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Towards More Robotic Assistance for Everyday Life

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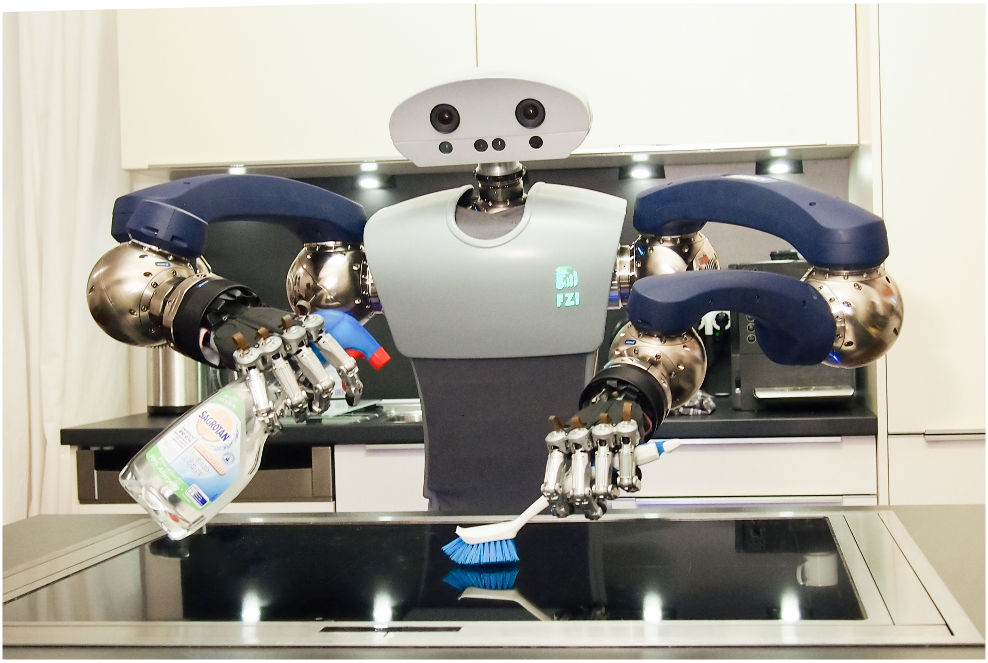

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The performance and flexibility of the latest robotic technologies make it possible to bring more and more robots into everyday life. However, this also creates a number of challenges: safety, legal requirements, reliability, reusability, and also business models must be considered in the specific, difficult conditions of everyday life. Furthermore, acceptance and interaction between humans and robots are of central importance for the success of service and assistance applications. This collection summarises 15 studies from the BMBF-funded program "Robots for Assistance: Interaction in the Field." The full studies are written in German and provide valuable insights into the challenges, potentials, and solutions for successful interaction in everyday environments. The collection is accompanied by this introductory article, which, in addition to the interaction focus of the studies, addresses other important aspects of successful service and assistance robots in everyday life. Finally, the Human-Robot-Interaction (HRI) studies are summarised in English to enable the comparison and discussion of their challenges and approaches.

1.1 Introduction

For many years now, robots have been regularly present in the press, in movies, or on social media, which makes them increasingly normal or even familiar to many people. Additionally, they are becoming more present in everyday, personal environments. In a great number of households, for example, robots are already helping to clean the apartment or mow the lawn in the backyard. In recent years, key robotic technologies like environment mapping, navigation, and perception have overcome important hurdles and reached impressive maturity. Therefore, it can be expected that in the near future, even more service robots will become part of everyday life, providing support and relief in a wide variety of areas.

Motivated by these trends, several scientific studies have been conducted to investigate the challenges and opportunities resulting from the interaction with service and assistance robots in practical, real-world applications. On the one hand, these Human-Robot-Interaction studies summarise the state of the art in research and technology in many relevant domains for everyday tasks. On the other hand, this collection of studies also presents solutions and approaches to many of the challenges identified in the field of Human-Robot-Interaction (HRI).

