

Review

Service Robots in Catering Applications: A Review and Future Challenges

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Abstract: “Hello, I’m the TERMINATOR, and I’ll be your server today”. Diners might soon be feeling this greeting, with Optimus Prime in the kitchen and Wall-E then sending your order to C-3PO. In our daily lives, a version of that future is already showing up. Robotics companies are designing robots to handle tasks, including serving, interacting, collaborating, and helping. These service robots are intended to coexist with humans and engage in relationships that lead them to a better quality of life in our society. Their constant evolution and the arising of new challenges lead to an update of the existing systems. This update provides a generic vision of two questions: the advance of service robots, and more importantly, how these robots are applied in society (professional and personal) based on the market application. In this update, a new category is proposed: catering robotics. This proposal is based on the technological advances that generate new multidisciplinary application fields and challenges. Waiter robots is an example of the catering robotics. These robotic platforms might have social capacities to interact with the consumer and other robots, and at the same time, might have physical skills to perform complex tasks in professional environments such as restaurants. This paper explains the guidelines to develop a waiter robot, considering aspects such as architecture, interaction, planning, and execution.

Keywords: service; catering; robot; waiter; human-robot; interaction; social



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1. Introduction

Typically, the idea the people have of a robot comes from a science fiction cinematographic vision, as shown in Figure 1a,b. They can sometimes look like human beings and are able to do the typical monotonous and boring tiresome daily task for us, acting as a service robot. However, nowadays, commercial service robots are far from this unreal cinematographic vision. There are well-presented service robots in our daily society, like the cleaner service robot Roomba with an affordable price. However, these devices are one of the first commercial development in a promising huge market of service robots.

If we go in depth on the universe of service robots, this one is continuously growing. Their applications and diversity are increasing. However, service robots do not have a generally accepted definition, due to this very changing market behaviour, the multitude of structures and application areas or the multitude of structures. We have found some definitions of service robots from world organisations to understand this continuous change

The International Federation of Robotics (IFR) has done an introductory definition. Among other things, it aims at distinguishing this kind of robots from other robotic platforms: “A service robot is a robot that works semi or completely autonomously to perform useful services for the well-being of humans and equipment, excluding manufacturing operations” [1].

IFR also declares that: “service robots may or may not be equipped with an arm structure as is the industrial robot. Manipulating industrial robots could also be considered as service robots, conforming to the above-stated definition, provided they are installed in a non-manufacturing environment” [1].



(a) Robot Bender.



(b) Robot TARS.

Figure 1. Different examples of TV robots that have appeared in films or series. (a) Bender. The foul-mouthed Futurama robot. (b) The multi-functional Robot TARS from the Interstellar film.

IFR mentions that: “the vast majority of the current service robots are mobile, but this is not a strict defining characteristic since they can also be fixed. In some cases, service robots consist of a mobile platform which has attached one or several arms that can be controlled in a similar model to the control of an industrial robot” [1].

Since 2007, the International Organisation for Standardization is reviewing the ISO 8373 (under development) (currently published 8373:2012). They work on: “the definition of the terms used in relation to robots and robotic devices that operate in industrial and non-industrial environments, for the standard inclusion of an official definition of service robots” [2]. From these definitions, we can only ensure that service robots are continually changing and evolving. These robots are becoming more and more complex, with new capabilities. These changes can be found in Section 2, in which the growth and the richness of the market economy for service robots are made evident. For this reason, Section 3 presents an updated classification of this type of robots and some examples. Following this classification, Section 4 describes the emergence of a new multidisciplinary category, as a sample of this constant update: the catering service. Catering robotics is concerning to professional scenario with social features and domestic abilities. Besides, it is introduced the waiter robot as an example of this new category. In Section 5, it is explained in more detailed the approach for developing a robot to be used as a waiter. For that, it has been taking into account different aspects like the environment, the design, the interaction with humans, the planner, etc.

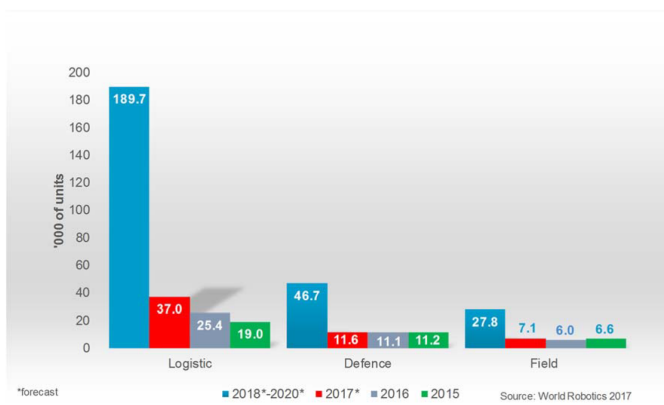
2. Service Robots Statistics

Delving into the IFR global robotics report [3]: “in 2016, the total number of professional service robots sold increased considerably by 24% to 59,706 units, compared to 48,018 in 2015. If we summarise some statistics of the main topics, about 25,400 logistic systems (manufacturing scenarios), they were installed in 2016, 34% more than in 2015 (19,000), representing 43% of total units and 21% of total sales (in value) of professional service robots. Service robots in defence applications, with 11,100 units, consider for 19% of the total number of professional service robots sold in 2016. In 2016, a total of approximately 5300 milking robots were sold compared to 5860 units in 2015, which represents a 10% decrease. Milk producers suffered financially. As a result, investments were advanced, and acquisitions were postponed. (Figure 2a). Sales of medical robots increased by 23%

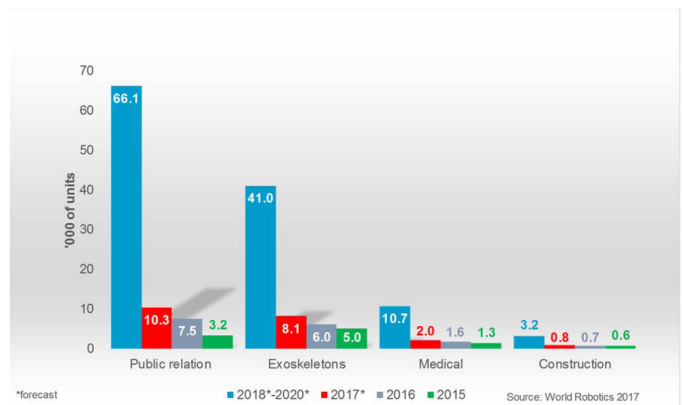
compared to 2015 to 1600 units in 2016, accounting for a share of 2.7% of the total unit sales of professional service robots. The most critical applications are robot-assisted surgery or therapy. Sales of powered human exoskeletons were up from 4970 units in 2015 to 6018 units in 2016. These are successfully used for rehabilitation and ergonomic support for reducing loads and have high growth potential”.

