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Review

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Abstract: The 2021 sales volume in the market of service robots is attractive. Expert reports from the International Federation of Robotics confirm 27 billion USD in total market share. Moreover, the number of new startups with the denomination of service robots nowadays constitutes 29% of the total amount of robotic companies recorded in the United States. Those data, among other similar figures, remark the need for formal development in the service robots area, including knowledge transfer and literature reviews. Furthermore, the COVID-19 spread accelerated business units and some research groups to invest time and effort into the field of service robotics. Therefore, this research work intends to contribute to the formalization of service robots as an area of robotics, presenting a systematic review of scientific literature. First, a definition of service robots according to fundamental ontology is provided, followed by a detailed review covering technological applications; state-of-the-art, commercial technology; and application cases indexed on the consulted databases.

Keywords: robotics; service robots; human–robot interaction; healthcare robots; robot-as-a-service; smart cities; AGV; AMR

1. Introduction

The objectives of the present review focus on a specific area of robotics: service robots. Based on information gathering and database analysis, this work highlights definitions, main product research directions, and commercial technology currently used in the mentioned field. This study can provide valuable information for researchers and product developers to estimate the future value of investments in service robots research and development.

This work addresses the following research questions:

- What is a service robot?
- What are the main technological trends in the area of service robots?
- What are the most common applications of service robots?
- What are the main commercial technologies on-board of the most recent service robots?

Problem Formulation

The problem formulation for the present work is based on a systems-thinking perspective to avoid poor problem formulation.

- Undesirable situation: There exists a lack of specialization in trend predictions for service robots due to the nature of emerging technology.
- Assumptions: The development trends in this research area can be predicted through a literature review and will be useful among researchers.

- The Feasible Conceptual Future Desirable Situation: A compendium of actual service robots and literature trends will encourage technology development.
- The problem: To formulate a methodology that effectively helps to identify relevant information to provide significant figures and data.
- The solution: The development of a systematic literature review based on existing methodologies and its effective dissemination of results.

Based on the previous statements, this research problem is classified by its objective complexity as a Wicked Problem. It has no clear stopping rules since there is no definitive "problem" and "solution," and the problem ends with the consumption of the resources (time, energy, others).

2. Materials and Methods

This study used Scopus (Elsevier's abstract and citation database, Amsterdam, Netherlands), IEEE Xplore (Copyright 2021 IEEE - All rights reserved. A not-for-profit organization IEEE digital library, New York, NY, USA) and Google Scholar (Bibliographic database owned by Google LLC Mountain View, CA, USA) to conduct a systematic search of relevant scientific publications. The literature search presents six sectors: definitions and classifications, robot technology, state of the art, commercial technology, trends, and applications.

This study is a systematic review that searches for topics of service robots in scientific literature. To select and revise relevant papers from each section, the PRISMA approach was used [1], as well as the following criteria:

1. Recent (2010–2020) literature review ensures a revision of the current state of the art of the technologies applied to service robotics, prioritizing papers published during the 2015–2020 period. Figure 1a shows the distribution of the years of publications of the revised papers for this review.
2. Among the selected literature for each section, the most cited works were revised extensively. Figure 1b presents the distribution of the number of references with an increasing number of citations of the revised literature.
3. The search of papers prioritizes journals with high impact factors; most revised papers were from journals with an impact factor higher than 1.0. Figure 1c shows journal impact factor of the revised papers in this review.
4. Additionally, Figure 1d shows the type of references (journal, conference proceedings, books, technical reports, and others) selected and their percentage.

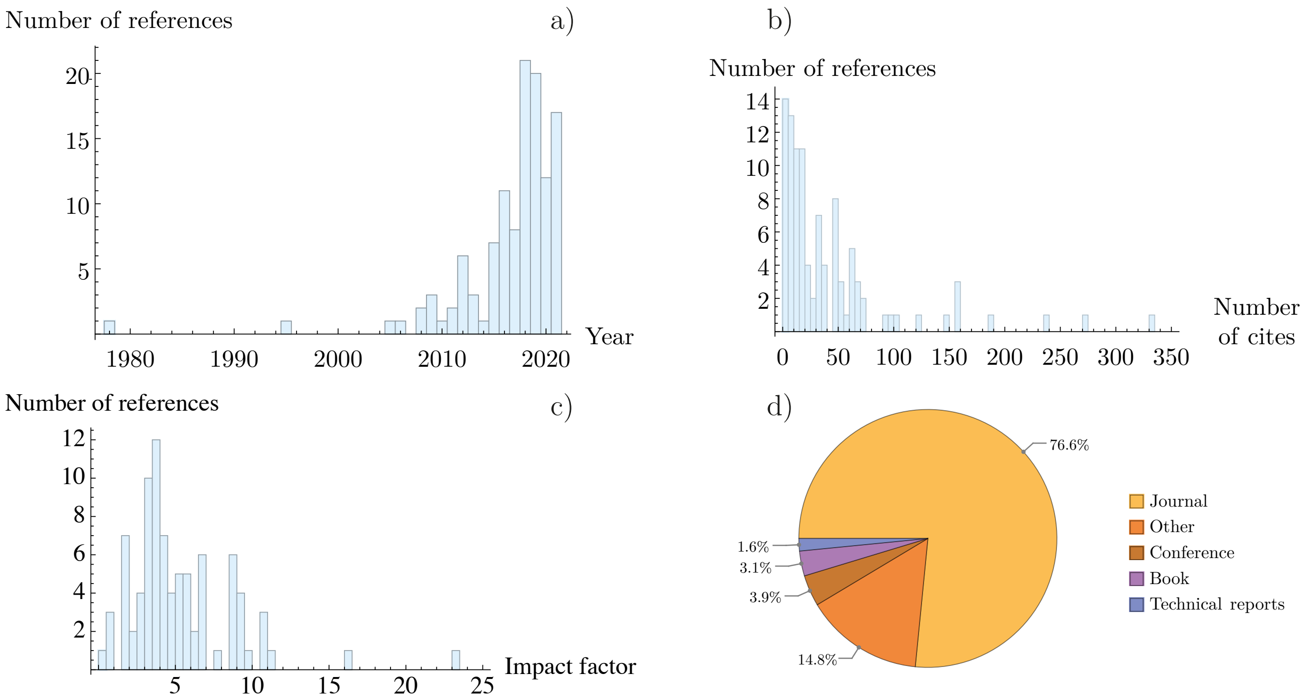


Figure 1. Statistics of the revised literature. A histogram shows the results of several reviewed references: (**a**) number of citations, (**b**) year of publication, and (**c**) impact factor. (**d**) Percentage of literature revised divided into journal papers, conferences, books, technical reports, and others.

3. Results

3.1. Definitions and Types

As part of robot categorization and definitions, the whole universe of robots can be divided into conventional and advanced robotics. Conventional robotics is also divided according to the fixation of the base; thus, one can identify mobile robots and robot manipulators, and conventional robotics also includes industrial robotics [2]. Following this idea, service robots belong to the field of advanced robotics. This general definition is valid but very broad, mainly because the field of robotics is a very vast research area, and proposing a general and universal definition is not a trivial task [3].

