assign importance (learnable weights and biases) to various aspects/objects in the image and be able to differentiate one from the other” [17]. The system’s action mapping is acquired from cooking recipe sites and then utilized after converting from natural language to a graph data structure, which has been pre-proposed in previous studies [18, 19]. The graph data structure is then converted into a Hierarchical Hidden Markov Model, “which is a probabilistic model to deal with sequential data such as the cooking process” [20].

C. Customer Customization

For a robot to be most effective in working with a person with disabilities, it needs to be explicitly tailored to the user. The chance for users to customize their machine can help broaden the range of disabilities the machine can accommodate. Not only does the robot need to be able to assist the user's needs, but it also needs to allow adjustment to the user's wants and tastes.

As previously mentioned, automation in the food industry is a rapidly growing field. Industry cooking robots and personalized kitchen robots focus on very different things. The goal is to have faster, more reliable, and cheaper ways of producing food in the industry. In a home kitchen, robots are expected to be adaptable to cook multiple recipes and adapt to the user’s subjective preferences. Researchers from the University of Cambridge investigated algorithms for optimizing food quality measures like taste, appearance, and texture in preparing an omelet; beginning from an uncracked egg to plating the omelet. They ran an experiment and used both batch and sequential Bayesian optimization and used four volunteers to rate the robot-made omelet on a scale from 1 to 10 on flavor, appearance, and texture. Based on the rankings, the robot changed different variables like whisking, salt, cook time, mixing, and pepper. The results indicated that this methodology could obtain quantifiable improvements for food optimization [21].

The aforementioned Chinese cooking robot [3] introduces the idea of pairing a cooking robot with a food delivery system. The researcher’s idea is to create their own delivery company with digital recipe couriers to bring pre-portioned and pre-cut ingredients and recyclable dishes. The couriers would arrive at the user’s home, empty the bin with

[2] Table example was provided by source [16]. This table represents the use of both Audio-Visual Multimodal Recognition (the listed category & ingredients) and Utilizing Cooking Knowledge From Websites (the generated steps/procedure).

used ingredients and dishes, and load the user's refrigerator with new ingredient boxes. This process can guarantee food hygiene with fresh ingredients and reduce the cost of those ingredients with no waste involved from the portioning. Cleaning up after preparing a meal can be more complicated than cooking, which would require disposable plates and utensils, as well as a nonstick pan. The current system suggests creating a specific company just for delivering, as it is a vital improvement in preparing a meal and cleaning up after it. Due to technological innovation since 2011, this technique can be simplified by attaching the robot's capabilities with an existing food delivery service.

In Sweden, research took place to document data consisting of video recordings that observed senior volunteers following recipes they chose themselves. Visual content analysis methods guided the analysis of the videos to identify the immediate help needed in the kitchen. The main focus of the research was on the following three tasks: physical manipulation, organization and coordination, and reorchestration and reorganization [22]. After analyzing the data, analysts designed relief for operational assistance to support practical operations of manipulating tools to complete actions in the kitchen and organizational assistance to help progression towards achieving the art of cooking. The critical role for operational assistance is a system that can secure or stabilize items across the work surface to allow full use of dexterity. For example, having a bowl or cutting board secured enables the user to both hands during actions like stirring or cutting ingredients.

Additionally, to encourage active and prosperous aging, adapting and coping to age-related changes is critical. Sensors that can keep track of kitchen items and tools are encouraged so that the system can provide support in maintenance, availability, and selection of tools in a way that reinforces the user's skills and competencies. This assistance can aid in organizational assistance as well. During the cooking process, users must keep up with a multitude of steps and items. Designing organizational assistance to keep track of locations of relevant objects and their movements during the process can optimize the simultaneous progression of different tasks and minimize movement in the kitchen space. Cooking skills were central to older adults' ability to live independently and contribute to successful and active aging.

IV. Future Analysis

As discussed before, there are eight main problem areas for those with disabilities; social isolation, dependent living, physical or cognitive impairment, mobility problems, inadequate health monitoring, lack of recreation, reminding problems, and fall problems [2]. Current robots that address disabilities have little overlap regarding specific functions to help relieve these problems. In the future, the goal would be to combine systems with helping relieve obstacles for people with disabilities. This combination could help reduce cost as well as space taken. In a state of the art of robotic technology to help older people, researchers concluded that two problem areas that were the least researched were social isolation and lack of recreation [2, 10]. The robot's collaboration will have to do with the severity of the users' disability. However, a cooking robot with an interface to interact with the user can help with social isolation and have a cooking activity to provide a recreational activity. The interaction between cooking with the robot can build the confidence of the users' mobility and bring satisfaction in completing a task with the help of the robot [4, 10]. Due to mistrust of technology, it is imperative that future robots, especially older adults, have attributes that are proven to be trustworthy [9]. Researchers observed that older people responded more positively to life-simulation features, eye contact, robot personalization, and obeying commands, all undervalued elements by roboticists [23].

Another important focus for the future of assistive cooking technology is that it is necessary to become accessible to all, not just price, but its capabilities to work with a wide range of disabilities. It is vital for future systems to be easily serviceable with a dedicated team of appropriately trained customer support to deal with all disabilities in the case of a system malfunction, which could leave users meal-less. Other factors worth adding are interaction assistance, calling life alert if the system's camera and audio sensor detect a fall, visual guidance for the visually impaired through the system's camera and speech interface, adding multi-leveled communication for multi-impaired users (using a combination of lights, sounds, and vibrations to communicate instructions), a reminder system for medicinal purposes (such as future appointments or even medication times), and a viable communication system that would allow users to dial emergency services quickly.

With time, commercial applications/services can be adjusted and added to be more inclusive towards differently-abled usability: such as access to Skype or Facebook Portal to easily connect with family and friends, adding a workout or physical therapy programs (that could be one on one or prerecorded) to lead the user through mobility stretches, and/or a delivery service similar to the one produced by the Chinese cooking robot. Like the aforementioned service, the goal is to connect the system to current companies like HelloFresh, Instacart, and Doordash to offer pre-packaged grocery delivery. The delivery service from the Chinese cooking robot has proven to reduce the tasks the robot system and the user has to perform by pre-portioning and pre-cutting ingredients while giving the user the ability to handpick one's meals.

V. Conclusions

This paper presented a multitude of approaches to automated cooking systems, with a heavy focus on making the system more modular, customizable, easily serviceable, small in dimension, and usable by a wide range of differently-abled users by increasing the number of users' communication components. Another heavy focus of the paper was identifying the ever-growing population of people with disabilities, age included, and the importance of cooking robots used to aid people with disabilities while still giving users independence. This review established the critical details of the machines and pointed out both flaws and "usable" components. While research for cooking technology has helped people, there is plenty of room for improvement. Future systems should embody the aforementioned traits while maintaining an affordable price.

"Start by doing what's necessary; then do what's possible; and suddenly you are doing the impossible." - Francis of Assisi

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