“Another strong growing sector (crucial for this article) is public relation robots. Almost 7500 units were sold in 2016, 133% more than in 2015. Most of these robots were telepresence robots, robots for mobile guidance and information with a sales volume of 7200 units in 2016 up from 3100 units in 2015” (Figure 2b).

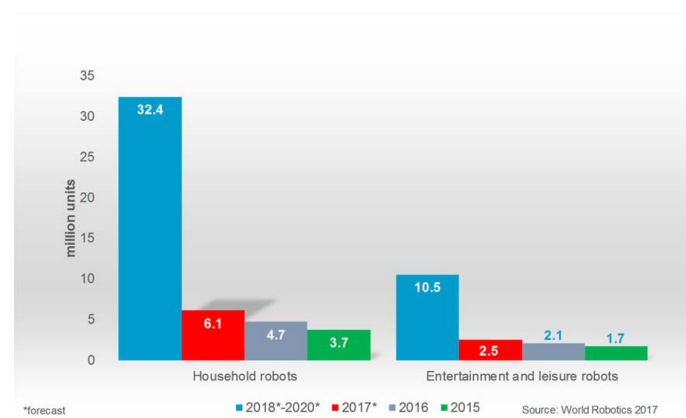
“Service robots for domestic and personal use are registered separately since their unit value is generally only a fraction of many types of service robots for professional use. They are also produced for a mass-market with completely different pricing and marketing channels. Until now, service robots for personal and domestic use are mainly in the areas of domestic robots, which include cleaning vacuum cleaners and floors, lawn mowing robots and entertainment and leisure robots, including toy robots, hobby systems, education and research” (Figure 2c).



(a) Professional service robots in more applications (first part).



(b) Professional service robots in more applications (second part).



(c) Personal or domestic service robots.

Figure 2. Unit sales 2015 and 2016, forecast 2017 and 2018–2020 for professional and domestic service robots [3].

3. Classification of Service Robots

They come in all forms and heights and most of the time and are mobile and autonomous. Depending on the usability, we propose the a classification divide in two main categories: “professional service robots” and “personal/domestic service robots”. Some examples of the latest robots designed are detailed inside this section. We can consider them representative for each class (Figure 3).



Figure 3. Classification of different service robots (A–J).

3.1. Professional Service Robots

For the private sector, “professional service robots” are still fascinating [3], either in the number of units sold or in the new fields in which the robotics are becoming indispensable.

(A) Defence Robots

Based on the previous reported data, “defence robots” have the most significant share of professional robots domain (Figure 3A). This is due to their units manufactured and their market value. The main characteristic of the defence robots is their short-lived and the reason is because they work in hostile scenarios. Inside this robotic class, three main divisions emerge: the unmanned aerial vehicles (UAV) like ProxDynamics’s Black

Hornet [4], unmanned ground vehicles (UGV) like Qinetiq’s MAARS [5] and unmanned underwater vehicle (UUV) (Table 1).

Table 1. Classification of defence robots according to the application environment.

Type	Description
UAV	They are used from the air. Sometimes they are known as drones. UAVs look like model aeroplanes and vary in size from small planes to full-size planes.
UGV	They are robots that work in contact with the ground. Usually, UGVs are employed for jobs where it may be inconvenient, dangerous, or the presence of a human is impossible.
UUV	These marvels have capabilities to operate underwater. The UUVs were designed to contribute to the following mission areas: Mine Warfare, Intelligence, Surveillance, and Reconnaissance and Mapping undersea environmental.

(B) Field Robots

The other primary domain is “field robots” (Figure 3B). In this class, milking robots are the most widely spread. The multi-box system GEA’s Mlone is one of the most intricate and novel milking robot. When the cow goes into the milking post, the robot checks the dimensions of the cow with a depth camera. From a central control station, it is possible to verify and monitor all tasks fast and efficiently. Basic and adjusted functions cows with particular requirements can be attended, while the Mlone system is milking the rest of the cattle automatically [6]. However, there are more robotics farmers like Dick from Small Robotisc Company. They have integrated Rootwave’s weed zapping technology to make autonomous non-chemical weeding a reality.

(C) Robots in medical settings

Moreover, one of the most important fields of professional service robots is intended to work in “medical settings” (Figure 3C). Its market value is very high. Due to a wide testing of the robots, an extensive range of accessories and a high complexity, the costs usually exceed 1 million US dollars per unit. There are three main categories within the field of medicine: Delivery/Nurse like Robear [7], Rehabilitation like LocomatPro’s Hocoma [8], and Surgical like CyberKnife Accuray’s CyberKnife [9] (Table 2).

Table 2. Classification of medical robots according to the application environment.

Type	Description
Delivery/Nurse	These robots aim to carry meds, lab specimens, sterile supplies, linens, trash, medical waste, patient meals and even disinfect bacteria or viruses.
Rehabilitation	Rehabilitation robotics is based on assisting different sensorimotor functions, development of different schemes of assisting therapeutic training, or assessment of the sensorimotor performance of the patient.
Surgical	The purpose of this kind of robots is to give enhanced diagnostic capabilities, a less invasive and comfier experience for the patient, or the capability to perform more accurate interventions.

Additionally, the current COVID-19 pandemic has revealed that healthcare facilities such as hospitals are exposed to threats as viruses that can affect enormously the effectiveness of internal processes and the responsiveness of these institutions. In this way, robot-assisted disinfection strategies seem to play an essential role in fighting against virus propagation. Robotics can cover the need for intelligent contingency systems in healthcare facilities. As an example, robots for disinfecting based on ultraviolet (UV) light emission is a promising solution to reduce the impact of viruses in hospital settings [10]. ABB has proposed a useful nursing application by using the YuMi robot for picking-up patient tests and transport them to the lab for processing, linens, or medications right to door [11].