Towards the search of a better standardization, some committees have worked to develop an ontology that unifies entities in the field [4]. The ISO (International Organization for Standardization) organized an expert committee in 2007 to accomplish this task and the efforts materialized into the ISO 8373:2012 standard that defines a service robot as a robot that performs useful tasks for humans or equipment excluding industrial automation applications [5]. The International Federation of Robotics (IFR) agrees with such definition and appends that the robot needs to have a semi or fully autonomous behavior [6]. Other authors consider the incorporation of a natural communication system and the presence of artificial intelligence (AI) as a must in the category of service robots [7,8] to allow such robots to adapt to an uncontrollable environment. Moreover, the IEEE RAS (Robotics and Automation Society) has dedicated efforts in the task of unifying terms using advanced applied ontological methodologies [9] that aim to validate existing ontologies for consistency. By the time this work is written (2021), some advances exist on the generalization of definitions, entities, classes, and agents [10,11], but there is still work to be undertaken in this sense. Some benefits of standardization and generalization are the facilitation of design, production, knowledge, and technology transfer processes between groups and among the Research and Development areas to properly determine a paradigm in terminology and formalism.

The ISO standard, as well as the IFR [12], classifies service robots in two main classes, as can be observed in Figure 2. The first class mainly includes robots for personal and domestic use, such as robots that perform domestic tasks, entertainment robots, elderly and handicap assistance, personal transportation, home security and surveillance, and other types of domestic robots. The typical applications of these robots include tasks of non-commercial nature.

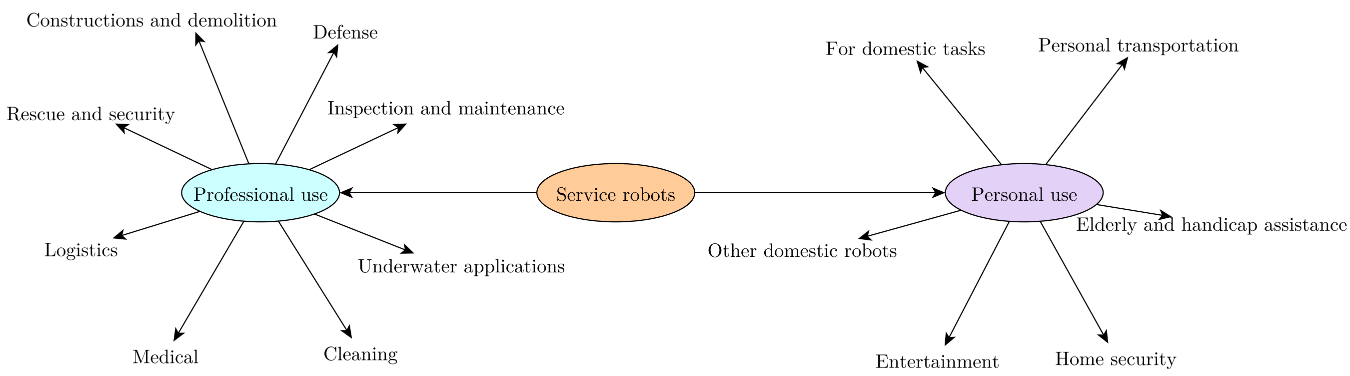


Figure 2. Taxonomy of service robots as proposed by the ISO 8373:2012.

Continuing with the classification, the second class is dedicated to service robots intended for professional use. The main taxonomy threads are field robotics, professional cleaning, inspections and maintenance systems, constructions and demolition, logistic systems, medical robotics, rescue and security applications, defense applications, underwater systems, and other professional service robots not specified above. The typical user for this kind of robot is an operator that has relevent former education or training in manual work. Contrary to personal robots, this specification involves commercial activities. The above classification can be better understood in Figure 3.

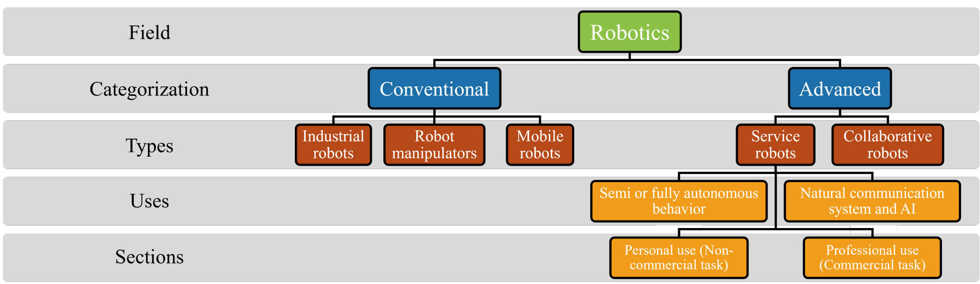


Figure 3. Robot categorization.

A complementary and more human-centric taxonomy is proposed by [9,13,14], where the main robotics definitions fall intro three classes depending on the human–robot interaction (HRI) level:

Class 1 The robot totally replaces the human worker in an environment that can be either hazardous or dirty and the task is usually of a tedious nature.

Class 2 The robot operates closely in cooperation with a human in order to increase comfort or minimize discomfort.

Class 3 The robot operates on the human body.

From the previous definitions arise some categorical problems. For instance, as pointed out by [9], an exoskeleton can be a medical robot when used in rehabilitation but can be a non-medical robot when used for assistance tasks, and can also be used in military tasks, contradicting the intended use of the robot. Further work is required to avoid ambiguous definitions, and ontology engineering provides the required framework for this disambiguation, as proposed by [15,16].

The technological stack of a service robot must address an uncontrolled environment and choose a clever combination of sensors in an integration effort to fulfill the required robot task to ensure a deep integration with humans [2]. Three main technical groups enable a service robot. These are software layers, contextualization, and human–robot interfaces. Software layers are primarily responsible for integrating the robotic device, connecting, and establishing a standard communication system for every component. Artificial intelligence is an important component of these robotic systems; tools such as TensorFlow or PyTorch execute machine learning algorithms and related tasks. Robotic systems need to know where they are and react properly based on their location, that is, to be aware of the spatial context of the environment [17]. This function is achieved via localization and sensorization. Finally, some human–robot interfaces implement its integration to the human workflow generally. Web dashboards, speech recognition, touchscreens, or even mobile device applications enable these interfaces. This technological stack is presented in a graphical form in Figure 4.

