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A Chinese cooking robot for elderly and disabled people

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Cooking themselves is very important and difficult for elderly and disabled people in daily life. This paper presents a cooking robot for those people who are confined to wheelchairs. The robot can automatically load ingredients, cook Chinese dishes, take cooked foods out, deliver dishes to the table, self-clean, collect used ingredient box components, and so on. Its structure and interface is designed based on the barrier-free design principles. Elderly and disabled people can only click one button in the friendly Graphic User Interface of a Personal Digital Assistant (PDA) to launch the cooking processes, and several classic Chinese dishes would be placed in front of them one after another within few minutes. Experiments show that the robot can meet their special needs, and the involved aid activities are easy and effective for elderly and disabled people.

KEYWORDS: Cooking robot; Chinese dishes; Elderly and disabled people; Barrier-free design.

1. Introduction

The proportion of aged people is growing rapidly throughout the world. It has been predicted that in United States, population of people over the age of 65 years is going to reach 20% of its population by 2030.[1] In China, between 2010 and 2040, the proportion of people aged 65 years and older will rise from 7% to 25%.[2–3]

Aging is considered to be a disability to the extent that it causes limitations in performance of activities.[4] Surveys[5–7] have shown that older adults have difficulty in performing one or more common self-care activities such as eating, dressing, bathing, or preparing meals in the kitchen. Other activities, such as stooping, crouching or kneeling, lifting or carrying 25 pounds (11.35 kg), etc., have been found to be difficult tasks for older adults.[8–10]

The increasing number of elderly people has resulted in increased demand for new solutions to support self-initiative and independent life. In recent decades, and still continuing, the research and development of service robots for the disabled and limited has become an active field, and is performed in many countries around the world.[11] Robotic Walkers[12] and robotic wheelchairs[13] are for mobility aids, and manipulation aids are applied to assist disabled users in eating, drinking, or object replacement.[14] Makin *et al.*[15] introduced Handy 1, the robotic aid to eating, which was developed to provide increased independence for the disabled during mealtimes. Yamamoto *et al.*[16] proposed a robotic aid system for the disabled, in which the robot could speak with operator and could use image processing function to know position and posture of dishes and target objects. Matsukuma *et al.*[17] developed an autonomous mobile robot for carrying food trays to the aged and disabled, to deliver meals on food trays, and to collect trays in healthcare and welfare facilities; this type of robots could help to reduce the shortage of healthcare resources. Though these robots and automatic systems did not focus directly on cooking, they were very important because they had carefully considered the special needs of the disabled and limited. If the disabled and the limited cooperate with the cooking robot, they could be taken care in a far better way.

On the other hand, the research on the cooking robots has also become a hot field. Scientists have separately presented many kinds of cooking robots and automatic systems. Fukuda *et al.*[18] presented a visual recognition expert system for cooking robots. Davidson *et al.*[19] developed a fuzzy control system for continuous cross-flow peanut roasting. Taki *et al.*[20] proposed a method to translate cooking works into cooking robot recipe for a robot system. Muthu *et al.*[21] introduced the autonomous CHEF-BOT that could cook south Indian dishes in a fully automatic fashion; the researchers believe that cooking robots are going to revolutionize our kitchens. Cooking supporting or cooperating systems have been also explored. Fukuda *et al.*[22] developed a cooking support robot, which suggested by voice and gesture what the human should do next. Gravot *et al.*[23] proposed a humanoid robot to cooperate with the user for cooking simple dishes. Kazuhiro *et al.*[24] presented a dish-handling robot system for a washer developed for a professional use. Since Chinese cooking in many ways is similar to Japanese cooking, the researches of Japanese scientists have been very helpful to develop Chinese cooking robots. For instance, Yan *et al.*[25] were first to propose the Chinese cooking robot, which had realized the basic Chinese cooking techniques and independent cooking.[25] Although these robots and systems were designed to cook or support cooking, they were not particularly designed for elderly and disabled people. Elderly and disabled people need special nutrition selections and the dishes should be designed and prepared differently. Therefore, it is very important that