(D) Logistic Robotic Systems

In the “logistic robotic systems”, 75% of current warehouses are manually operated, and they have no supported automation at all. These warehouses deal with demands for increased productivity and throughput. Existing workers with good layout design and mobile material handling equipment are supporting this increased demand. In this scenario, logistic service robots have their place with a good market value. The atypical working places that require fast and tedious work is not a problem for them, and two good technological examples (shown in Figure 3D) are the Kiva robot from Automated Material Handling Systems [12] and the Brokk 400 demolition robot [13].

(E) Maintenance Robots

The first robots to gain acceptance in the world (cleaning the windows or the floor) were the cleaner robots or “Maintenance robots”. Moreover, novel professional robotic cleaning approaches are emerging: inspection robots or solar panel cleaners (Figure 3E). One of the newest and most complex robots of solar panel cleaners is E4. It is a waterless cleaning system developed by Ecoppia [14]. The robotic inspection systems are becoming too important. They are able to come to inaccessible scenarios like pipes for inspection and cleaning. One of them is Versatrax 450 built by Inuktun [15].

3.2. Personal Service Robots

“Personal or domestic service robots” had a huge increment in variety and units sold in the last few years. Nevertheless, its low market value is not comparable with respect to professional service robots.

(F) Social Robots

In this case, “social robots” are used as a personal service robot. These robots are designed to work surrounded by people safely and efficiently, and to increase people’s lives value by helping, caring, teaching and entertaining (Figure 3F). On the one hand, the robot Maggie is a robotic platform aimed for study Human–Robot Interaction (HRI) designed and built by Carlos III University of Madrid [16]. They are focused on the adjustment the potential of Maggie and provide to human users novel method of operating, learning or stimulating. On the other hand, REEM by PAL Robotics is another example of humanoid service robots [17]. The entertainment in public environments or helping people are the typical uses for REEM.

(G) Domestic Cleaner Robots

“Domestic cleaner robots” are the most widespread personal service robots, and their goal is related to household cleaning tasks in the house (Figure 3G). Over personal cleaning robots, two central classes rise according to the scene where they work: indoor robots and outdoor robots (Table 3). Two recent examples are iRobot’s Looj and Eco Pool’s Solar-Breeze robots. On the one hand, the company iRobot is well known by its vacuum cleaners, but in this case, the Looj robot goes through and cleans gutters [18]. On the other hand, the Solar-Breeze revolutionises pool cleaning in an intelligent, sustainable and straightforward way. Solar-Breeze effectively removes dirt and debris from the water while navigating the pool. The reduction of sink and bacteria on the pool is appreciable [19].

Table 3. Classification of personal cleaning robots according to the scenario.

Type	Description
Indoor	This type of robot performs household cleaning tasks inside the house. Nowadays, it is possible to find numerous and different household tasks that have been automated and replaced by cleaner service robots. In fact, in the market, there are robots that sweep and scrub the floor, robots that clean the windows of difficult access or robots that clean the air.
Outdoor	This type of robot performs its tasks outside the house. On this side, it is possible to find other tasks that robots can also perform. For example, there are robots that cut the grass, robots that clean the pool or even robots that unblock pipes.

(H) Research/Educational/Competition Robots

“Robot platforms for research” is an vital approach in the personal service robots domain (Figure 3H). Many institutions and companies are developing their version of robots and use them for teaching [20]. These research centres are participating in robotics competitions to encourage and motivate new generations. They are developing new sophisticated robotics platforms like TEO. One of the most advanced platforms of this type is the humanoid robot TORO from the Institute of Robotics and Mechatronics (DLR). The humanoid walking robot, TORO, is a research platform for a scientific purpose. It mainly deals with locomotion and dynamics [21]. Another advanced robotics platform is the KIT’s Armar III robot. The main goal of this humanoid is to mimic the sensorimotor and sensory capabilities of human beings closely. The robot can deal with household scenarios. It can deal with the objects and tasks found in it [22].

(I) Assistance Robots

“Assistance robots” cannot be ignored as another personal service category. In this one, it is important to consider the work of research centres and companies. This group covers the aspects of robotics in the healthcare process. The main role of these robotic systems is to assist hospitals and specialised centres. This assistance can be provided with both the carers and the patient directly (Figure 3I). For better classification, the different assistance robots are grouped according to the place of their application environment (Table 4). A good example is the assistant manipulator Asibot. It has a symmetrical construction and is fitted out with special conical connectors on each tip. This configuration makes it able to climb between static and very simple docking stations situated in the kitchen. This ability of the Asibot transforms it into a mobile robot able to assist in domestic and office structural environments [23]. Another example is Ari from Pal Robotics. Its capabilities could easily adapt to carry out many of the tasks including hospital reception, patient registration, provide health assessment and also entertain users at hospital waiting rooms or at home. ARI may also be used to remind users to do different tasks, based on monitoring of physiological or behavioural [24].

Table 4. Classification of assistance robots according to the application environment.

Type	Description
At hospital	The operation of a hospital or health centre comprises a complex system of tasks. These tasks are not only limited to medical care but also require a combination of logistics, administration and organisation tasks.
At home	The demand for home care services and facilities is growing. The ambient intelligent systems provide their service in a sensitive and receptive manner and are discrete in our environment. Supervision systems are used to monitor users or patients in their homes related to the healthcare process.

(J) Therapeutic Robots

Alongside the assistance robots, the “therapeutic robots” emerge as another category. This scope covers post-operative or post-injury care. Here, the direct physical interaction of a robotic system helps improve recovery or acts as a replacement for the lost function (Figure 3). Table 5 shows a classification of the contribution of robotics in this field according to how the robotic system is fitted to the user’s body. Three groups can be identified: prostheses, orthoses and rehabilitation aids [25].

Table 5. Classification of therapeutic robots according to how it is fitted.

Type	Description
Prostheses	Prostheses are defined as external devices that partial or totally replace a limb. This definition includes any device placed within the body for structural or functional purposes.
Orthoses	Orthoses are an external device that is used to modify the structural and functional characteristics of the neuromuscular and skeletal system. It does not replace a member or organ but replaces or reinforces its functionality.
Rehabilitation Aids	This Rehabilitation Aid systems or treatments (therapies) help to recover motor functionality through training. This training is based on physical or cognitive exercises, and the therapy is adapted to the patient.

A good example of rehabilitation aids is Mini from the Carlos III University of Madrid [26]. It is an advanced interactive robot that assists elders suffering Alzheimer’s disease, or other causes of cognitive impairment, and also their caregivers in environments like hospitals and extended care facilities [27]. Another therapeutic platform is Tenoexo. It is a compact and lightweight hand exoskeleton or orthoses. The EMG-controlled device assists patients with moderate to severe hand motor impairment during grasping tasks in rehabilitation training and during activities of daily living. Its soft mechanism allows for grasping of a variety of objects [28].