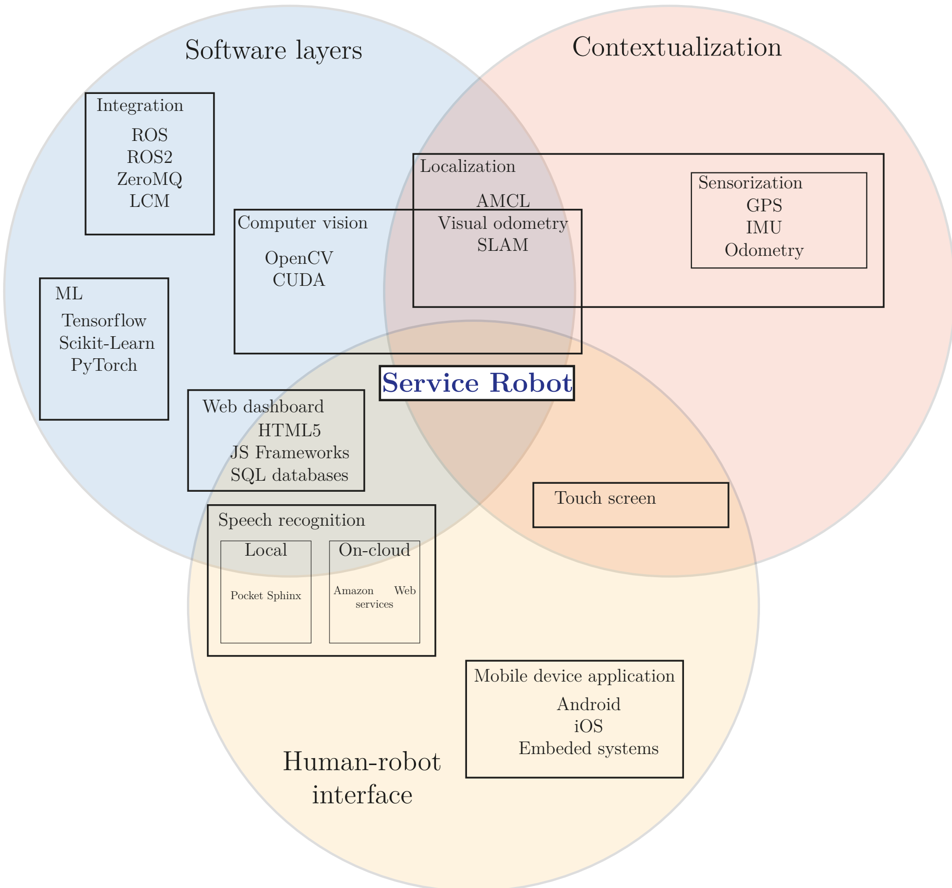


Figure 4. Common components of a service robot with examples of the technological stack available as in 2021.

Background

The technological evolution of service robotics is very vast and extensive. Its technological development will boost economic interest in different areas of growth and future market niches. There are some emerging visions and opportunities to develop new technologies and services, such as the Internet of Robotic Things [18] as a merge of pervasive sensors with robotic and autonomous systems. Another example is Robot Process Automation (RPA) as an emergent technology that mimics the steps taken by a human to complete a task [19]. RPA implies the automation of repetitive processes that involve routine tasks, structured data, and deterministic outcomes [20]. The optimization of RPA routines uses different techniques grouped in Robotic Process Mining (RPM) [21]. Its function is to determine the importance and prioritization of a routine or task, converting the RPM in a functional tool to RPA routines. Despite the progress made so far, it is important to state that to keep researching and developing new service robots and automating tasks, there must be at least one economic reason to do so. Complementing the above, the banking and financial industry is a fundamental pillar and one of the main drivers of digital disruption [22]. In the near future, new technologies, trends, and applications of service robots will emerge. However, is there a way to forecast a service robot's impact and the future trends that service robotics will have? To answer this question, we need to look into technological evolution to predict disruptive innovations and identify which service robotics technologies are likely to experiment with fast growth and development. Due to this reason, we are going to look into several theories related to technology evolution.

The theory of technological parasitism for the measurement of the evolution of technology and technological forecasting [23] aims to measure the evolution of technology. It takes the ecology of parasites and their evolvement as a reference to estimate technological growth and its dynamics. This approach foretells which innovations and developments are likely to have fast progress and an easy society acceptance. This research, to achieve the measurement of the evolution of technology, takes several approaches (hedonic, RAND, functional and structural, wholistic and holistic approaches) [23]. It concludes it is possible to have a measure on the technological evolution, but is challenging and complex to foretell which technological innovations are going to have fast growth.

A theory of classification and evolution of technologies within a generalized Darwinism [24]. Following the previous theory, the synergy between humans and technologies propagates and generates a parasitic ecosystem. Thus, this idea implies that all the agents participating in the ecosystem are supposed to benefit. In this theory, a taxonomy is presented to differentiate the possible human–technologies interactions (parasitism, commensalism, mutualism, symbiosis, amensalism, or competition) [24]. This classification between humans and different technologies proposes an explanation of how the technology evolves, how complex systems are going to be socially implemented, and the impacts the different interactions are going to have on the economics of innovation.

A theory of the evolution of technology: Technological parasitism and the implications for innovation management [25]. The adaptive behavior derived by high competition between firms and nations impels the technology evolution. In this theory, it is stated that host technologies that have a high number of technological parasites are more likely to have an accelerated evolution, rather than the ones who have low technological parasites. This condition results since having more "parasites" involves having more complex systems, with more interactions between technologies and more benefits driven by those interactions. It also considers that because a specific technology has more "parasites," more humans are focused on developing new operations and uses (could be performed through a host technology or a parasite technology).

The above can be a very general view of technological development. However, it allows us to lay the foundations to estimate future disruptive inventions and the impacts of innovations on social dynamics. Moreover, the change generated by disruptive technologies highly tends to change competitive advantages that a firm could have in a determined market. Some examples of firms that implement disruptive technologies are Apple Inc. (introducing wireless headphones to the market) and AstraZeneca (generating innovative treatments treat lung cancer) [26]. However, these new technologies imply a change in industrial behavior, leading companies to destroy (directly or indirectly) older products, goods, or technologies, to keep their leadership on their market, maximize profits, and/or protect competitive advantages [27]. Nevertheless, constantly generating innovations can be a problem for companies if they are not planned incrementally. To solve this, Coccia presented a conceptual framework of problem-driven innovation to explain industrial and technological change and the importance of solving problems by researching and developing radical innovations, either to maintain competitive advantages, maximize profits, or stay leaders in their sector [28]. Moreover, firms must consider the behavior that technologies have in the market since there is an asymmetry in the technological cycle of disruptive innovations (having a down phase shorter than the up phase) [29]. Empirically speaking, this behavior depends on the offer and demand on the markets, the grade of acceptance of a particular product that uses disruptive technologies, and by what firms want to sell.

Given all the above, it is crucial to consider the impact that service robots will have on the economics of innovation, its life-cycle, and that they could be a radical innovation in some fields that destroys or replaces the operation worth of preliminarily established technologies applied and used in markets [30]. There is a variety of tasks that researchers must develop for the use and implementation of service robotics, such as object detection, task/motion planning, activity recognition, navigation and localization, knowledge representation and retrieval, and the intertwining of perception/vision and machine learning techniques [31].

There are many areas of opportunity to apply service robots; however, there may be countries that have very incipient markets for the use of these new technologies, so one option may be to resort to foreign markets [32]. Besides, giving robots with cognitive and affective faculties, by working out infrastructures that allow them to establish compassionate connections with people, is a priority task [33]. Definitively, due to the constantly changing social mindset and current status quo of humans, the discussion on social, ethical implications, and concerns of using service robots is open, but the economic impact and social changes that service robots produce will likely accelerate their technological evolution.

