1 Introduction

Chapter 1 reviews definitions and classifications of service robots.

1 Introduction into service robotics

1.1 STRUCTURE OF THE WORLD ROBOTICS 2022 - SERVICE ROBOTS

Chapter 1 introduces to the structure of this book and to the IFR service robot classification scheme. The classification by application is the base for IFR service robot statistics and chapter 3 of this book.

In 2022, the International Federation of Robotics (IFR) Statistical Department carried out a market survey of service robots for the 23rd time. From a list of over 1,000 companies worldwide, a questionnaire was sent out to ask for data on sales in 2020 and 2021 and expectations for the timespan from 2022 to 2025. Additional data was gained from desktop research conducted from July to August 2022. Chapter 2 presents the statistics resulting from this research.

Chapter 3 provides detailed information on application areas of service robots, including a collection of typical products, prototypes, and suppliers. This chapter was completely revised in this edition of World Robotics – Service Robots to comply with the revised application classification scheme. The brief examples of real-world applications provided in that chapter are complemented by more detailed case studies on the use of service robots that can be found on the IFR website at https://ifr.org/case-studies/service-robots.

Chapter 4 provides an overview of the service robot industry structure. This includes a list of all service robot producers that are known to the IFR. If you represent a service robot producer that is missing in our list, please contact IFR Statistical Department (statistics@ifr.org) so that we can add your company.

About the IFR Service Robots Group: Founded on October 9, 2002, the IFR Service Robots Group is open to all companies producing service robots, components, or related services. Next to the excellent networking opportunity, it is the right place to discuss all antitrust-compliant, industry-relevant issues and topics. For further information, please contact the IFR Secretariat (secretariat@ifr.org).

1.2 DEFINITIONS: ROBOTICS, SERVICE ROBOTICS, INDUSTRIAL ROBOTICS

1.2.1 1.2.1 STATEMENT ON REVISED ISO VOCABULARY DEFINITIONS (ISO 8373:2021)

In December 2021, ISO published a revised version of standard 8373. A first investigation of this update by IFR Statistical Department revealed potential implications for IFR industrial robot statistics. The IFR Service Robot Group will be discussing the revised vocabulary definitions in one of their future meetings and decide if adjustments to IFR definitions are necessary.

As the most recent survey had been conducted under the same definitions as in the previous year´, the following sections are still citing ISO 8373:2012.

1.2.2 ISO 8373:2012 VOCABULARY DEFINITIONS

ISO 8373:2012 "*defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments*" (§1). These vocabulary definitions relate to both, industrial and service robotics.[12] This section describes the ISO definitions needed to understand IFR classifications schemes and to distinguish IFR industrial robot statistics and IFR service robot statistics.

According to ISO 8373:2012, a **robot** is an "*actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks*" (§2.6). Actuated mechanisms that are lacking the number of programmable axes or that are fully teleoperated (no degree of autonomy) but satisfy the definitions of industrial or service robots otherwise, are called **robotic devices** (§2.8).

Note 2 to §2.6 determines that **the classification into industrial robot or service robot is done according to its intended application**. Industrial robots are robots "*for use in industrial automation applications*" (§2.9), while a service robot "*performs useful tasks for humans or equipment excluding industrial automation applications*" (§2.10).

Note 2 to §2.10 explicitly states that **the mechanical type/kinematics of a robot is insufficient to distinguish industrial robots from service robots**. Hence, by ISO definition, the application is a sufficient criterion to distinguish industrial from service robots, but the kinematics are not.

An **industrial robot** is an "*automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications*" (§ 2.9). Note that **the minimum number of axes is three for industrial robots but only two for robots in general**. Chapter 1.7 of World Robotics Industrial Robots provides an in-depth elaboration of IFR's definition of industrial robots and industrial robot classification schemes.

[12] ISO 8373:2012 Robots and robotic devices - Vocabulary; http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=55890.

A **mobile robot** is by §2.13 a robot that can travel under its own control. Its base is a mobile platform (defined by §3.18). By §3.20, automated guided vehicles (AGV) are "*mobile platforms following a predetermined path indicated by markers or external guidance commands…*" An AGV is therefore not a robot but a robotic device as it lacks the autonomy to determine its own path or navigate without external guidance.