4. An Emerging Class of Service Robot: Catering Robotics

In the previous section, a classification of the different existing service robots has been presented. It is undeniable that every year, companies and research centres develop innovative robots thinking in the market necessities. The robot abilities and capabilities are continuously improved and updated. From this new situation, robots can perform new tasks that they could not do before in new environments. One of these scenarios is catering service in professional environments, where robotics solutions have a huge potential to be applied. Concerning the classification presented, it is reasonable to think that the robots introduced in this kind of environment should have social features and domestic abilities (serving, cooking, etc.) among others. Then, any robotic development in this field is difficult to classify into any subcategory of service robots described. Thus, the new category of catering robotics is proposed.

If we focus on the Bureau of Labor Statistics (part of the U.S. Department of Labor) [29], they reported that: “more than 3.4 million people work in serving in places such as cafeterias, fast-food restaurants and food preparation, with a median wage of \$9.44 per hour. More than 4.7 million people are working as waitresses and waiters, receiving a median wage of \$9.61 per hour. There are approximately 2.3 million cooks who earn a median salary of \$10.99 per hour”. The catering industry is a significant sector where many companies are investing much money. Therefore, in a few years, this industry will have an explosion of production and investment in the robotics field, and it will follow the grown development in catering robotics. It seems that it will be a logical next topic for robotics, with a vast market [30].

On the one side, considering previous researches related to catering service robots, we found some examples. Most of the robotic platforms are autonomous mobile robots and

they are dedicated to taking orders through a tablet or serving dishes on a large and fixed tray. All these tasks are very predetermined.

For example, in [31] HERB is presented as a home exploring robot. This is focused on the development of object manipulation skills. This mobile autonomous manipulator has algorithms of search and recognition of objects, learning of the environment, or planning and execution of grasping tasks. The PR2 robot by WillowGarage is another whole service robot. It is composed with a dual-arm system for bi-manipulation tasks [32,33]. This assistance robot has skills related to the identification of dynamic obstacles, navigation or execution of grasping tasks. Another one is the Care-O-bot system, which is already in its 3rd generation. It appears as a friendly butler, explicitly designed for domestic environments. The most special thing about this robot is its 7 DoF light-weight arm with its tactile sensors on the fingers, making possible advanced grips [34]. In the DESIRE platform, the main goal is to give to this robot the skills towards the use of service robots in everyday scenarios. The DESIRE robot is a bi-manipulated research platform focused on manipulation and perception abilities required scenarios with human beings [35]).

On the other side, also catering service robots are being put to work out front in the restaurant industry as well (Figure 4). In fact, we can also see some examples of companies investing in these robotic platforms. In some countries (for instance, China and Pakistan), restaurants are using robots to serve food and take orders [36,37]. Pizza Hut has used Pepper robots, made by Japanese company SoftBank, to restaurants in Asia [38–41]. However, robot waiters have not been a hit in all facets of food-service. Chinese restaurant chain Hewelai found out the difficult way after spending in robot waitstaff for three restaurants, at the cost of more than \$7000 per unit. There were problems from the beginning. The robotics platforms regularly broke down and were unable to complete basic tasks such as pouring drinks, taking orders, or carrying bowls of soup. Two of the restaurants closed [42,43].

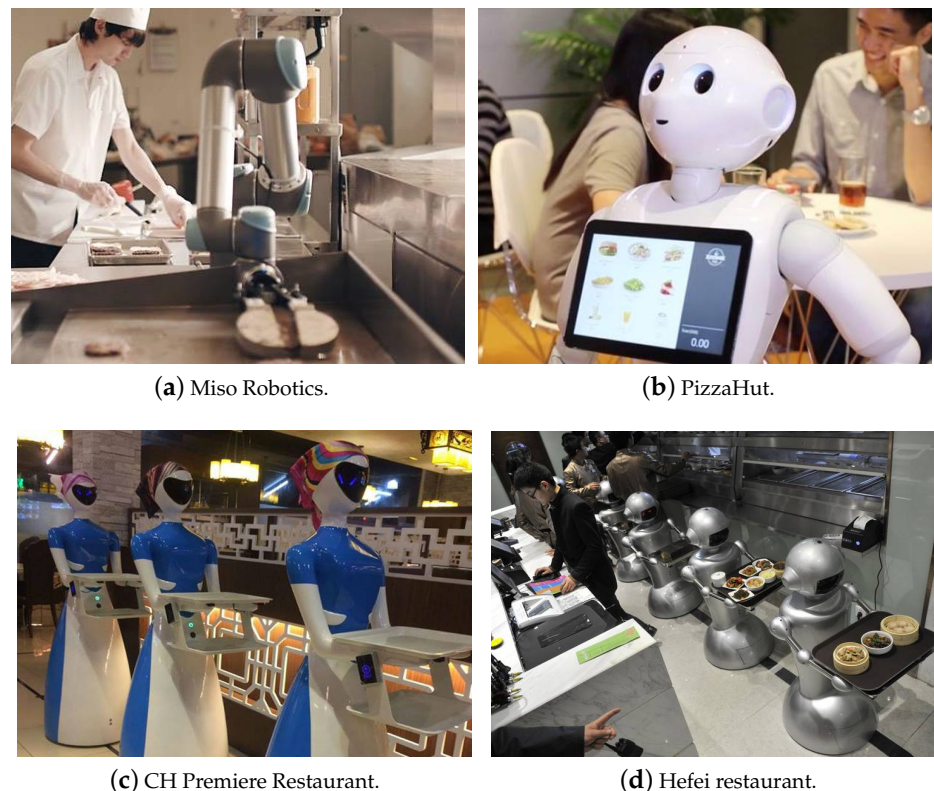


Figure 4. Different examples of service robots working in a restaurant or in a kitchen nowadays. (a) Chef robot from MISO ROBOTICS. (b) Robot Pepper in a PizzaHut restaurant. (c) Robot Collection from CH Premiere Restaurant (Malaysia). (d) Robot platoon from Hefei restaurant (China).

As stated in the last paragraphs, there are still too many problems to solve in the latest robotic restaurant projects. It is evident that this new line of catering robots has yet to mature. Before us, a wide range of possibilities for improving opens. This section explores two ideas: the tasks of a catering robot and the versatility of a humanoid robot.