3.2. Robots Technology

An under-studied field of research is the economics of technical change and technology management. A theory on the classification and evolution of technology considers the taxonomic characteristics of the interaction between technologies. The proposed classification makes an analogy with the evolution of parasites considering generalized Darwinism: parasitic technologies, commensal technologies, mutualistic technologies, and symbiotic technologies [24]. The classification of parasitic technologies is based on parasite–host relationships, and it has been shown that technologies with a high number of parasites have a high evolution. This theory provides a new perspective to explain and generalize the evolution of technology to sustain the competitive advantage of companies and nations [23].

The rapid development of service robots is mainly due to the fourth industrial revolution. In our current era, a person can obtain information and technology from the internet. However, due to the inherent speed of technological changes enjoyed by today's society, it is often overlooked and tends to be forgotten. All this technological research and development would change humankind and how it is and, according to Schwab [34], there are three main reasons why the ongoing fourth industrial revolution is changing our daily lives: The velocity in which current technology is evolving (exponential growth rather than linear growth), the breadth and depth the information has reached in today's society, and its impact on entire systems that are changing their paradigms from a micro to a macro level [7].

Before even starting to explain the new technologies that service robots are bringing and implementing, we need to go into depth into the levels that society will be affected, besides the tasks that will be executed by service robots. Taking up what was written by Wirtz et al. [7], alongside the micro-level, using service robots in different areas would bring advantages such as personalized service for each person/client, homogeneous quality service, accelerated learning, interconnection, to mention a few. Along the meso-level, service robots will become a solution to a market necessity, a commodity instead of a critical source, and reduce payroll expenses. Along the macro-level, service robots will reduce the number of unattractive, time-consuming jobs that imply task repetition and the need to be present in one place due to the nature of the job (as a receptionist for the hotel), which would directly lead to a reduction in expenditures in general.

Across the literature reviewed in this paper, and taking into account the classification presented by Rubio et al. [35], we can resume the current uses, developments, and applications of service robots in the different operations areas as shown in Figure 5. This search used the ScienceDirect and Scopus databases during September 2021. It should be noted that the research carried out to establish a state of the art (SoA) for this work could be biased due to the large fields of application that service robots have. We include the leading research and developments that other researchers and peers have been undertaking; however, there may be more information about other applications not considered in this paper.

Delving into each area reviewed in the literature, the leading technologies applied to service robots can be identified. In the area of health, especially in the area of mental health, chatbots and virtual embodied artificial intelligence (AI)-supported psychotherapeutic devices are being tested to deal with anxiety and depression [36]. In addition to this, some of the disruptive technologies applied for the analysis of COVID-19 are the Internet of Medical Things (IoMT), data science and big data, blockchain, virtual reality (VR), telemedicine, 5G, AI, drones, and autonomous robots [37]. Nowadays, the creation of a mobile healthcare robot is possible thanks to AI, machine learning, facial recognition, and teleportation technologies [38]. There are arising openings for the operation of robotics to endorse ubiquitous healthcare that may reflect in cheapening medical expenses and adding the amenity of cases and people in general [39]. Alongside the education field, educational robots are implementing different learning models to enhance learning student performance. There is a wide variety of models such as adaptive learning, agent-based learning, and smart learning [40]. Other implementations are teleoperated, autonomous, and convertible robots to assist elementary school teachers during classes [41,42].

In the technology and kinetics area, unmanned aerial vehicles (UAV) require a ground control station (GCS), batteries, fuel cells, or hybrid power sources to work, as well as power management strategies for real-time monitoring of power consumption (rule-based and fuzzy logic strategies) [18]. Unmanned ground vehicles (UGV) require the development of robotic frameworks and platforms. Some of them are the Robot Operating System (ROS), Middleware for Robotic Application (MIRA), Yet Another Robot Platform (YARP), Lightweight Communications and Marshalling (LCM), Mission Oriented Operating Suite (MOOS), and Universal Robotic (Urbi), to mention a few [43]. Moreover, rescue robotics as autonomous robots should use field-deployable technologies and work in real-world environments [44]. Some service robots and robotic platforms tested in farms and factories use IoT, edge, and cloud computing through virtualization and AI technologies, pushing its commercial adoption [45,46].

There are also great opportunities and growth areas in the field of leisure and recreation, starting with the tourism sector; technologies such as information-centric networking, cloud computing, big data, blockchain, AI systems, and IoT are essential in the development of robotics in tourism [47]. Traditional hotels will have to transform into smart hotels and implement interconnectivity and interoperability to support business partners' applications, use big data to forecast revenues more precisely, and use instant translation devices to avoid miscommunication [48]. Not only will resorts' experiences change, but the shopping customer experience will change due to service robots. The implementation of neuroscience, business process automation, blockchain, digital twins, VR, AI, mobile robots, location-based wearables, and machine-to-machine interaction through IoT by organizations are going to provide immersive and personalized environments to consumers [49]. Moreover, the inception of humanoid service robots (HSRs) by companies will generate competitive advantages against their competitors and trigger compensatory consumer behavior [50]. However, the use of service robots is not only limited to experiences and buildings; direct robot–human interaction will go further due to the use of wearable affective robots that will imitate cognitive competencies. Examples of these service robots are social robots that recognize emotions, affective robots, and intelligent brain wearables that recognize electroencephalography (EEG) data. They use natural language processing, pattern recognition, data mining, and other machine-learning techniques to achieve a human brain working mode simulation [51]. Lastly, service robots related to sexuality are no longer a fantasy due to the interest in human–robot interaction focused on sexual robots programmed with AI [52].