ISO 8373:2012 further distinguishes personal from professional service robots. According to §2.11, a **personal service robot** is a "service robot used for a non-commercial task, usually by laypersons," while **professional service robots** are "service robots used for a commercial task, usually operated by a properly trained operator". The **operator** is a "person designated to start, monitor and stop the intended operation of a robot" (§2.17).

1.2.3 DEVIATIONS OF IFR DEFINITIONS FROM ISO DEFINITIONS AND IFR REFINEMENTS OF ISO DEFINITIONS – SERVICE ROBOTS

IFR generally defines robots according to ISO 8373:2012. There are, however, some details that based on IFR's experience are not helpful to unambiguously distinguish the different robot categories, or that might be in contrast to the primary goal of IFR statistics – which is to provide information on the robotics industry to inform the robotics industry. IFR service robot statistics will therefore deviate from ISO definitions in specific details described in this section.

Delimitation of industrial robots and service robots

IFR generally adopts the ISO criteria that define the application in industrial automation applications versus non-industrial automation as sufficient to classify a robot as industrial or service robot while the kinematic is not a sufficient criterion. Unfortunately, **ISO 8373:2012, §2.10 note 1** mentions only a few examples but does not provide a full list of industrial automation applications. IFR, therefore, developed its own application classification schemes for industrial robots (see World Robotics Industrial Robots, chapter 1.7) and service robots (see World Robotics Service Robots, chapter 1.4). These classification schemes have been developed in IFR's Robot Supplier Committee and IFR's Service Robot Group. The IFR Robot Supplier Committee has also defined **kinematic robot types as typically and mainly found in industrial robotics.**[13] By ISO definition, the kinematic type is not a sufficient criterion to qualify a robot as industrial robot. However, the Robot Supplier Committee decided to include all robots of typically industrial kinematic type in the industrial robot statistics. Robots with an industrial robot kinematic that are in service applications are, therefore, counted in both statistics: In IFR industrial robot statistics such cases are counted in application class 905 ("other applications") as well as in their actual application class in IFR service robot statistics.

[13] IFR industrial robot type classes are: 10 – articulated, 20 – cartesian/linear/gantry, 30 – cylindrical and spherical, 40 – parallel/delta, 50 – SCARA. See World Robotics Industrial Robots for more details on these types.

Autonomous mobile robots (AMR) are often used in industrial environments, but they do not satisfy the definition of an industrial robot: Neither do they have three axes, nor do they have manipulation capabilities. **IFR classifies AMR as service robots**. If the AMR is equipped with a robot arm (i.e. an articulated robot), **IFR statistics count the robot arm separately.** The articulated robot is counted as an industrial robot and the AMR platform is a service robot.[14]

Personal versus consumer versus professional service robots

ISO 8373:2012, §2.11 distinguishes personal from professional service robots focusing on the non-commercial versus commercial nature of the robot use. Based on IFR's experience, the inclusion of the commercial or non-commercial nature of the task does not offer any benefit but rather creates confusion. For example, social robots can be applied both in non-commercial tasks (as a fun gadget or as a toy at home), and commercial tasks (e.g. in care centers). Exoskeletons can be used to support workers, or in rehabilitation therapy (commercial tasks), or as a personal mobility assistant in everyday life (non-commercial task). IFR uses therefore the terminology **consumer robots** in contrast to **professional service robots**. Consumer robots are service robots that do not require professional training -neither for setup nor for operation- or as in ISO terminology: they are intended for the layperson. Examples are domestic cleaning robots, automated wheelchairs, and social interaction robots. In contrast, professional service robots require a professionally trained operator. Examples are cleaning robots for public places, delivery robots, fire-fighting robots, rehabilitation robots and surgery robots in hospitals.