On the one hand, a catering robot needs enough skills and abilities to develop multiple tasks. Actually, these robots should be able to work with food and drinks, preparing the food for cooking or plate meals, cleaning dishes for an excellent presentation, transport plate meals, moving across the restaurant, avoiding people, chairs or tables, going up or downstairs.

Moreover, catering robots present unique challenges for robots. They have to be created to work with human beings in tight spaces. There is also grease, smoke, water, heat and steam to contend with. The most critical challenge is what the robots are working with. Food and drink over a tray are clearly unpredictable when they have to be served to a customer. The instability of these when the robot is moving makes the task even more difficult.

On the other hand, humanoids are robots with their body shape built to resemble the human being body. The design might be for functional purposes, such as the locomotion studies, such as interacting with environments and human tools, for experimental purposes, or other purposes. The fundamental difference between humanoid robots and other mobile platforms is the movement. Humanoids walk like human beings. They use their legs with a biped gait. Considering human behaviour and its minimum energy consumption, humanoid robots replicate the step planner while walking. Therefore, researches on control or dynamics of humanoid platforms have frequently turn into more critical. We consider the problem of stabilisation of a biped robot while walking very important. We could choose to provide a stable position as a challenge and an aim of control. The idea could be keeping the CoM of the robot inside the support polygon generated by the feet.



Figure 5. Figure that shows the main idea of what a future waiter robot could be.

The possibilities of a humanoid robot are numerous. The ability to socialise with humans and their environments make this robot very useful. They push the boundaries of engineering, cognitive science and biology, producing a mountain of scientific papers in many areas related to humanoid robotics, including A.I., perception, robotic navigation,

cognitive robotics, computational neuroscience, compliant grasping and manipulation, speech recognition, and the integration of these fantastic technologies within total humanoids.

4.1. Classification of Catering Robots

Considering the combination of catering's tasks with the humanoid robot's capabilities, the opportunities intensify. One of the most interesting would be a waiter humanoid robot transporting a drink on a tray in its hand [44]. During this task, the robot should be able to maintain its stability while trying to keep the balance of the drink on the tray (Figure 5). So, how should they be this catering services robots?

From this robotics progressive evolution on the market, catering robots are arising. Improvements in the algorithms of navigation, perception, artificial intelligence, or mechatronic systems (mechanics, hardware, computing) allow creating more complex tasks in challenging environments. This new group of robots in the field of catering could be included within the private sector, in particular, the group of professional service robots [45].

The catering industry is a vast sector that brings vast revenue. Nowadays, companies have found the appropriate moment to invest in robots for this new sector, and two types of robot catering have emerged depending on the interest rate of the company: robochefs and robowaiters.

4.1.1. Robochefs

On the one hand, skills of cooking robots are focused on manipulation. Most of them aim to assist human beings with repetitive tasks for food preparation (Figure 6). Some robots make cocktails or drinks. Whatever these robots usually have limited mobility, sometimes even null. These robots have complex perception systems and precise and sophisticated grip systems with different interchangeable tools to achieve the task.

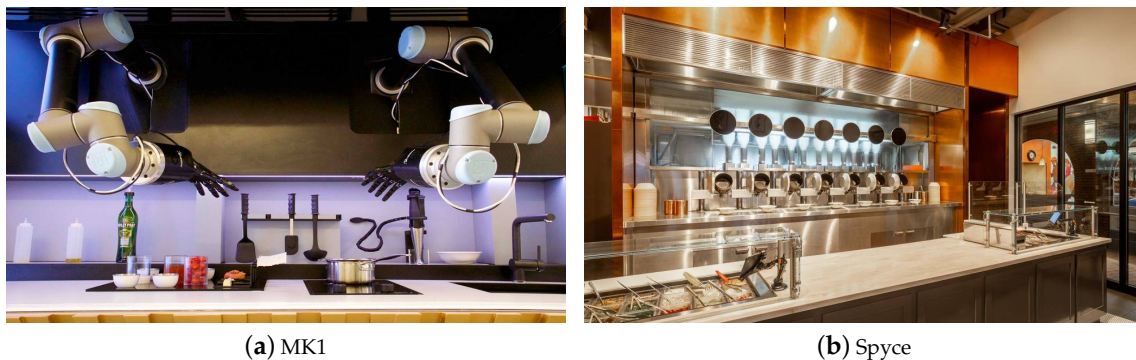


Figure 6. Two different examples of robotchefs. (a) MK1. The robochef from Moley Robotics that cooks with the skill and flair of a master chef. (b) Spyce. The restaurant with a robotic kitchen.

The concept of robochef or robotic kitchen can be found all around the world. Spyce, a restaurant opened in Boston, priding itself of dishing out food cooked by a nine-foot-long, 14-foot full robotic kitchen [46]. Moley Robotics, a British company, has built a fully automated cooking robot MK1 [47]. In India, two Bengaluru engineers have showcased Julia, a mechanised cooking pot that can dish out food in twenty minutes [48].

4.1.2. Robowaiters

On the other hand, some examples of social waiter robots are the robot Pepper implanted in the PizzaHut restaurants for taking orders and processing payments [38] or the PR2 robot of Willow Garage trying to serve beers and work together with other robots [40]. These waiter robots have skills focused on interaction with humans and their environment (Figure 7). Those can perform numerous tasks, from serving food and drinks, to taking orders, while they are moving around the restaurant. A restaurant is a continually chang-

ing scenario, where there are obstacles, such as tables, chairs, customers or other robots; that the waiter robot must recognise and overcome. Therefore, a waiter robot must have essential skills related to locomotion, manipulation, perception of the environment and social interaction.