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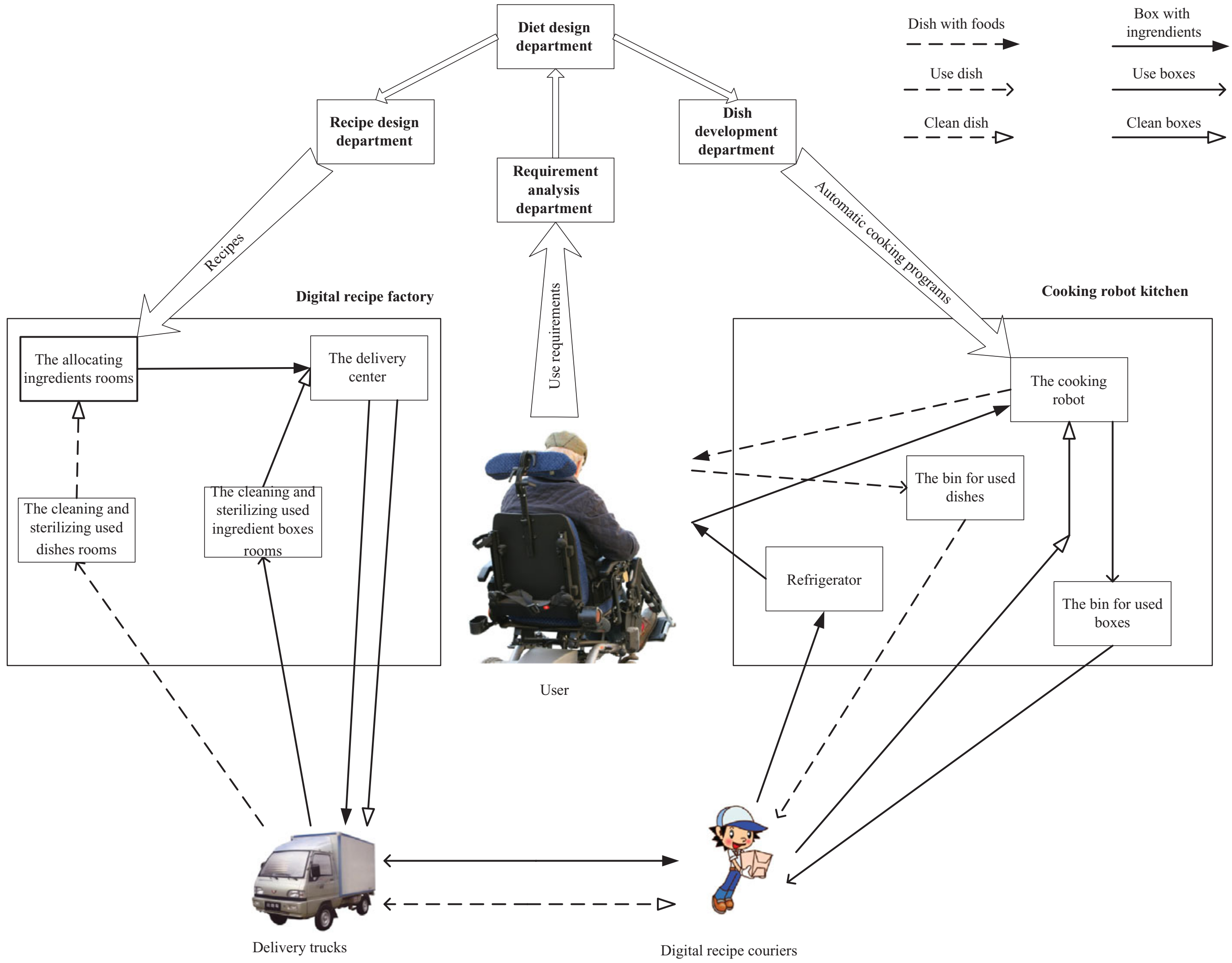

Fig. 1. The user-centric cooking solutions for elderly and disabled people.

elderly and disabled people should be able to operate the cooking robot easily.

Current practice considers older or disabled people as a special group set apart from the rest of the society. As such, demands are placed on the designers to produce special designs for this group.[26] This paper presents a cooking robot for elderly and disabled people to be used in their homes based on barrier-free design principles and human factors. People with plastered legs are generally confined to wheelchairs and usually it is difficult to prepare ingredients by themselves, hence ingredients have to be prefabricated.

When considering the methods of prefabrication, we found the cooking robot had better not prepare ingredients by itself. Otherwise, it would be a terrible problem to maintain hygienic norms, and the cost would be too high to be borne by normal families. However, if we build a supply chain to prepare and deliver ingredients, food hygiene could be guaranteed and the cost would be reduced greatly. As it is tiring and complicated to cook, the cooking robot should be operated easily and cooking should be completely automatically. Elderly people should also avoid to clean dishes and woks because cleaning is a very difficult task for them. Hence, a package of user-centric solutions should be considered.

2. The Cooking Solutions for Elderly and Disabled People

Though a ready food service, such as a fast-food service, seems to be cheap, it is not very good for elderly and disabled people in China. Chinese dishes would better be eaten as soon as possible after cooking and most Chinese dishes would look terrible and taste bad when packed and delivered. It is more important that elderly and disabled people should be specially considered. Their dishes should be designed and prepared differently according to their health needs.

Where do the ingredients come from? Who and how clean are the used dishes? It needs a series of solutions instead of a robot alone. The user-centric solutions presented in this paper are shown in Fig. 1. Firstly, the Requirement analysis department will collect and analyze information about those special users. As the result of analysis, nutrition requirement reports will be sent to the Diet design department. In the diet design department, balanced and healthy diets will be designed for different users. If new dishes are listed in the

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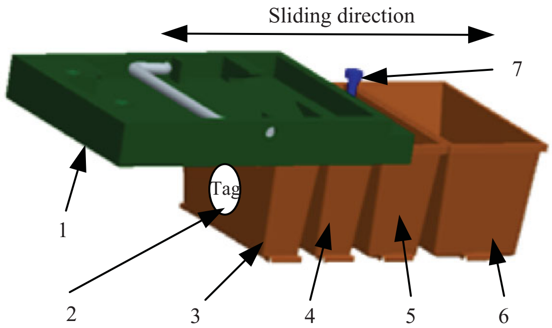

Fig. 2. The 3D model of ingredient box component. 1. The box cover. 2. The RFID tag. 3. Box No. 1. 4. Box No. 2. 5. Box No. 3. 6. Box No. 4. 7. The pin.