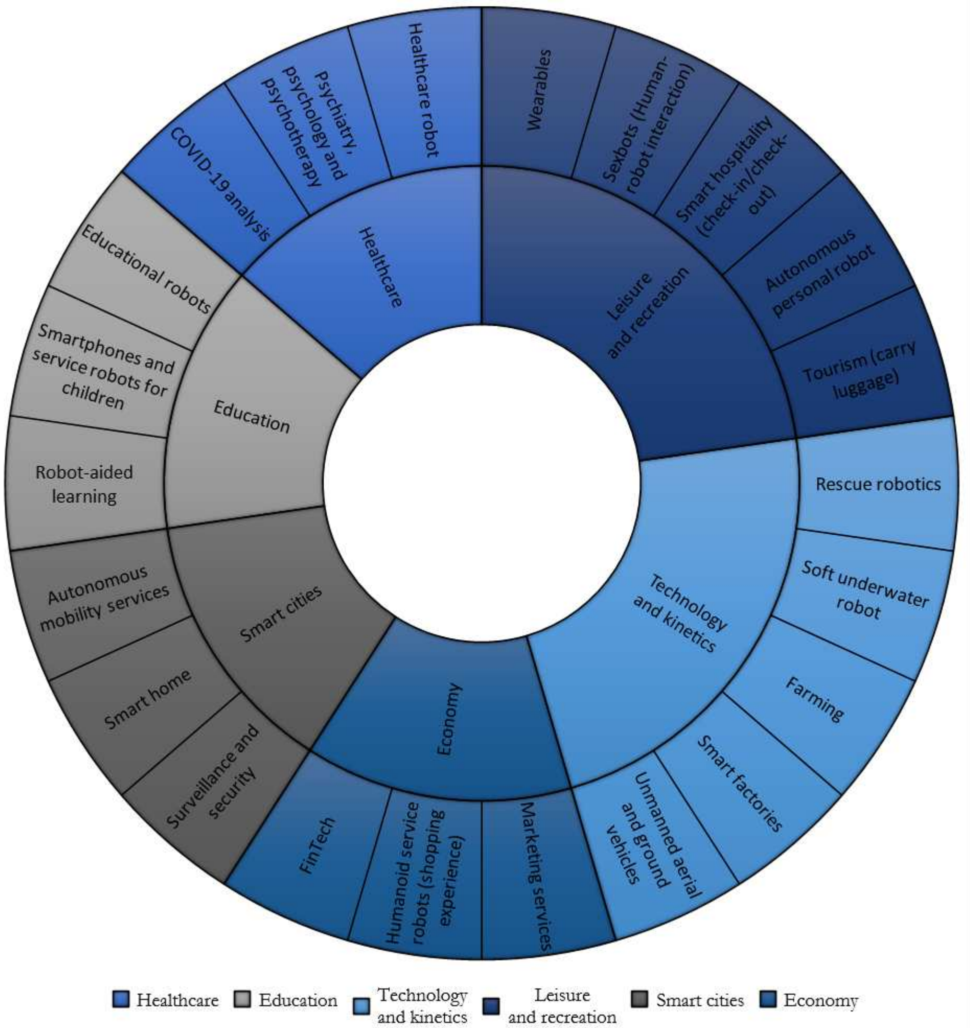


Figure 5. Uses and applications of service robots in different operation areas.

Thinking about smart urban environments, autonomous vehicles (AVs) is a concept that comes to mind. Technologies related to AVs are vehicles automation, automation, and electrification of public transportation, and electric propulsion [53]. Moreover, the term smart home is becoming more relevant, implying the use of cloud servers, cloud learning services, and machine-learning algorithms. Besides, a home service robot must be capable of recognizing human body activity, tracking a human position, sound-based human activity monitoring, and fall detection and rescue [54]. Assistive robots can also be used as caregivers in smart homes for elderly people [55]. Context awareness is an important topic related to surveillance. To achieve a context-aware model applied to an intelligent surveillance robot, techniques such as data mining, Bayesian network, collaborative filtering, and machine learning are applied [56]. People's economy is an important topic to consider; therefore, the development of financial technology (FinTech) supported by AI is vital for the world's economy [57]. Self-service technologies (SSTs) such as automated teller machines, self-checkouts, and self-service kiosks are likely to use and implement service robots with human-like characteristics such as memory, gaze, and gestures [58].

As shown below, the principal technologies related to service robots are artificial intelligence, the Internet of Things, human recognition, machine learning, blockchain, and big data. Table 1 states and summarizes some keywords used by authors.

Table 1. Operation areas, applications, and keywords related to service robots.

Operation Areas	Applications	Keywords
Healthcare	Interacts directly with humans, handling routine logistical tasks, disinfecting rooms, helping transport patients, moving heavy machinery.	Artificial intelligence, ethics, medicine, robotics, COVID-19, blockchain, Internet of Medical Things (iomt), Industry 4.0, healthcare, 5G.
Education	Serve as a tutor or a peer in a student's home. Teaches and quizzes a student on the topics they are having trouble with in the classroom, be controlled by a teacher.	Children's learning, N-screen, remote control, robot-based learning, streaming, hardware design, sign language, social child–robot interaction, service agent.
Technology and kinetics	Uses in military, scientific, agricultural, commercial, policing, surveillance, product deliveries, distribution and logistics, aerial photography fields, calculation, and decision making through artificial intelligence algorithm.	MATLAB, multibody dynamics, robotics, wheeled mobile robot, extreme environments, IoT, edge-computing, artificial intelligence, power supply, energy management, locomotion, navigation, perception, sensoring.
Leisure and recreation	Diversified booking method, improved pre-arrival experience, increased personalized data collection, new costumer experiences, shopping assistant, chatbots-as-a-service, exhibitions, and events.	Artificial intelligence, automated tourism, intelligent automation, service robots, customer experience challenges, physical and social realms, emotion cognition, social robot.
Smart cities	Establish the digital model of physical space and social space, collect data of the environment and its own operation, respond to various needs in real time.	Assistive technology, elderly care, home service robot, smart home, IoT, surveillance robot, intelligent service, context awareness, future service scenarios, value networks.
Economy	Increase in productivity in service organizations and their ability to generate insights. Robots can open spreadsheets and databases, copy data between programs, compare entries, and perform other routine tasks.	Artificial intelligence, finance, robo-advisors, robots, technology adoption, anthropomorphism, humanoid service robots, human–robot interaction, public service, trust, turn-taking.

3.3. Commercial Technology

Currently, the technology level in service robots is emerging; that is, the technology started to be commercialized by some vendors. Industry leaders have pilots and deployments in commercial service robots such as SoftBank Robotics, Furhat Robotics, Smart Robotics, and Temi. From a consumer perspective point of view, this level of maturity implies the very first generation of products, a very high price, and customization. Accordingly, a few firms dominate personal service robots, mainly taken by vacuum cleaners such as iRobot, approximating the market as an oligopoly.

Within the global market, there are different items of service robots, with some sample commercial robots presented in Table 2. There are applications on logistic, defense, public environmental, medical, field, exoskeletons, construction, inspection and maintenance, professional cleaning, and other uses. It is essential to mention that, for the most part, from 2018 to 2020, the sales of each item doubled. Moreover, the sales value of professional services robots has increased by 32%, which means 11.2 billion USD from 2018 to 2019 (data taken from EMIS). Furthermore, the COVID-19 pandemic can potentiate this growth. Robotic disinfection solutions, robotic logistics solutions in factories and warehouses, or robots for home delivery are examples of this trend, according to the World Robotics 2020—Service Robots report, presented by the International Federation of Robotics (IFR).

A significant sector that is currently adopting service robots is the hotel sector. As presented in [59], there exists a correlation in positive online reviews of hotel services to the use of service robots, and it also happens to increase the motivation of guests to write a review providing evidence of the service given by the robot. Another example of early commercial adoption of this technology is the catering and delivery business. According to [60], malls and university campus cafeterias are adopting delivery robots in order to reduce queue lines, thus reducing the mean delivery time. Such a study demonstrates an increase in business profit up to 95.4% when implementing the so-called Contactless Meal Order and Takeout Service (MOTS).

However, as of today, in 2021, market researchers, [61], have studied the relationship between the perception of value in consumers and users of service robots. A categorization presents the relative value of the robot as hedonic or utilitarian (hedonic refers to the value that enters via emotion or feelings, utilitarian value refers to value selected via rational behavior or monetary value) in different aspects such as hotels, hospitals, airports, and other tourism activities. The cited study throws two important conclusions: the utilitarian value is essential to obtain customers, and the hedonic value will attract more clients and *catch the eye* of the new possible users. Such values prompt a design guideline in the future of service robots. The following main conclusion suggests that, at the current stage, users are unlikely to pay attention to the utilitarian value of service robots. However, the more engaged society is with this kind of robot, the more likely it will increase actual utilitarian value.

The perceived responsibility in case of malfunction of a service robot triggers another pitfall when developing commercial technology. The work by [62] calculates the *degree of responsibility* in the errors that happen on the robot end and on the user end. The results happen to be inconsistent with the self-serving bias [63], which states that people attribute their successes but not the failures. In the study context, the adverse outcomes (errors and undesirable situations) are attributed to the service customer/user, and positive outcomes are attributed to the service robot.