1.2.4 SCOPE OF IFR SERVICE ROBOT STATISTICS

In contrast to the IFR industrial robot statistics, which counts robots only, **IFR service robot statistics include robotic devices in some applications.** One example are surgery "robots", which are (tele-) operated in manual mode and thus robotic devices because they lack autonomy. Another example are assistance robots for disabled people, which are intended to support only when needed. Application classes that include robotic devices mention this in the description (see tables 1.2 and 1.3). **Ground-based, aerial, and water-based vehicles are only included if they possess autonomous navigation capabilities** that exceed a simple autopilot function (steady course and altitude or depth).

Excluded service robot applications

IFR is the voice of robotics and represents the robotics industry. There are applications that use robot technology or technology that is often related to robotics but that is not represented by IFR. The following applications are excluded and not represented by the IFR:

[14] Even if the AMR is sold with a manipulator, this combination is actually two separate robots mounted together.

Military: IFR promotes the peaceful use of robots. The use of robot technology for military purposes is neither covered in World Robotics and IFR statistics nor does IFR represent this industry. **Dual use technologies are respected in their civil applications, only**.

Passenger transportation: The transportation of passengers in self-driving vehicles is an important future topic. Autonomous navigation technologies are used in robotics as well. Particularly in the segment of *outdoor delivery robots in environments with public traffic,* the challenges are similar to the ones faced in self-driving cars and buses. However, IFR considers passenger transportation as a part of the automotive industry. IFR does not represent the automotive industry and therefore World Robotics and **IFR statistics do not cover autonomous passenger transportation vehicles**.

1.2.5 SUMMARY: IFR SERVICE ROBOT DEFINITION

- **A service robot** is an actuated mechanism programmable in two or more axes, moving within its environment, to perform useful tasks for humans or equipment excluding industrial automation applications.
- In some applications, manually controlled **robotic devices** with limited or even without autonomy are included. This is particularly relevant if legal requirements prohibit autonomy (e.g. surgery robots) or the purpose of the application requires only limited autonomy (e.g. assistance robots for disabled people).
- A **consumer service robot** is a service robot built for use by everyone. Neither operation nor setup require a professionally trained operator.
- A **professional service robot** is a service robot built for use by trained professional operators.
- **Autonomous mobile robots** (AMR) are professional service robots. If they are equipped with a manipulator, the manipulator is separately counted as an industrial robot.

1.3 COMPLIANCE AND PRIVACY (SERVICE ROBOT STATISTICS)

IFR Statistical Department ensures the confidentiality of individual company data and compliance with antitrust regulations. Access to raw data is strictly limited to IFR Statistical Department staff. IFR Statistical Department will never provide company-level data to third parties neither outside nor inside the IFR. This means that IFR Statistical Department publishes only aggregated data. IFR Statistical Department will not reveal data if a data point consists of less than four observations. This is to prevent mathematical retrieval of company-level data.

1.4 CLASSIFICATION OF SERVICE ROBOTS

In the previous edition of this report, IFR introduced a new scheme that distinguishes service robots along two dimensions: the robot application and the type of movement. Both classification schemes consist of classes at the lowest level, which are aggregated to groups. The application classification scheme adds an additional hierarchy level, the category, which contains several groups.

There are four major types of movement that serve as the groups of this scheme. Service robots can move either ground-based (A), water-based (B), aerial (C), wearable (D), or none of those (E). On the class-level, ground-based robots can either be rolling (A1), walking (A2), be fixed in place (A3), or have any other ground-based type of movement (A4). Water-based robots can either be swimming (B1) or diving (B2). Aerial robots are usually flying (C1) but there might also be hovering robots in the future (C2). Similarly, wearable robots are powered exoskeletons (D1) today, but there might be other types of wearable robots (D2) in the future. Robots that do not fit into any of these classes, e.g. robots for orbital space or hybrid robots that fit into more than one of the above classes, can be classified as type E1. The full classification scheme including descriptions of each class is presented in Table 1.1.