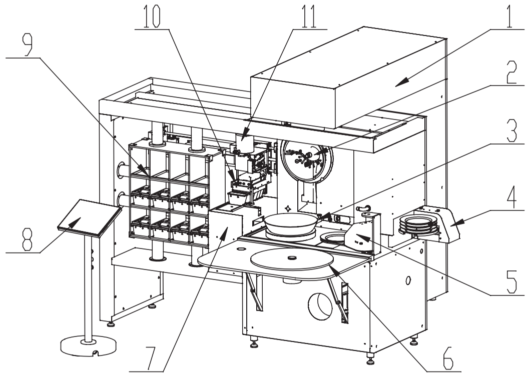

Fig. 3. The structure of Chinese cooking robot for elderly and disabled people. 1. The fume treatment module. 2. The stirring and dispersing module. 3. The wok movement module. 4. The containing dishes module. 5. The delivering dishes module. 6. The rotary table. 7. The feeding ingredients module. 8. The touch-screen system. 9. The ingredient box storage. 10. The loading ingredient boxes module. 11. The feeding water–starch module.

diet tables, the Dish development department will develop automatic cooking programs of these dishes, and these new cooking programs will be uploaded to cooking robots. At the same time, the Recipe design development will design new recipes for these dishes, and the new recipes will be sent to Digital recipe factories (DRFs).

A DRF consists of cleaning and sterilizing used dishes rooms, cleaning and sterilizing used ingredient boxes rooms, allocating ingredients rooms and a delivery center (DC). In accordance with the standards of dish prefabrication, materials will be cleaned and cut, and some of them will be mixed, prepared and shaped. The ingredients of a dish will be allocated proportionally in a special box component (see Fig. 2) for delivering. These standardized dishes (over 300), in each box component, can contain at least 500 g of material. Digital recipe couriers (DRCs) will send ingredient box components and put them into users' refrigerators.

Just before cooking, the user should take out box components from the refrigerator and locate them into the robot. During cooking, if all ingredients in the boxes have been put into the wok, the robot will grasp the box component and put it into a bin for recycling. The bin is normal, but it should be big enough and can be moved easily. After meal, the user should put used dishes into another bin for recycling. This bin is a normal one but should be big enough to carry recycling material. The bins full of used ingredient boxes and dishes will be brought to the DRF by DRCs. In the DRF, firstly the bins, the box components and the dishes will be cleaned and sterilized. Then the clean box components will be transmitted to the allocating rooms and bins and dishes will be transmitted to the DC. DRCs will deliver the bins, the box components filled with ingredients and the cleaned dishes from DC to users. They will also put the cleaned dishes into the robots. The dishes used by robots are special, and can be obtained from most of supermarkets.

3. The Structure of the Cooking Robot

The structure of Chinese cooking robot for elderly and disabled people is shown in Fig. 3. The loading ingredient boxes module will search the ingredient box storage, grasp and transmit the box component, and locate the box component in the box frame of the feeding ingredients module. The wok movement module, the feeding ingredients module, the feeding water–starch module, the stirring and dispersing module, and the fire control module (it is not marked in Fig. 3) will cooperate to realize the function of automatic cooking. The containing dishes module, the delivering dishes module, and the wok movement module will cooperate to realize the function of automatic taking out cooked food. The delivering dishes module and the rotary table will realize the function of automatic dish delivering. The touch-screen system has the interface of human–computer interaction, and it can organize other modules and dispatch tasks through CAN-bus. The fume treatment module is optional. The overall 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).

As a kitchen facility for special people, the cooking robot should comply with the existing standards. In China the standard is JGL 50-2001,[27] which stipulates that the height between the cabinet's top and the floor should be less than 1.4 m, the height of cabinet itself should be less 0.8 m, and its depth should be less 0.3 m. The standard also stipulates that the height of work-face should be between 0.9 m and 1.1 m. It further stipulates the parameters of table: its height should be 0.7–0.8 m and width over 0.45 m.

Just as cabinet, the ingredient box storage is of three levels (see Fig. 1). Each level has four cells and each cell can only contain a box component. The height of the storage is 0.685 m (less than 0.8 m), and the height between its top and floor is 1.387 m (less than 1.4 m). The cell's depth is 0.23 m (less than 0.3 m). The height of middle level is between 0.925 m and 1.15 m, and the box component could be raised over 0.935 m (between 0.9 m and 1.1 m) to put into the storage. Usually, a normal Chinese family (with 3–5 people) needs four dishes (or three dishes and one soup) in every meal. Therefore, the middle level of storage can meet the needs of most of the families. More levels could be used in situations with more people, for example, a party consisting of older people.

The rotary table's height is 0.8 m, length is 1.1 m, and width 0.75 m (over 0.45 m). The touch-screen's locating height and angle of view are tunable and can adapt to different users.

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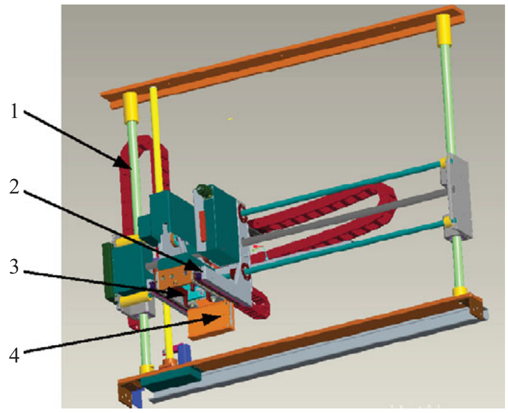

Fig. 4. The 3D model of the loading ingredient boxes module. 1. X–Y table. 2. The telescopic boom. 3. The grabbing manipulator. 4. RFID transceiver.

4. Key Functions

Cooking is not only physical but also mental, so it is tiring and complicated to the aged. In order to achieve a high degree of automation, release the aged from tiring functions, and make working limited as much as possible, the robot supports four key functions: automatic loading ingredients, automatic cooking, automatic sending dishes, and self-cleaning.