Table 2. Sample commercial service robots.

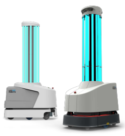
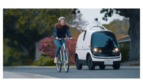
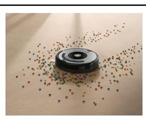
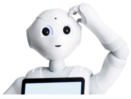
Figure	Commercial Name	Developer	Classification	Application
	UVD Robot [64]	Blue Ocean Robotics	Professional use—Healthcare—Class 1	Cleaning surfaces using UV on hospitals.
	MyAppCafe—Street barista [65]	My App Cafe GmbH	Personal use—Food—Class 1	A robotic manipulator is installed in a cell and serves coffee with no human help and using a mobile application interface.
	EksoNR [66]	Ekso Bionics	Professional use—Healthcare—Class 3	Exoskeleton that aids and accelerates therapy among users that suffer spinal injury.
	Nuro R2 [67]	Nuro Inc.	Personal use—Delivery—Class 1	Autonomous mobile robot that drives through the city and delivers goods requested using a mobile application.
	Roomba [68]	iRobot	Personal use—Cleaning—Class 1	Floor vacuum floor cleaner.

Table 2. *Cont.*

Figure	Commercial Name	Developer	Classification	Application
	Pepper [69]	SoftBank Robotics	Personal use—Multiple uses—Class 1	Humanoid that recognizes faces and emotions is currently used in airports and schools to provide assistance.
	Turtlebot 2 [70]	OSRF	Professional use—Education—Class 2	Low-cost robot kit for prototyping and learning.

3.4. Scientific Literature

Due to the rapid advances in robot technology combined with AI, the creation and implementation of service robots in different industrial sectors have increased dramatically. Service robots can be in different forms; they can be virtual, chatbots, humanoids, and non-humanoids [61]. Thanks to the advances in robotics and the implementation of AI, machines can perform even more complex and repetitive tasks [59].

Some AI and natural language processing applications emerged as a COVID-19 response to protect and prevent further damage due to the health crisis that emerged in 2020. An example of this technology implementation is the Intelligent Voice Assistant for Coronavirus Disease Self-Assessment, a deployment that successfully merges natural language processing and cloud computing to create a virtual service robot that helps to diagnose symptoms related to COVID-19 [71].

The demand for service robots grew for the attention of social distancing and health-monitoring protocols due to the COVID-19 outbreak. Therefore, many industries have opted to include service robots as part of their staff to improve customer experience, service quality, and efficiency, as well as to reduce labor costs [72]. For example, service robots can provide more accurate services reducing mistakes and becoming more reliable and consistent than human employees. More importantly, robots can perform tasks without stopping, at a faster pace than humans, as well as carry multiple, repetitive, and mundane tasks without protesting [72].

Human–robot interaction is in constant development; the acceptance of service robots has flourished. To illustrate this idea, Figure 6 shows a prediction of the near future on the potential development of service robots. However, since it still is an early stage of development of the service robots, some groups of persons are open to their use, while others express concerns related to the negative consequences [61].

The recent and fast development of robotic technologies has inspired tourist corporations to adopt service robots. An excellent example of this is the service robot "Pepper". The benefits of this adoption were a noticeable increase in the customer's satisfaction, as well as creating a positive word-of-mouth [73]. For instance, medical robot assistants are being used to monitor patients and alert the medical staff when needed. Nowadays, the implementation of robotic medical assistants has increased due to the COVID-19 outbreak, resulting in a valuable and efficient way to monitor and control highly contagious diseases patients [74].

An exploratory study reveals that service robots are becoming a popular and more recurrent feature in tourism. This study suggests the tourism market perceives implementation of service robots as valuable, not only for interested technological visitors but also by an increasing number of customers [59]. Other studies have implemented service robots in restaurant companies to reduce work hours and improve service quality. The restaurant industry suffers from product losses constantly when the total demand exceeds the service production capacity. Results demonstrate the robots have reduced 20 work hours of the service staff, also improving labor productivity (sales per hour) and reducing the losses dramatically due to lack of production; with the implementation of service robots, the service production sustained a higher and more efficient pace [75]. Current robotics applications will be covered in the next section. Moreover, we wondered about the terms associated with our search, so we constructed two different word clouds. One including single keywords used by the authors in the reviewed papers (see Figure 7) and one including composed keywords (see Figure 8).

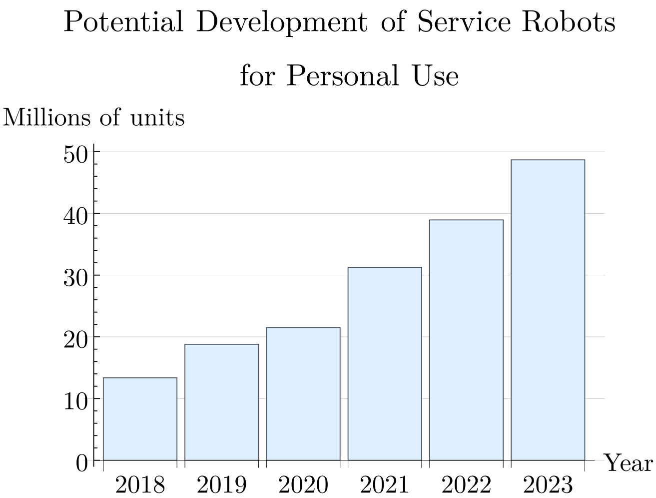


Figure 6. Service robots potential development for personal/domestic use.

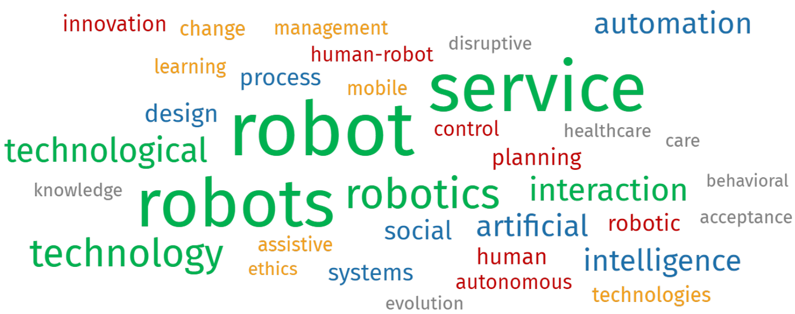


Figure 7. Word cloud of simple keywords used by authors in the reviewed literature.

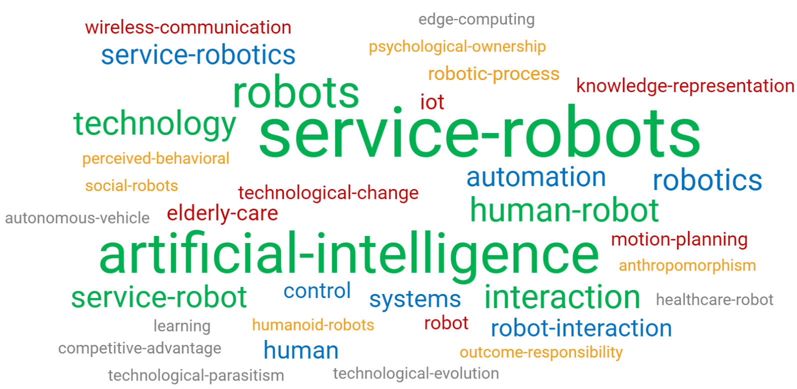


Figure 8. Word cloud of composite keywords used by authors in the reviewed literature.