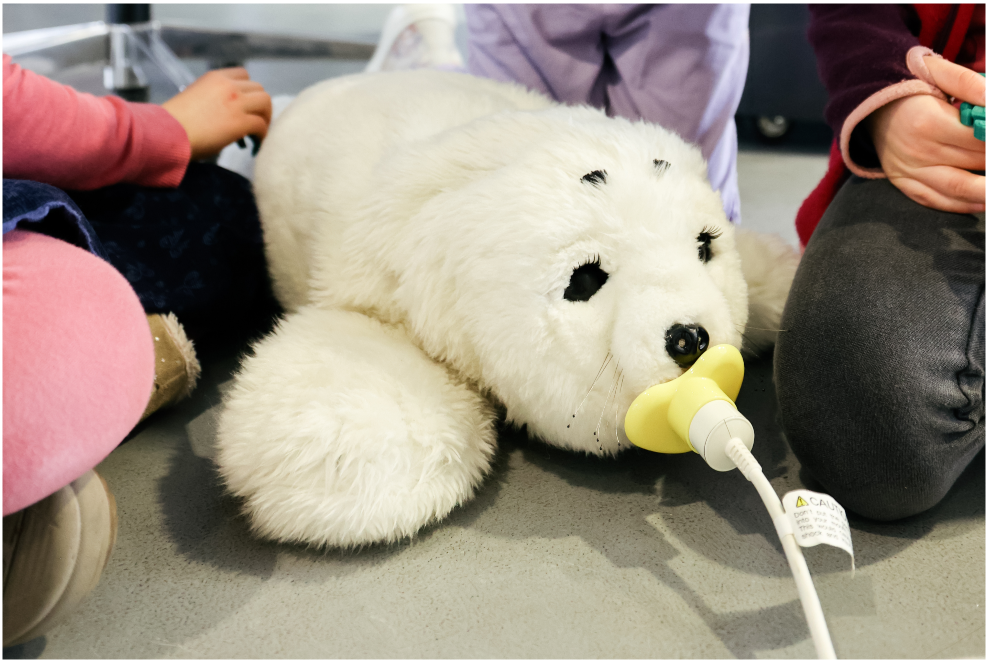

Figure 1.1: AIST's robot Paro is used in healthcare. The picture shows the first contact with a robot for a group of preschool children. ©FZI Forschungszentrum Informatik

This accompanying article can be understood as an introduction, preface, and extension to this collection of studies. It will summarise the HRI studies, which are originally written in German, in a concise way to make them accessible to a wider community. As an extension, this work will address aspects outside the HRI topic that arise across all considered domains and use cases: reusability and transferability, performance and robustness, safety and security, business models, and economics. These aspects were not the focus of the collection of studies. However, they are relevant as they can contribute to bringing more service robots into the field.

The state-of-the-art in service and assistance robotics has made impressive progress. Today, there are already many highly complex, powerful, and yet robust robots available on the market, such as PAL's TIAGo (Pages et al., 2016), Boston Dynamic's Spot (Guizzo, 2019), Aldebaran's Pepper (Pandey and Gelin, 2018), MetraLabs' SCITOS (Hawes et al., 2017), AIST's Paro (Šabanović et al., 2013), iRobot's Roomba (Jones,

2006) and many more. However, their introduction to real-world applications varies strongly. Some of these systems are still in the evaluation phase within pilot field trials, and some are deployed in small numbers, while others, like vacuum robots, have already hit the mass market. Research in this area focuses mainly on the challenges of grasping and manipulating everyday objects, navigating in (un)known environments, object recognition using 2D and 3D sensors, and the interaction mechanisms between humans and robots.

1.1.1 Manipulation Tasks in Everyday Environments

The environment outside an industrial production site is typically unstructured, cluttered with many different objects, and a great challenge for robots. Pavlichenko et al. present an approach for mobile dual-arm manipulation that addresses these challenges by combining semantic segmentation, object pose estimation, grasping, and motion planning (Pavlichenko et al., 2018). In particular, manipulating unknown objects and interacting with tools in complex, unstructured environments is difficult and requires understanding an object's function. Template manipulation skills and affordances of objects are promising approaches to address these challenges (Romay et al., 2015). In Starke et al., a new deep neural autoencoder for human grasps or unknown objects has been developed to better transfer these skills to robots. The design and control of humanoid robotic hands make it easy to interact with objects made for humans, such as tools, but human-like hands can also be understood as highly flexible multipurpose grippers (Ruehl et al., 2014, Chua et al., 2003, Tieck et al., 2020). Household environments, including kitchens, are often seen as a benchmark for manipulation tasks in everyday life (Yamazaki et al., Stückler et al., 2012). Additional complexity regarding handling objects occurs if these objects are soft, deformable, or dynamic. Pizza tossing combines all of these issues and is a great challenge for robots (Satici et al., 2016). Maitin-Shepard et al. were among the first to demonstrate high robustness in grasping and folding towels with a two-arm vision-based approach (Maitin-Shepard et al., 2010). Reliable manipulation skills are challenging but also essential in domestic environments (Ciocarlie et al., 2014).