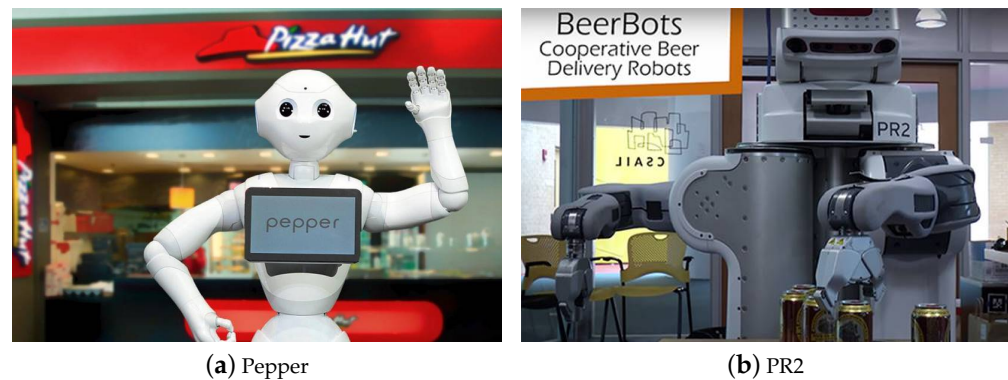


Figure 7. Two different examples of waiter robots. (a) Pepper. The social humanoid robot from SoftBank Robotics. (b) PR2. The robotic research platform by Willow Garage.

There is some evidence that the waiter robots are still very simple. However, the foundations to implement and integrate this new type of robots into society are already being established. At this moment, they can barely perform one or two complex tasks. The conditions in which the robot is moving is minimal and controlled, and also the movements are very elementary and pre-defined. Therefore, in the next subsections, all the requirements, limitations, characteristics and skills, that a future social waiter robot should have, are exposed.

4.2. Challenges for a Waiter Robot

Research in robotics has evolved from quasi-stationary robotic platforms to mobile and autonomous service-oriented robots. From constrained scenarios to real dynamic environments. These mobile robots are almost ready to work and help as service robot due to the novel investigation in fundamental robotics algorithms like mapping, planning, and perception. Therefore, now we have the opportunity to apply this new knowledge has the opportunity to be applied in different ways: developing more complex tasks, which may serve to help or replace human beings, depending on socio-economical or security goals.

It is possible to progress in the up-and-coming waiter application in the area of professional service robots by supporting humans as assistants. These new social waiter robots are going to be very similar to personal robots, which have to move around the home (dynamic environments for humans), interacting with humans verbally (HRI) or even physically (manipulation) [49–51].

Therefore, robots related to the waiter domain will have very similar characteristics to personal service robots applied to the private sector. Thereby, waiter robots will be able to assist in a restaurant and support human beings in tasks like serving customers, cooking food, preparing cocktails, taking orders..., as a chef, a barman or a waiter [45]. Taking into account all these tasks, there is a logical discussion. Which are the most demanding trials that robots will have to confront in human environments? For waiter robots, the three exacting types of challenges are organising and cleaning a house, preparing and serving food, and working with a person collaboratively. Researching in the field of catering can be an excellent opportunity to solve some challenges and achieve new ones. However, what is the real task of a waiter robot during its job in a restaurant?

A useful catering robot needs to perform reasonably, within an acceptable time frame and not being constrained by the environment. For achieving this, a waiter service robot must be provided with different capacities like human-robot interaction, recognition and

tracking people, planning, reasoning, object recognition, classification and grasping. Nevertheless, these skills are active and interdisciplinary study areas by themselves. Thereby, the integrative character of the waiter service robot investigation offers novel challenges. They are focused on accurate and robust abilities. The skills have to be correctly chosen, improved or even generated from scratch for the achievement of these requirements. However, there are one more very important part from all these challenges described: the interaction with the environment.

Nowadays, there are many robots capable of manipulating objects and moving around environments satisfactorily. In most cases, this is achieved by testing the robots in virtual simulations, in controlled environments, or operated by humans [52,53]. However, human environments have several challenging features. These generally are beyond the control of robot developers. We have to address with some trials summarised in the next list [54]:

- By humans, for humans. The objects and the environment are adapted perfectly to humans and their capabilities.
- Presence of people. The robot can be close to users while they move.
- Other actors. Other robots can collaborate.
- Conditions of the object. The objects can be located in different places at different times, or even change in shape and size.
- Architectural obstacles. The robot can be encountered with doors or stairs.
- Sensory variations. Some examples are changes in brightness, background sounds, or dirty surfaces.
- Dynamic variations. The scenario may change independently of the robot interaction.
- Real-Time Constraints. The robot must know the implicit environment restrictions.
- Use of tools. Some tasks require the use of particular tools.

Besides, due to the exceptionality of the robots, it is really difficult to evaluate them in real and dynamic environments. We can include the lack of a benchmarking methodology or the loss of measures and procedures. An option to perform accepted and feasible benchmarking is by using real scenarios. With this idea, the integration of robots is easier for both economic and development levels. However, it has the disadvantage that robots are limited to simple tasks [55–57].

It is not very appropriate to assume that the environment through which the robot moves is static. In our case, a social waiter robot works in a restaurant which has characteristics that perfectly match the dynamic scenarios previously described. In fact, in a restaurant, it is possible to find both dynamic and static objects. For example, all objects and the environment are custom-made for human beings. Other people and robot waiters can be walking around the restaurant. Objects (such as dishes) can be in the kitchen and then on the guest's table, with or without food. There are architectural elements to consider as tables, doors, stairs, or slopes. The luminosity or noise will not be constant during the workday. Even robots may have to use tools such as a tray or cooking utensils. In Figure 8, there are some examples of different situations in a restaurant.

All these changes can happen while the robot fulfils its task or within its trajectory. The waiter robot must identify these changes in the environment, mainly detected by the robot's sensors. It is evident that in a restaurant, the waiter robot must be able to handle dynamic environments.

To see social waiter robots working in this type of environment, those must-have features similar to human beings. Waiter robots will need legs and arms like a human being to move anywhere and manipulate anything. They will also need some skills to develop complex tasks. All these questions will be discussed in the following section.



Figure 8. Different and possible scenarios within a restaurant in which a waiter robot should be able to manage. From left to right and from top to bottom, there are some architectural obstacles such as stairs, an area of tables, other waiters and guests, ramps and entrance or exit doors.

5. The Approach to Develop a Waiter Robot

During the process of developing a robotic platform, it is essential to consider what the objective of the robot is. For example, a rover-type robot will move faster and better than a humanoid robot on uneven terrain. An RGB camera will not contribute to an underwater robot. Therefore, it is necessary to know what tasks will be developed by the robotic platform, to define the characteristics and skills of this one. In the case of a social waiter robot and this changing environment, the robot should be able to do some diverse tasks. A survey of the most important tasks is presented in the next list:

- Take orders from guests like food and drinks
- Deliver orders to the correct customer.
- Welcome clients at the entrance.
- Guide customers to their seats.
- Cheer clients up by recognising their mood.
- Take reservations for the seat.
- Grasp dishes or drinks.
- More duties ...