3.5. Applications

There are several applications where service robots can add value; due to their versatility, the different needs of each industry will lead the design process.

A new frontier entering the market in industrial robotics are new, easy-to-use collaborative robotics solutions, where the robot advantages such as precision, speed, and repeatability come together with the flexibility and cognitive skills of human workers [76]. In the past years, industrial robots were robust, used to perform a specific task, and placed into a cage for the safety of others. However, collaborative robots are designed and prepared to interact and work alongside humans [77].

Recently, the development of collaborative industrial robots for the manufacturing process has increased. There are automatic guided vehicles (AGVs), as observed in Figure 9, that are a type of service robots whose primary functionality is to help in the realization of internal transport processes [78]. Another application is the human–robot interaction (HRI), which is becoming a new trend thanks to technology and advances in perception, cognition, and control algorithms. As interest in these robots increases, so do the benefits of their implementation, such as productivity and production line flexibility [79], resulting in increased production and demand from industries to integrate them [80].

A significant application for service robots is daily-life assistance. It is very complex because, for comfortable assistance, the robot must recognize its surroundings, including the motion of humans, the position of the objects, and obstacles such as stairs [81]. The principal objective in this application is to reach effective communication between the robot, its real-world environment, and the people in it [82]. In such a situation, the robot must have a manipulator that can grasp, transport, and place objects, as these are fundamental capabilities for this type of service robot [83].

Figure 9. Example of AGV robots [78].

A robot-integrated smart home (RiSH) refers to a house that contains at least one service robot, a sensor network, a mobile device, cloud servers, and remote caregivers [54], so the service robot controls everything inside the house from afar. A telepresence robot system performs assistive functions to improve the well-being of elderly persons. It can assist them to do daily activities independently, to encourage social interactions to combat the sense of isolation or loneliness, and to help the professional caregivers in routine care [84]. However, in this scope, it is crucial to consider the acceptance of service robots by elderly people considering the psychological variables for proper interaction between people and technology [85].

Another application where service robots are being incorporated and are considered the workforce of the future is in operation and management, including the hotel industry [86]. In this case, a bellboy robot performs hotel-related functions such as walking alongside guests and providing information about the city and the hotel [87]. Depending on these functionalities and the total interaction with hotel guests, the overall experience of the visitors will change [88].

In recent years, the primary purpose of developing more robots has been to improve productivity. However, with the current COVID-19 pandemic, a more urgent purpose has arrived [89] where robots present significant advantages. We have been involved in the revolutionary development of mobile healthcare robots as there is a need for people to avoid physical interaction [38]. It enables the closer analysis of this need in order to ensure the regulation of social distancing rules [90].

Hand gestures will be the usual method to manipulate human–computer interfaces (HCIs); however, to assist people with motor disabilities, an HCI must be designed especially for them. The help of service robot platforms in communication with three-dimensional (3D) imaging sensors and a wearable armband explores this solution [91].

As technology advances, society must adapt to new trends. Therefore, students and teachers have incorporated some of the latest technologies, overcoming many obstacles in the process. One of these technologies is the NAO humanoid robot that is currently being used in computer and science classes from elementary schools to university classes in many countries around the world [92].

Regarding business and financial institutions, there has already been considerable progress automating specific tasks implementing RPA and RPM concepts. As an example, Vodafone combines RPA and RPM to identify non-standard orders that require a high level of human interaction, which helps to reduce the time invested into checking complex orders before delivering to a supplier [93]. In the banking industry, some cases using RPA are: automatic report generation, opening an account, audit and compliance, chatbots, anti-money laundering, among others [94]. The combination of RPA and IA can lead to improved operational efficiency and increase the impact on the economics of innovation. However, RPA implementation is limited to business and banking; industries such as insurance, manufacturing, logistics, government, and public security can also take advantage of this technology [95], thus, it is of utmost importance to determine the current degree of automation in an organization's business processes to correctly identify tasks and processes that can be automated or improved [96]. RPA is an emerging technology that will have many applications, but one of the critical challenges to fully take advantage of this technology is to transfer digital tasks (performed in an environment with a virtual desktop interface) to cyber-physical tasks and processes [97].

Service robots can navigate through inaccessible or unsafe environments for the Urban Search and Rescue (USAR), where human teams cannot enter. The principal features that these types of robots must have are speed, weight, robustness, reliability, affordability, adaptability to different environments or tasks, and provide excellent two-way audio and/or video communication [98]. As well as the shown applications in the previous section, service robots have become a significant worldwide trend. The following section covers some robotics trends.

3.6. Trends

The revision of the literature on service robots identifies diverse trends in the fields of healthcare, industry, home service, and multi-purpose indoor environments. Regarding the type of robots, trends in autonomous navigation [99,100], mobile robots [35], unmanned autonomous systems [101,102], and imitation learning systems [103,104] were identified.

Healthcare: The current global population trend has shown an increase in elderly persons, as well as an increase in more populated cities; therefore, there is a higher demand for healthcare services such as medicine and nursing [105]. According to Archibald and Barnard [105], three types of service robots oriented to health exist: doctor, nurse, and home health care robots. Regarding nursing robots, applications have been implemented for feeding assistance, automated soaping and showering for the elderly, robotic therapeutic companions, pharmaceutical transporters, pick-and-place patients in bed, and ambulation assistants [105]. A human action recognition algorithm using depth cameras, object detection, and human joint identification techniques supports patients with mild cognitive impairment (MCI) at their homes. Assistive living robots could be of use to MCI patients, as they can identify potential risks due to errors and avoid dangerous accidents [106].

Other studies have implemented physical exercise programs in elderly health centers with success. In this study case, 41 volunteers underwent a training program with a humanoid Aldebaran NAO robot and with a human coach [107]. The study results showed a good response towards the humanoid coach, at least for the training program. When analyzing a factual information task between robot and human, the human coach was more efficient. A biomechanical rehabilitation, one degree of freedom (DOF) robotic handle for post-stroke patients applies an adaptive reinforcement learning (RL) algorithm [108]. By constantly adapting the difficulty level of a virtual "nut-catching" game, depending on the skill level of volunteers, patients can learn at a faster pace while not losing their motivation.

A telemedicine robot (see Figure 10) was developed in [109], composed of a four-wheel base, a robotic arm, and a tablet, acting as the head of the robot. The robot also includes an array of ultrasound sensors and cameras. The robot allows automated navigation combining its sensors and actuators, including obstacle avoidance and object manipulation tasks (e.g., the floor and shelves). It implements routines such as TakeMedicine, WallFollowing, and Doorpassing. Other applications are also included, such as fetching, providing reminders, calendar, and interpersonal communication [109].