4.1. Automatic loading ingredients

Recently, technological advancements, such as the development and widespread use of wireless LAN (WLAN), ultrasound, and Radio Frequency Identification (RFID), have spurred various ideas and innovations to be applied on daily living.[28] RFID and WLAN are also used in robots. A RFID tag is pasted on Box No. 1 (see Fig. 2). Before the box components leave the DC, information will be written into the RFID tags. The information contains the dish ID, shelf life, production time (accurate up to minutes), the box component ID, and a sign to mark that the box component is permitted for cooking. A box component is composed of four boxes and a cover. The cover has two slide-ways. The boxes can slide in slide-ways in the direction as marked in Fig. 2. The boxes will depart from the cover if they slide out of the slide-ways. After all four boxes are covered and the pin is pushed down, the box component will be locked and boxes can't slide any more. The robot can push down and poll up the pin at right time. During transmitting and delivering, the box component is locked, but during cooking the pin will be polled up and the boxes can slide free.

The function of automatic loading of ingredients is mainly achieved by the loading ingredient boxes module. It is composed of the X–Y table, the telescopic boom, the grabbing manipulator, and the RFID transceiver (see Fig. 4). Before cooking, the user needs to take box components from the refrigerator and put them into the ingredient box storage. Poka-yoke designs are used in the ingredient box storage to proof mistakes. A box component can't be placed in a wrong position or with a wrong direction. Each cell in the storage corresponds with the coordinates of X–Y table. Firstly, the grabbing manipulator moves to certain cell's coordinates and then stretches the telescopic boom. At the same time, the RFID transceiver closes with the RFID tag and reads the information mentioned therein. If the information shows the box component is permitted for cooking and is not out of date, the grabbing manipulator will grasp the box component, transmit, and locate it to the box frame of the feeding ingredients module and poll up the pin. Otherwise, the robot will search left cells. After cooking, the mark "Already used" will be written on the RFID tag, and the used box component will be sent to the bin for recycling. The process of automatic loading of ingredients is shown in Fig. 5.

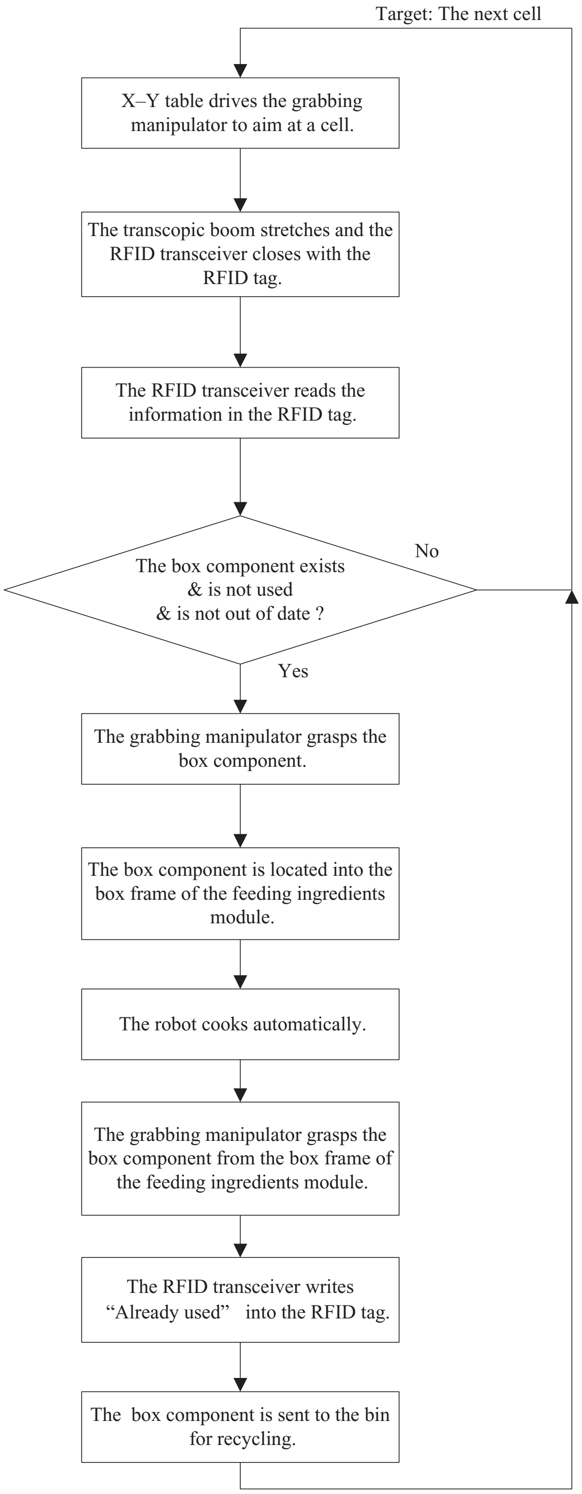

Fig. 5. The processes of automatic loading ingredients.

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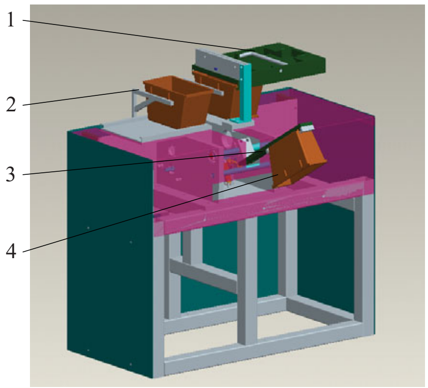

Fig. 6. The 3D model of the feeding ingredients module. 1. The box cover. 2. The box frame. 3. The feeding manipulator. 4. A box.