Table 1.1

Classification of service robots by type of movement

Type		Description
A	Ground-based	Robots that move or stand on the ground
A1	Rolling	Rolling on wheels or chains
A2	Walking	Walking on legs
A3	Fixed in place	Immobile, cannot change physical location by itself, standing on the gound, desk or other fixed place, also hanging
A4	Other ground-based	Gound-based but none of the above (A1-A3), e.g. crawling, snakeing, climbing
B	Water-based	Robots that swim or dive (autonomous
B1	Swimming	Swim on the surface of the water, Note: If the robot can both swim and dive, it is counted as diving (B2)
B2	Diving	Dive under the surface of the water
C	Aerial	Robots that move through the air
C1	Fly	Flying in the air
C2	Hover	Hover above ground
D	Wearables	Robots that are worn by people
D1	Exoskeletons	Powered human exoskeletons
D2	Other wearables	Wearable robots other than D1
E	Others	Robots that are not A-D
E1	Other robots	Robots that do not fit into classes A-D, e.g. robots for orbital space Robots that fit into multiple classes, e.g. hybrid robots for water and ground or air

Source: IFR

The classification of service robots by application follows the concept outlined in chapter 1.2.4. This means, there are two distinct categories: consumer robots (AC – “applications, consumer”) and professional service robots (AP – “applications,

professional"). Chapter 3 of this book provides comprehensive explanations and examples of robots for each application class. Therefore, this section keeps explanations and descriptions rather brief and simple.

In the segment of consumer robots, there are three major application groups: domestic tasks (AC1), social interaction and education (AC2), and care at home (AC3). Robots that are intended for consumer use but do not fit into AC1-AC3 can be classified in class AC99 in group AC9 (other consumer robots). Domestic tasks are floor cleaning (AC11), window cleaning (AC12), gardening (AC13), outdoor cleaning (AC14), and other domestic tasks (AC19). Robots intended to be companions or to provide social interaction are classified in AC21, whereas robots specifically designed for education purposes are in AC22. Application group AC2 is an example that justifies the deviation from the ISO 8373 criterion of commercial versus non-commercial use to categorize service robots (see chapter 1.2.2). For instance, education robots are usually used at school or in similar environments, where teaching is the commercial activity of teachers. But teachers are professionally trained to impart knowledge, and not to operate robots. Care at home applications refer mainly to mobility (AC31) and manipulation assistance (AC32). Robots that offer other care functions are classified as AC39. Note that care robots grouped in AC3 can also be used in professional care centers. The decisive criterion for consideration as a consumer robot in AC3 is the suitability for use by laypersons. Laypersons can also be professional caregivers that are not specifically trained to use robots. Also note that all classes in group AC3 include robotic devices because limited autonomy might be required or desired in care applications. If the use of a care robot requires professional training or education, it should be classified as "other medical robot" (AP69). Table 1.2 offers a full overview of all consumer application groups and classes.

Table 1.2

Classification of service robots by application

-consumer applications-

Application		Description
AC	**Consumer robots**	**Robots intended for use by everyone. No professional training required.**
AC1	Robots for domestic tasks	Robots for housekeeping and similar tasks around the house
AC11	Domestic floor cleaning (indoor)	Wet and dry cleaning of floors, e.g. vacuuming and wiping of floors
AC12	Domestic window cleaning	Cleaning of windows
AC13	Gardening	Gardening tasks, e.g. lawn mowing
AC14	Domestic cleaning (outdoor)	Outdoor cleaning tasks around the home, e.g. pool cleaning, yard cleaning
AC19	Other domestic tasks	Domestic tasks other than AC11 to AC14
AC2	Social interaction, education	Robots with social interaction functions, robots for children and student education
AC21	Social interaction, companions	Main purpose of the robot is to interact with and entertain users at home
AC22	Education	Robots desigend specifically to educate children or students
AC3	Care at home	Robots that support people in need of care (e.g. seniors or handicapped people) in their homes or home-like environments (e.g. retirement homes)
AC31	Mobility assistants	Robotic wheelchairs, robotic rollators/walkers, exoskeletons for walking disabilities. Includes robotic devices.
AC32	Manipulation aids	Robots that support seniors or disabled people in the manipulation of their environment (e.g. meal assistance robot, manipulators mounted to wheelchairs). Includes robotic devices.
AC39	Other care robots	Robots for care at home that do not fit into AC31 or AC32. Includes robotics devices.
AC9	Other consumer robots	Consumer robots that do not fit into any of above classes
AC99	Other consumer robots	Consumer robots that do not fit into any of above classes

Source: IFR

The category of professional service robot applications uses eight different application groups plus group AP9 with class AP99 “other professional service robots” which is the appropriate class for all service robots that do not fit into any of the following groups and classes.