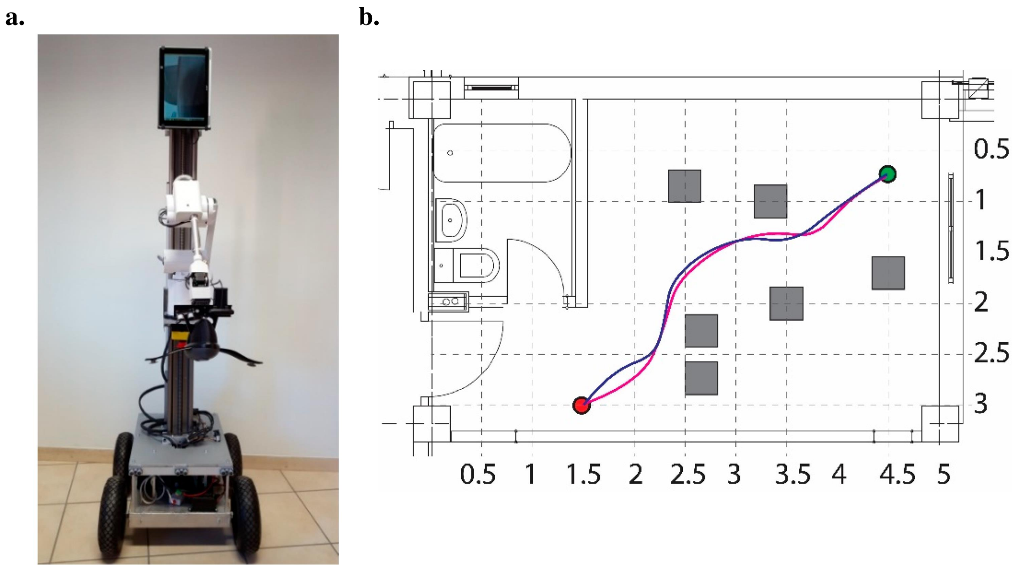


Figure 10. (**a**) Autonomous telemedicine robot system for assisted and independent living. (**b**) Simulated and experimental paths of an obstacle avoidance trial in a real-world scenario (center for the elderly), executed by the telemedicine robot developed in [109].

Industry: Different applications of service robots have been implemented for the industrial context. In [104], a machine learning technology enables a chatbot to provide support to customers in financial-product sales. Using robots to work continuously, text information from FAQs, call center response manuals, and office documents were used as input to a machine learning model to generate artificial conversation about bank services to interested customers. The use of unmanned aerial vehicles (UAV) has been reported in high risk tasks, such as transmission line inspection in China, Japan, Spain, and Britain [102]. By implementing UAV control and combining image processing and artificial intelligence, UAVs have performed autonomous inspection. These types of robots use a combination of visible light and thermal infrared sensing, as well as LiDAR technology [102]. Although UAVs are useful for safety purposes, manual inspection still outperforms in some scenarios, and it can also perform repairs, while UAV cannot.

Collaborative robots, usually robotic arms or semi-humanoid robots, represent an intermediate automation level between manual and fully automated manufacturing. In this approach, the robot acts as an assistant to a human during specific tasks. Vision-based collision prediction systems, capacitive sensing (skin detection), and safety design parameters, and routine instrument these types of robots [110]. Another typical application for industrial robots is object manipulation. An exciting study case is that of the first Amazon Picking Challenge [111], challenging 26 teams (primarily academics). The challenge involves designing autonomous robots to pick objects from a warehouse shelf. Objects of different shapes and sizes were used (Oreo cookies, an outlet protector, and a softcover book are some examples), and the teams used different approaches. Among the most common solutions were suction actuators, 3D imaging sensing, and a geometrical and/or color recognition approach for feature selection.

Home service: Some application trends in home service are in education, entertainment, household, social interactions, gaming, security, and rehabilitation [112]. A home voice-activated semi-autonomous vehicle robot was implemented in [113]. It consisted of a modified lawnmower and an IoT control module through voice-activated Alexa commands. Humanoid robots can help in house chores, grasping and carrying objects, opening doors, and entertainment [114].

Multi-purpose indoor environments: Positioning systems using sensor fusion for indoor positioning tasks mainly uses ultrasonic sensors and information from radar and odometry [115]. A mobile robot using a robust convolutional neural network (CNN) algorithm for person identification, tracking, and locking followed the identified persons through different rooms, with great accuracy [116]. The development of a robotic waiter system integrates different autonomous navigation algorithms and sensing approaches, such as IMUs, odometry, SLAM, and adaptive Monte Carlo simulation [100]. Artificial vision methods identify tables in a restaurant as well as persons. Another approach of indoor positioning, Steady Delivery, makes use of sensor fusion, involving radar, ultrasonic sensors, and odometry [117]. Table 3 presents the current trends of service robots.

Table 3. Service robots' current trends.

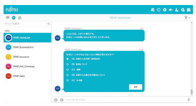
Field	Figure	Commercial Name	Robot Type	Application
Healthcare		Aldebaran NAO robot [107]	Humanoid robot	Physical exercise programs in elderly health centers.
		Care-o-Bot [109]	Mobile robot assistant	Implements routines such as taking medicine, wall following, and door passing.
Industry		Financial Services Solution Finplex Robot Agent Platform (FRAP) [104]	Chatbot	Provide support to customers in financial-product sales.
		Yaskawa Motoman [111]	Autonomous robot	Autonomous robot to pick objects from a warehouse shelf.
Home service		R1 [114]	Humanoid robot	Help in house chores, grasping and carrying objects, opening doors, and entertainment.
Multi-purpose indoor environments		Festo Robotino [114]	Mobile robot	Indoor positioning system for service robot applications.

Table 3. *Cont.*

Field	Figure	Commercial Name	Robot Type	Application
		Pioneer P3-DX [115]	Mobile robot	Wall detection and obstacle avoidance, autonomous navigation.
		Beta-G [115]	Mobile robot	Waiter robot (identify tables in a restaurant, go to the target table to serve the food).

4. Conclusions

From the presented review, the emerging status of service robots technology in the world and as a research area becomes more evident. This carries essential opportunities for early research, development, and investment in commercial technology as a strategic decision for long-term profit [118]. Despite the fact of the good will of robotics, some challenges are still present. Some of them are the lack of generalization and formalism in classifications and taxonomy [10], the current perceived utilitarian value [61], battery and autonomy modelling and estimation [119], ethics [36], and even design problems related to gender biases based on the occupation of the robot [120]. These challenges are opportunities for future research questions or different research groups. Moreover, a solid field of service robots is healthcare and cleaning robots. Consequently, with the COVID-19 pandemic, a push in these technologies was observed [37,90] and must be taken into account when performing research in this area. After the *accelerated development* in these technologies (caused by the COVID-19 spread) reaches a plateau, it may be an interesting research question to study the degradation or improvement in service robot-related areas. As a final remark, despite the fact of current opportunities and observations in the field, estimations [50] point that, one way or another, service robots will undoubtedly be part of our daily life in the near future. This study will help researchers as it provides valuable information on recent developments of service robots. This work can serve as a starting point for researchers when studying this field. Moreover, we consider it helps to estimate the future value of the investment in service robot research and development. Consequently, the readers will contribute to this work by producing more studies and expanding the research area.

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