4.2. *Automatic cooking*

The automatic cooking part of the robot is an improved and developed one based on the automatic Chinese cooking robot, which has been presented by Yan *et al.*[25] It can finish the basic Chinese cooking techniques, automatically put the raw materials in the wok, and heat equally the food in the wok. Notably, before ingredients are fed into the wok, the box frame of the feeding ingredients module will drive the box component to slide out position of the cover's slide-ways and the feeding manipulator will grip the bottom of the box and drop the materials into the wok. The 3D model of the feeding ingredients module is shown in Fig. 6. So far, the robot can cook over 300 Chinese dishes that are typical for the aged. If new dishes are required, they can be developed soon.

4.3. *Automatic sending of dishes to the table*

The robot automatically sends dishes to the table involving three key links: preloading of clean dishes, automatic taking of cooked food out, and automatic delivering of dishes to the table.

4.3.1. Preloading of clean dishes. Clean dishes will be preloaded into the containing dishes module by DRCs. The system of robot supplies the interfaces for DRCs to preload, but they will be hardly used by individual. The holding dishes manipulator can at most hold 24 clean dishes. Before cooking a dish, the robot will check whether there are dishes through a pressure sensor on the manipulator. If no dishes are detected, the robot will stop cooking and ask for dishes. The 3D model of the containing dishes module is shown in Fig. 7.

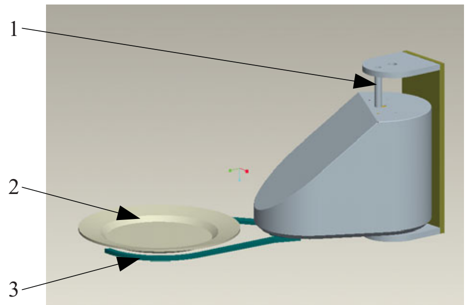

Fig. 8. The 3D model of the delivering dishes module. 1. The rotary axis. 2. A dish. 3. The delivering dishes.

4.3.2. Automatic taking out cooked food. The delivering dishes module, the containing dishes module, and the wok movement module cooperate to take out cooked food. Figure 8 shows the 3D model of the delivering dishes module. The delivering dishes manipulator can rotate around the axis and rise up and down. Just before cooking gets finished, it will rotate below the holding dishes manipulator. Then the holding dishes manipulator will open, and the dishes will slide down and drop into the delivering dishes manipulator. After that, the holding dishes manipulator will close, and only one dish will be left in the delivering dishes manipulator because the gap between two manipulators is controlled precisely and is slightly larger than the height of a dish. At last, holding the dish and moving down a little, the delivering dishes manipulator will rotate back to the position where the wok movement module will rotate the wok to take out cooked food.

4.3.3. Automatic delivering dishes to the table. At idle time, the rotary table (see Fig. 9) is released down. Before cooking, the table will be raised automatically. The center of the table is a turntable, which is driven by a motor. After taking out a dish, the delivering dishes manipulator will rotate above the turntable, open, and leave the dish on it. Every time, before another dish arrives, the turntable will rotate to avoid the stacking of those dishes. During a meal, users can switch on the dining mode of the rotary table, and the turntable will rotate at a speed of 1–2 rpm. It is helpful for users to reach out for dishes that are far away from them.

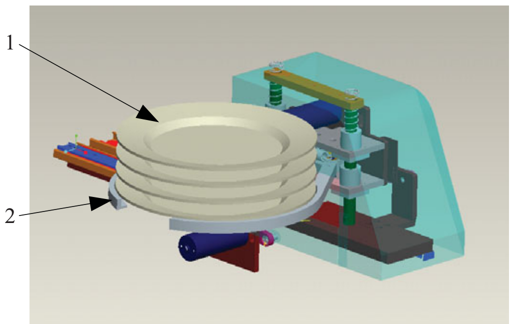

Fig. 7. The 3D model of the containing dishes module. 1. Clean dishes. 2. The holding dishes manipulator.

Fig. 9. The 3D model of the rotary table.