Agricultural applications of all kinds are grouped in AP1, which consists of four classes. AP11 includes all activities related to the cultivation of plants, from plowing the field to harvesting in greenhouses or outdoors. Robots for milking are in AP12, whereas other robots for livestock farming are in AP13. Agricultural robots that do not fit into any of the above can be classified as AP19.

Professional cleaning robots are – in analogy to domestic cleaning robots – divided into floor cleaning (AP21), and window and wall cleaning (AP22). Professional cleaning robots are also used for tank, tube, and pipe cleaning (AP23), hull cleaning (AP24). As a consequence of the Covid 19 pandemic, many companies offer disinfection robots, so that the new classification scheme offers class AP25 for such machines. Professional cleaning applications that do not fit into any of the above can be classified as AP29.

Robots for professional inspection and maintenance are classified by the object that they are designed for. Robots designed for inspection of damage in building and civil construction of all kinds are classified as AP31. Inspection of tanks, tubes, pipes, and sewers is application class AP32. Note that robotic devices are not included in this group. There are numerous robotic devices available that provide inspection and maintenance services with manual remote control. It is beyond the scope of this publication and the

representation of the IFR to cover all these machines. At least some basic autonomous functions like navigation are required to qualify a machine as a robot (see chapter 1.2.3).

Application group AP4 covers construction (AP41) and demolition (AP42) robots.

Group AP5 includes various logistics and transportation robots. Note that logistics is a very generic term that covers a wide range of different robot applications. Some logistics applications like packaging, pick and place, and palletizing are considered are industrial robotics and thus covered by the companion publication World Robotics Industrial Robots. Service robotics for logistics and transportation in the classes AP51-AP54 are classified along a two-dimensional matrix. The first dimension refers to the intended use indoors (AP51, AP52) or outdoors (AP53, AP54). The second dimension is the robot's ability to safely cope with public traffic. In a non-public environment, only people that are trained for the safe use and coexistence with the service robot may cross its path (AP51, AP53). Of course, the robot must still have safety features, but the supplier can expect that every person in the robot's working area knows about the dos and don'ts. This is different for robots that are applied in public traffic (AP52, AP54). In indoor environments, public traffic refers to visitors or any other general public that is not trained for the safe cooperation or coexistence with the robot. The robot must be able to react safely and anticipate unsafe behavior of people in its proximity, e.g. by stopping or slowing down its motion. In outdoor environments, public traffic may even require the robot to be able to autonomously participate in street traffic (which usually not covered by today's legal frameworks). Today, many robots used for outside logistics in public traffic are of aerial type. Logistics also includes inventory management, e.g. counting and refilling of stock (AP55). Any other type of service robot for logistics or transportation that is not covered by AP51-AP55 can be classified as AP59. Note that passenger transportation is generally excluded by this scheme. In earlier ages of robotics, some companies suggested mobile platforms that could be used to transport people. The IFR concluded that such vehicles should generally be considered as cars or buses and are therefore beyond the scope of World Robotics or the representation by the IFR.

The group of medical robotics also includes robotic devices, i.e. robotic technology that lacks sufficient autonomy to qualify as a robot. This refers to classes AP61 (robotic diagnostics), AP62 (robot-assisted surgery), and AP63 (robotics for non-invasive therapy and rehabilitation). In contrast, robots that handle and process samples in medical laboratories (AP64) and other medical robots (AP69) must be sufficiently autonomous.

The group of search and rescue and security robots includes robotic devices. These are used for firefighting (AP71), disaster relief (AP72), or security (AP73). Note that this includes only non-military applications (see chapter 1.2.3).

Hospitality robots are used for food or drink preparation (AP81) and for mobile guidance, information, or telepresence (AP82). Note that robots designed for various kinds of food delivery are grouped in AP5, and those for telepresence in the medical field (i.e. robots that feature sensors for tele-medicine) are classified as AP69.