All these possible tasks to be developed by a waiter in a restaurant or pub are related to different robotic topics. Some of these topics are social interaction with human beings, navigation, manipulation, computer vision, task planner, and others. In the end, taking into account these considerations, requirements, and the workspace environment, it could be possible to define the fundamental skills so that a robot can behave like a waiter. In the case of a waiter robot, there are four main features or skills: Robot Architecture, Human–Robot Interaction, Robot Planning and Plan Execution. These characteristics are described next.

5.1. The Architecture for the Waiter Robot

Careful design of the shape of a robot can reduce the use of perception and control systems, neutralise the uncertainty and improve senses. Social scenarios have multiple conditions with respect to industrial environments. The lack of adequate robotic platforms can be a severe obstacle to research. From my point of view, there are three crucial aspects of the architecture definition of a waiter robot: the form, the unknown, and security [57–59].

- “On Human Form” . Human scenarios are usually suitably adapted to the shape of human beings. Sometimes, benefiting of these conditions, humanoid robots are able to make easier handling works. For instance, in the human scenarios, we can find different objects over a horizontal surface in most case. A human could reach them adequately in these locations. In the same way, a humanoid should recognise and handle these objects more efficiently if its manipulator touch or its sensors point to this horizontal plane. Obviously, all the objects manufactured are conceived to be used by a human hand. So, we will design grippers with a variety of grip ranges to handle multiples and different objects.

A logical method to implement humanoids that emulate the human shape is taking advantage of the features of the scenarios where humans live. In this way, the waiter robot could go upstairs, or open doors locate dishes on the table or kitchen or interact in a friendly way with guests (Figure 9) [60–62].

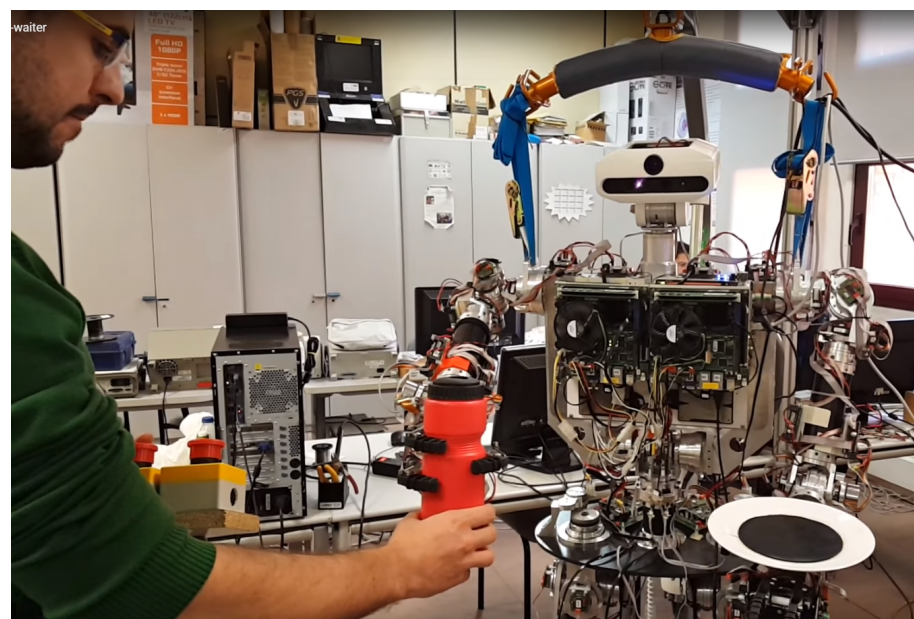


Figure 9. A possible and critical situation with a waiter robot while it is serving drinks.

- “Designing for Uncertainty”. Traditionally, industrial robots have avoided compliance control for the robot at the expense of stiff, precise, and fast operation. This one is a compromise on the design when the state of the job is known. Force and compliance control is more profitable for collaboration with customers safely in human scenarios. It can be applied while examining the environment or coping with uncertainty. In the design of a robot hand, a good example could be the optimisation of different parameters. The idea can consist of improving object grasp with uncertain physical properties. We can build a hand out of compliant elements of variable stiffness. We can incorporate position or tactile sensors or include tendons for the actuation. Combining the compliance of the hand and a new versatility, we could make robust grasping. Even it could grasp different objects with sensing uncertainties. Our humanoid robot developed by the “RoboticsLab” research group uses F-T (Force–Torque) sensors in both wrists of the arms. These sensors offer the possibility to have a compliant control of the tray of the waiter robot. This compliance allows us to work in unknown environments (external disturbance) and to adapt to geometric uncertainty (balance position). On our robot TEO, this compliant control helps to control the stability of the transported object in an unknown scenario where the robot can be disturbed by human’s hit, the whole-body controller, or the own balance control of the object [63,64].

- “Safety”. Robots have to be safe if they work with people. In the traditional industry, robots with manipulation are hazardous, so it is generally forbidden to enter into the workspace of a robot when working. The damage generally happens during accidental physical contact. Above all, impacts are the most critical, and those depend on the speed, mass and other characteristics of the robot [65].

There are already companies that are adding some security elements to their robots. Some examples of such companies are Neuronics or KUKA. In the case of Neuronics, the Katana robot has been developed. Its safety methods are based on the use of lightweight materials, low speeds and low power. In the case of KUKA, the IIWA arm is a robot with a compliance controller. The controller is capable of adjusting its compliance using the feedback of its torque sensors.

Other methods are based on mechanical safety like the Manus robot. This robot has some current limiters in the motors to avoid the forces of impact. In the case of the waiter robot, the ability to adjust the compliance of the body will allow better control of the stability of the robot and the transported object [66–68].

5.2. Interaction between Humans and Robots

It does not make much sense that a waiter robot cannot communicate with the customers. For example, in a restaurant or pub, it is necessary that the waiter robot understands and takes note of the orders of the clients. Therefore, elements or tools are required for interaction with humans.

In this way, several modalities could be used, but not all could be useful. This is going to depend on the task. Pointing to a menu may be less feasible than asking for a drink through speech. Nevertheless, a pointing gesture is more natural and automatic to show the table in which consumers should sit on [69–71].