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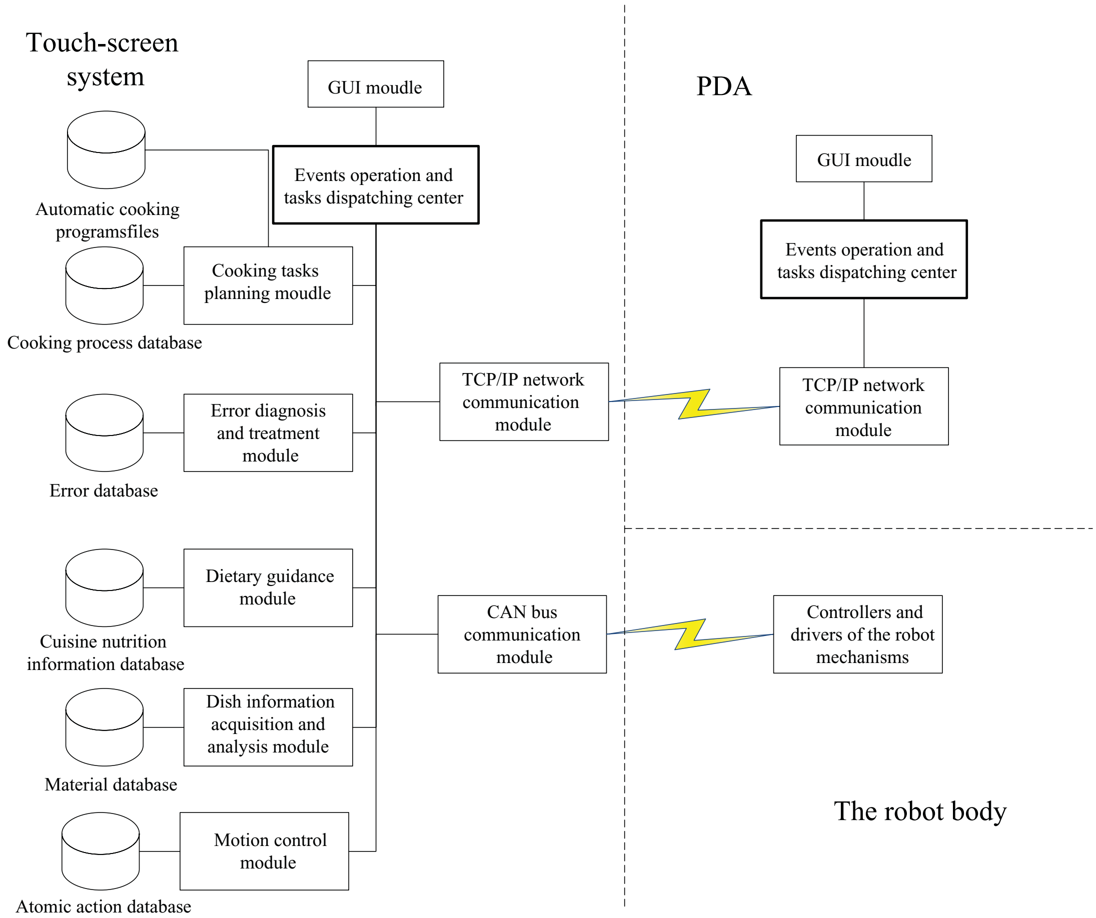


Fig. 10. The structure of the software.

4.4. Self-cleaning

After cooking a dish, the robot will self-clean. The parts that are going to be cleaned are the wok, the stirring tool, the wok cover, and the sink. After the wok is covered, hot and pressed water will spout into the wok from the nozzle beside the stirring tool. At the same time, the stirring tool will rotate at a high speed. After stirring, the wastewater will be dumped into the sink, and the wok will become vertical. At this time hot and pressed water will spout out from the nozzle, which is beside the containing dishes module, aimed at the wok, and will flow into the sink from the wok. After spouting and stirring twice or thrice, the wok, the cover, and the stirring will be nearly cleaned. After the wok is again covered, from another nozzle, which is also located beside the stirring tool, high temperature steam will jet out in order to dry and sterilize the wok, the cover, and the stirring tool. In the sink, a garbage processor will chop chunks of materials and water will wash out all the scrap.

In addition, DRCs will regularly take off the wok, the cover, the stirring tool, and the sink and bring them to the DRF for thorough cleaning and sterilizing.

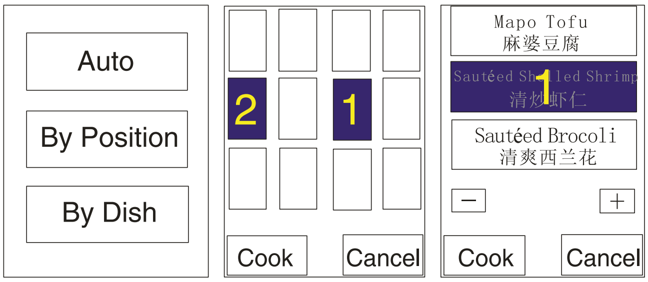
5. User Interface

The cooking robot offers two ways to interact with users. One is a touch-screen system and the other is PDA. Both of these can support English and Chinese.

The touch-screen system can be used alone, and is a WLAN server for the PDA. The LCD panel and the touch panel are 17 inch in size, and their large size is helpful to use large-size icons, buttons, texts, and spacing. The operating system is based on Linux2.6.20 kernel, and the GUI applications are developed based on Qt3.3.6 and C++ language, and compiled with GCC.

The PDA is an iPad112 produced by Hewlett-Packard. Its screen is 3.5 inch in dimension and more details can be obtained from its website www.hp.com. Applications in the PDA are developed in VS2005, C++ language.

The software is designed based on an event-driven architecture (see Fig. 10). Both the touch screen system and the PDA have a Graphic User Interface (GUI) module, an events operation and tasks dispatching center, and a TCP/IP network communication module. The events operation and tasks dispatching center will handle all types of events that come from all other modules. Via this center tasks are also dispatched from one module to another. Actually, the center connects all other modules and helps them to cooperate with each other. During cooking, the cooking tasks planning module will cooperate with the motion control module based on Hierarchical Task Network (HTN). A cooking task mainly comes from an automatic cooking file corresponding a dish and can be adjusted by other modules. Firstly, a cooking task is planned as a sequence of cooking processes, and then every cooking process is translated to atomic actions. The TCP/IP network communication module is used to communicate



(a) (b) (c)

Fig. 11. User Graphic Interfaces in the PDA. (a) Selecting operation modes interface; (b) the by-position mode interface; (c) the by-dish mode interface.

between the touch-screen system and the PDA. Through CAN bus, the touch-screen system can control the robot body and collect information. The dietary guidance module can advise the elderly and disabled how to keep a balanced diet. This module together with the dish information acquisition and analysis module will also help the cooking tasks planning module to plan the cooking tasks in a manner to minimize nutrient losses for special users.