Table 1.3

Classification of service robots by applications

-professional applications-

Application		Description
AP	**Professional service robots**	**Robots intended for use by trained professionals.**
AP1	Agriculture	Robots for agricultural and farming applications
AP11	Cultivation	Plowing, seeding, harvesting, weeding, fertilizing, pesticide spraying of/for crop plants and fuit indoors (greenhouse) and outdoors (field, vineyard)
AP12	Milking	Milking
AP13	Other livestock farming	Livestock farming, except milking, e.g. feeding, barn cleaning
AP19	Other agriculture	Agriculture, but none of the above
AP2	Professional cleaning	Robots for professional cleaning applications
AP21	Floor cleaning	Cleaning of horizontal areas, e.g. floors in offices, hotels, public buildings, streets and sidewalks. Note: Robots for barn cleaning are included in class AP13
AP22	Window and wall cleaning	Cleaning of windows, walls and other vertical areas
AP23	Tank, tube and pipe cleaning	Inside cleaning of tanks, tubes or pipes
AP24	Hull cleaning	Outside cleaning of hulls (aircraft, train, other vehicles, tank, container)
AP25	Disinfection	UV, spray, wiping or other disinfection methods
AP29	Other professional cleaning	Professional cleaning other than above
AP3	Inspection and maintenance	Robots for inspection and maintenance
AP31	Buildings and other construction	Outside detection of damage in buildings, plants, bridges, tunnels and other civil construction
AP32	Tank, tubes, pipes, sewers	Inside detection of leakage in tanks, pipes, or sewers
AP39	Other inspection and maintenance	Inspection and maintenance, but none of the above
AP4	Construction and demolition	Robots for construction and demolition
AP41	Construction	Installation of buildings and other constructions, earthwork
AP42	Demolition	Tear-off of buildings and other constructions
AP5	Transportation and logistics	Mobile robots for transportation of goods or cargo and other logistics functions
AP51	Indoor environments without public traffic	Cargo/goods transportation in indoor environments without public traffic only, e.g. warehouses, factories, non-public areas of hospitals, airports, etc.
AP52	Indoor environments with public traffic	Cargo/goods transportation in indoor environments with public traffic, e.g. hospitals, hotels, restaurants
AP53	Outdoor environments without public traffic	Cargo/goods transport in outdoor environments without public traffic only, e.g. harbors, airports
AP54	Outdoor environments with public traffic	Cargo/goods transport in outdoor environments with public traffic, e.g. home delivery, parcel delivery in the streets
AP55	Inventory	Counting and refilling of stock and inventory
AP59	Other transportation and logistics	Mobile robots for transportation and logistics applications not mentioned above. No passenger transportation.
AP6	Medical robotics	Robots in medical applications
AP61	Diagnostics	Robotic diagnostic systems. Includes robotic devices.
AP62	Surgery	Robots for invasive therapy (surgery). Includes robotic devices.
AP63	Rehabilitation and non-invasive therapy	Robots for therapy (except surgery) and rehabilitation of patients after surgery or accidents. Includes robotic devices.
AP64	Medical laboratory analysis	Handling or processing of samples in medical laboratories
AP69	Other medical robots	Other robots for medical applications. Note: Robots for transportation in hospitals are included in class AP52
AP7	Search and rescue, security	Robots for emergency situations
AP71	Firefighting	Robots for Firefighting. Includes robotic devices.
AP72	Disaster relief	Robots for detection or rescue of survivors. Includes robotic devices.
AP73	Security services	Robots for security functions, e.g. surveillance, bomb squad support. Includes robotic devices.
AP8	Hospitality	Robots for interaction with guests or visitors
AP81	Food and drink preparation	Robots for food or drink preparation
AP82	Mobile guidance, information, telepresence	Robotic information desks or guides, e.g. in museums, shops, hotel receptions. Robots for virtual participation in real-world events. Note: Telepresence robots specifically designed for the medical field are covered in AP69
AP9	Other professional service robots	Robots that do not fit into any of the above classes
AP99	Other professional service robots	Robots that do not fit into any of the above classes

Source: IFR