Human–Robot Interaction (HRI) is a multidisciplinary area. It seeks more natural and active methods of interaction between robots and humans [72]. Mainly, the intentions of humans are expressed through speech, expressions, gestures and sounds. Waiter robots have to be conscious of those expressions and moreover understand them. Below, it is presented the two possible HRI modules equipped in the TEO humanoid robot. Depending on the scenarios, these modules could be combined to improve the robot’s communication capacity.

The first HRI system is the camera and the second one is the microphone. These two devices are located at the head of the robot. The reason is that the robot has to see and listen in the best possible way. Therefore, if we intend to interact with a humanoid robot, this is the most logical location. With these sensors, it is possible to develop basic functionality in the robot. Some examples are the detection or tracking of people, the recognition of facial expressions, acoustic localisation, the recognition of specific gestures, and others.

- “Detection and tracking”. This method is one of the most important HRI’s for interaction with humans. The detection or the tracking of people could be the first approximation for the use of other HRI methods [73–75].
- “Facial expression”. The identification of facial expression allows a waiter robot a natural way of interacting with clients. Robots can use this tool to know if their actions are executed correctly or to express empathy. Nevertheless, we must address some challenges before a waiter robot could fully employ this method of communication.
- “Acoustic localisation”. Based on acoustics and for humans, talking is an effortless way to communicate. Therefore, verbal communication is apparently the most intuitive way to communicate with a waiter robot. In this regard, a robot that can listen and talk will develop a robust interaction with humans [76].
- “Pointing gestures”. This one is another promising and intuitive way of communication [77,78]. Signalling with a gesticulation can show objects, locations, or the number of orders of the same drink for an application of a waiter robot. Describing the shape of an object or its localisation verbally can be more difficult and less precise than pointing the object [79]. However, pointing gestures are not easy to recognise [80].

The difficulty lies in a precise 3D detection of the positions of hands or the face in motion of a new client in a non-static environment under unknown and changing lighting conditions. Besides, the identification of a designated point at the appropriate moment is complex when the client is signalling the point.

5.3. Robot Motion Planning

Robot Motion Planning is usually responsible for solving the question of “how”. There are three problems to discover: “how can the robot move from one place to another?” (trajectory planning), “how can it reach an object?” (planning of movements), or “how can it perform the desired task?” (task planning) [81–83].

Mainly, trajectory planning and movement planning are considered in this sub-section. For the implementation of the navigation for mobile robots, an essential operation is the route planning. Moreover, there are other important actions like self-location, planning of routes, construction and study of maps [55,84,85]. All these operations are fundamental for a waiter robot inside a restaurant.

- “Robot location”. For the question “Where am I in the restaurant?”, robot location gives the solution. For the question “how should I get to the table?”, The route planning gives the solution. Or even, “where am I going?” In the end, the process of construction and interpretation of the map defines the geometric representation of the scenario of the robot.
Related to the waiter robot’s reference frame, the idea is to describe the position in the restaurant. This operation is necessary to know the position of tables, doors, or even people moving.
- “Path planning”. This one can be local or global. On the one hand, the planning of the local route is applied to dynamic scenarios. While the robot is obtaining sensory information and walking, this one is planning. Moreover, a different route is created if the environment has changed.
On the other hand, the planning of the global trajectory can only be done if the environment is static, without modifications. In this case, the robot knows the scenario correctly.
- “Motion planning”. This one is related to the method of selection of movements and their corresponding inputs. At the same time, all restrictions must be met (avoidance of obstacles, avoidance of risks, etc.).
Motion planning can be described as an algorithm based on a set of computations. These computations provide sub-objectives or set points for robot control. These computations and the resulting plans are based on a proper model of the robot and the environment in which it is moving [86].

5.4. Plan Execution

A series of movements is the performance of a planning system. These movements have a symbolic description—for instance, the execution of grasping and delivering an order in a waiter task can be composed by the next movements:

1. Move to a table.
2. Look for a proper workspace.
3. Manipulate food and drinks.
4. Come back and so on.

These movements still have a symbolic description. Such a description is not sufficient for the low-level controller. The planning system cannot understand how the table looks or where the drinks are. Hence, we need understandable instructions for the low-level controller, previously interpreting these movements by a plan execution system [87–89]. For the description of the plan execution to perform tasks in a waiter’s robotics domain to do multiple works, two approaches have been defined.

- “Pre-programmed capabilities”. In this procedure, the robotic platform has pre-programmed skills, like navigating to the kitchen, following a person, serve a drink, etc. Related to this strategy and based on commands, the robotic platform could do these works. Nevertheless, at the end, the solution of the performance of more and different intricate works in dynamical environments would be impossible.
- “Plan execution system”. The other method is to use a plan execution system. With the composition of different pre-programmed robot capacities, this plan execution system concedes the resolution of intricate tasks. For the domain of the waiter robots, it can be quite complex if all the objects should be modelled within the planning area (tables, chairs, other waiters, dishes, cutlery). This complicated domain can do the planning issue unmanageable.

A deliberative system supports the translation process (from actions to commands). Here, the plan execution system might request extra data to interpret the responses. For instance, it is possible to claim the deliberative system the position of other waiters or the location of the table where the chips should be served. The plan execution supervises the performance of the task to check if the objective is reached. In the case of a non-repairable failure, it will request the planning system to produce a new plan [44,90–93].

6. Conclusions

Nowadays, society is becoming more and more technological and is open to new advances in every aspect of the daily live. Robotics is growing by leaps and bounds, and every day, new robots are designed and manufactured by companies and research centres around the world. These new developments are slowly filling the technological gaps and opening new markets.

In this article, we have explained the importance of service robotics and how it is affecting its market economy. We can observe evolution in constant growth and expansion, and each year, more companies invest in the purchase of robots to improve their production and profits.

The review of the latest and most advanced service robots shows their great evolution in last years. Thus, their classification is more complex as well. This updated review presented divides service robots into two major classifications: professional robots and personal robots. Then, different subcategories has been established with the existing technologies but new categories are emerging.

The application of new tools and technologies causes the appearance of new robot solutions with greater and better abilities. The waiter robot has been chosen as an example of these new solutions, in an emerging category with open challenges. The waiter robots must connect their social interaction skills (typical of personal robots) with their motor skills in a restaurant (typical of professional robots). In fact, the catering sector is beginning to invest in robotics, and several companies are encouraged to create the first waiter robots. However, these developments still have limited features. Therefore, it has been proposed how the future waiter robot should be, taking into account several factors: the tasks to be carried out, the work environment, the architecture/design, the interaction with humans, the planning of the movements and the execution mode.

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