5.1. *Object size on the screen*

Objects displayed on small screens should not only be big enough to be hit successfully, but also small enough to house several objects on the screen at the same time. Thus, the optimization of object size and display size is of crucial interest in modern device design.[29] Jin *et al.*[30] points out that a designer who applies these button size and spacing guidelines needs to be cognizant of the target population using his design. If the target is older people with relatively normal manual dexterity, then a button size of 16.51 mm and spacing of 3.17 mm to 6.35 mm should be appropriate for screen layouts that require rows of adjacent buttons. However, for older adults with poor manual dexterity, a larger button size, at least 19.05 mm, and a larger spacing, 6.35 mm to 12.7 mm, are required. In the touch-screen system of the robot, the size of the smallest buttons is 30mm × 45mm, and the spacing size is 8 mm at least.

Siek *et al.*[31] and Chaparro *et al.*[32] have found in their experiments that older participants were able to select the correct button (fine motor control) and push the button while holding the PDA (pincher strength) with the same accuracy as done by younger participants. Siek *et al.*[31] also found no difference in age groups, and concluded that both older and younger participants performed the button press task at the same level. Older participants preferred 25-mm icons (mean = 18.5 mm, standard deviation = 6.687 mm) because of less glare, but they were able to read 15-mm icons (older: mean = 10 mm, standard deviation = 4.082 mm). In Siek *et* al's experiments, the icons were complicated and difficult to recognize for the older participants. If the icons were very simple (e.g., color blocks), their size could be smaller. In the PDA of the robot, the icon size is 10mm × 12mm at least, and the smallest spacing is 3.33 mm.

5.2. *Operation modes*

Besides considering the size of objects on the screen, the GUI should be as simple as possible. Three simple cooking modes are offered by the robot: the auto mode, the by-position mode, and the by-dish mode. Figure 11 shows several GUIs of PDA. The touch-screen system's GUIs are similar but the objects on the screen are much larger and more beautiful. The voice prompts will play when entering an interface. After power-on and getting connected with the server successfully, the PDA will show the interface as depicted in Fig. 11(a). It will launch automatic cooking immediately to click the "Auto" button. It will, respectively, enter the by-position mode or the by-dish mode to click "By position" button or "By dish" button. In the three modes, the robot always detects whether there is a

Fig. 12. The photo of the cooking robot for elderly and disabled people.

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Table I. The ages and sexes of 12 invitees.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Age (years)	65	65	65	65	67	67	68	70	71	73	73	76
Sex	F	F	M	F	F	M	M	M	F	M	M	M

F: female; M: male.

box component in a cell, and checks the information in the RFID tag if the box component exists.

5.2.1. Auto mode. If the "Auto" button is clicked, the robot will search in the ingredient box storage following the preset scope and sequence. Once a box component is available, it will be taken out and the robot will cook immediately. Users can ask DRCs to preset the scope and the sequence, and they can deal with it themselves because the operations are very easy. Given no preset, the robot will search the whole storage from upper top to lower bottom. In this mode, users need only click one button, and cooked dishes will be delivered to the table.

5.2.2. By-position mode. If the "By position" button is clicked, the interface like in Fig. 11(b) will show. Each white block corresponds to a cell in the storage. When users click a white block, it will be selected and highlighted, and at the same time a sequence number will be shown in the center of the block. The box component in the corresponding cell will be checked and the dish will be cooked with the sequence. If the highlighted block is clicked, the block will turn white again and the selection of the cell will be canceled. Figure 11(b) shows an example, wherein two box components in the middle-level cells are selected and the robot will first take the left third cell and then the left first one. Clicking the "Cook" button will launch cooking process and clicking the "Cancel" button will return to the interface as shown in Fig. 11(a).

5.2.3. By-dish mode. If the "By dish" button is clicked, similarly with the auto mode, the robot will search in the ingredient box storage following the preset scope and sequence. However, when an available box component is found, it will not be used to cook immediately. The dish ID read from the RFID tag will be recorded and translated to the dish name by the robot. After the whole scope is searched, the dish names will be listed on the screen. Dishes can also be selected and the sequence can be set just like by-position mode (see Fig. 11(c)). Buttons "+" and "−" are used to scroll the list. In the same way, clicking "Cook" launches cooking and "Cancel" is used to return.

Obviously, in the three modes, the auto mode is the simplest, the by-position mode is the most efficient, and the by-dish mode is the easiest to understand. Moreover, all of them are easy to grasp.

6. Experiments

In order to verify the functions of the cooking robot (see Fig. 12), experiments were performed. Twelve elderly people were invited to use the robot. Their ages and sexes are listed in Table I. They were divided into three groups, and each invitee in each group cooked the following four dishes: mapo tofu, sautéed marrow, sautéed marrow, and sautéed brocoli. All ingredients were supplied by the DRF, which has been built, and DRCs played their roles well.

Table II. The attitudes of 12 invitees toward activity 1 and activity 2.

	R1	R2	R3	R4	R5
Activity 1	5	6	1	0	0
Activity 2	8	4	0	0	0

Activity 1: To take the ingredient box components from the refrigerator to the storage.
Activity 2: To put used dishes into the bin for recycling.
R1: totally acceptable; R2: acceptable; R3: barely acceptable; R4: unacceptable; R5: totally unacceptable.

Table III. The evaluations of 12 invitees toward three operation modes.

	G	M	B
Auto	9	2	0
By Position	7	4	0
By Dish	2	3	6

G: good; M: medium; B: bad.

During experiments, all invitees could accomplish two aid activities: "To take the ingredient box components from the refrigerator to the storage" (Activity 1) and "to put used dishes into the bin for recycling" (Activity 2). Table II lists their attitudes toward these two activities. Only one (76 years, the oldest one) thought Activity 1 was barely acceptable (R3), whereas others thought it was acceptable or totally acceptable. All the invitees thought that Activity 2 was acceptable or totally acceptable. Obviously, both of them had no obstacles.

During experiments, most invitees chose the PDA to operate the robot. They explained that the PDA seemed handy and they could operate the robot even when they were having meals.

Invitees also evaluated three operation modes (see Table III, where G means good, M means medium, and B means bad). Most of them (nine invitees) thought the auto mode was good and no one thought it was bad. Only two invitees thought the by-dish mode was good, but six ones thought it was bad. Clearly, the elderly are more inclined to operate in a simpler way. Actually, they thought that it was unnecessary to select dishes and set a sequence since they could easily put the ingredient boxes into the storage. On the contrary, they were very satisfied with the auto mode. They commented that the auto mode was not only the simplest but also the most practical, and if they put all four ingredient

Table IV. The ingredients and nutrients of the four typical dishes.

Dishes	Ingredients	Nutrients
Mapo tofu	Tofu 250, beef 75 g, tempeh 15 g, pepper 3 g, yellow wine 5 g, salt 3 g, MSG (monosodium glutamate) 2 g, pea starch 5 g, peanut oil 15 g, shallot 5 g.	Calories 543.85 kilocalorie, carbohydrate 13.98 g, fat 30.88 g, protein 50.14 g, cellulose 3.07 g.
Sautéed shelled shrimp	Shrimp 350 g, winter bamboo shoots 5 g, carrot 5 g, peanut 5 g, spring onion 3 g, ginger 3 g, garlic 3 g, corn starch 15 g, salt 2 g, yellow wine 3 g, msg 1 g, vinegar 1 g, lard oil 50 g.	Calories 815.73 kilocalorie, carbohydrate 48.86 g, fat 53.03 g, protein 37.55 g, cellulose 0.41 g.
Sautéed marrow	Marrow 350.0 g, salt 3.0 g, MSG 2 g, dried small shrimps 10.0g, onion 10.0 g, lard oil 20 g.	Calories 262.66 kilocalorie, carbohydrate 18.48 g, fat 18.68 g, protein 7.19 g, cellulose 2.22 g.
Sautéed brocoli	Brocoli 200 g, carrot 100 g, salt 2 g, pepper 1 g, chicken essence 1 g, sesame oil 1 g.	Calories 117.5 kilocalorie, carbohydrate 18.5 g, fat 2.45 g, protein 9.4 g, cellulose 4.33 g.

Table V. The final score for the four dishes by 12 invitees.

No	Name	Color	Sapor	Meaning	Shape	Nutrition	Scent
1	Mapo tofu	G	E	G	G	G	G
2	Sautéed shelled shrimp	E	E	G	E	E	E
3	Sautéed marrow	E	E	E	E	G	E
4	Sautéed brocoli	E	E	E	E	E	E

E: excellent; G: good; F: fair.

boxes into the first four cells accordingly with the search setting, then the auto mode could be the fastest one. Usually, it took 2 to 3 min to cook a dish. All invitees were satisfied with its efficiency. When they had meals, they also thought the turntable was helpful. Nevertheless, they advised the rotary table should be bigger in size.

The four dishes are recommended by experts, which are typical and suitable for the aged. Their ingredients and nutrients are list in Table IV. Table V shows the final score for the four dishes by the invitees. In addition, the result shows the invitees were satisfied with the cooking abilities of the robot.

7. Conclusion

Aging is becoming a global social problem, and living quality of older people is paid more and more attention. This paper presents a cooking robot for elderly and disabled people who are confined on wheelchairs. Around the robot, a package of solutions is presented. The structure and interfaces of the robot are designed based on the barrier-free design principles and keeping in view the elderly and disabled people's special characteristics fully. The robot can automatically load ingredients, cook, take cooked foods out, deliver dishes, and self-clean. Aid activities provided by users are easy and the aged are competent to deal with them. Three operation modes are supported, and the auto mode is preferred by the aged. Experiments show that the elderly people are satisfied with the cooking ability and the convenience of the robot. However, the solutions presented in this paper are validated by a small group only, and it is possible that large-scale applications could lead to a lot of unexpected problems.

In addition, there is much room for improvement in the cooking robot itself. For example, the method how to put clean dishes into the robot should be simplified. Another problem is the size of the robot. The robot is designed with 12 cells in the storage for being used in the situations with more people. Its size is large, and perhaps in some kitchens there is not enough space for it. However, a Chinese family usually has about four members and needs four dishes (or three dishes and one soup) in every meal. Four cells will be more suitable. Therefore, the size of robot can be much smaller after removing eight cells from the store. Furthermore, if more costs are permitted, an independent delivering dish robot, for example, a mobile robot that has been developed by Matsukuma *et al.*[17] can take dishes away from the cooking robot and bring them to the special users, and the users can even have meals in their bedrooms. Therefore, the rotary table could be removed and the size could be reduced further.

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