Figure 1.2: Robotic arm during manipulation tasks in a kitchen environment from BMBF-funded project AuRorA. ©FZI Forschungszentrum Informatik

1.1.2 Human-Robot-Interaction with Non-Experts

The acceptance and success of robots in everyday life strongly depend on the usability and acceptability of these systems. In particular, the interaction has to be intuitive, efficient, and satisfactory for everybody, including non-experts. The work of Ajoudani et al. provides a good introduction to the challenges of multimodal interfaces, the wide range of interaction-modalities as well as benchmarks for Human-Robot-Interaction (HRI) (Ajoudani et al., 2018). Understanding the intentions of users is essential for the robot to be able to adapt. In everyday environments like public places, the interaction is short, and it is impossible to apply individual instructions or user-specific training. Therefore, speech and gesture recognition models must be able to generalize and work with a wide range of users (Matuszek et al., 2014). Not only is it crucial for the robot to understand the human but the human should also receive information about the robot's next planned actions.

Augmented reality (AR) is a good modality to intuitively show the upcoming robot movements, for example, with a light overlay from above (Bolano et al., 2019). Combining multiple modalities like verbal and non-verbal feedback from the robot together with personalized social behavior can further improve acceptance, efficiency, and ease of interaction (Aly and Tapus, 2013, Bolano et al., 2018). An anthropomorphic design and appearance greatly influence the interaction in open, public environments. Fink explains the interesting theoretical background by social sciences and provides lessons from robotics research in this area (Fink, 2012). Touch and physical contact with a robot create a very direct and intuitive non-verbal interaction modality. However, it is not easy for a robot to identify the contact location if it is not at the tool center point (TCP). On the other hand, complex communication related to emotions can be part of touch, making it a very challenging interaction modality (Magrini et al., 2015, Yohanan and MacLean, 2012). As many robots can achieve high velocities and apply significant forces, human safety is a critical aspect that needs to be addressed when dealing with HRI. Fortunately, new regulations make it possible to carry out risk assessments and allow close, physical contact between robots and humans in a defined safe way. Even more safety aspects regarding contact scenarios, also for mobile robots, are well summarised in the work of Vasic and Billard (Vasic and Billard, 2013).

1.1.3 Navigation in Dynamic, Complex Real-World Applications

Simultaneous Localization and Mapping (SLAM) is a critical capability for mobile robots in highly dynamic everyday environments. Major scientific papers and open-source software packages have made this technology available to the service robotics community. Kohlbrecher et al. present their powerful hector_slam stack in (Kohlbrecher et al., 2011). GMapping (Grisetti et al., 2007), Cartographer (Hess et al., 2016), and many other SLAM implementations have reached a great maturity that makes it possible to apply SLAM in industrial automated guided vehicle (AGV) applications. However, additional challenges need to be addressed in domestic, office, or public environments. 3D map representations are an extension that helps to address these challenges (Hornung et al., 2013, Besselmann et al., 2021). It is possible to take advantage of the special character of these environments. For example, in Alves

Figure 1.3: Servicerobot HoLLiE in interaction in a healthcare surrounding. ©FZI Forschungszentrum Informatik

et al. (2013) the ceiling lights are used as natural landmarks to improve the navigation and localization of a mobile robot. Other planning approaches use human motion prediction with a social cost function to create collision-free paths that maximize acceptance (Kollmitz et al., 2015). Semantic navigation can also be beneficial for navigation in real-world applications. Understanding the environment enables efficient interaction and path planning with mobile robots (Kästner et al., 2020). Environmental obstacles are interpreted in terms of their risks, allowing safer paths to be chosen (Puck et al., 2020). Machine learning is also being applied to navigation more and more. Pérez-D'Arpino et al. present an approach based on reinforcement learning that allows robots to navigate fluently around humans in everyday environments (Pérez-D'Arpino et al., 2021). Other new approaches make use of deep reinforcement learning for a safe and efficient collision avoidance policy. This can create a decentralized sensor-level collision avoidance by one or multiple robots in complex, dynamic, and crowded everyday environments (Fan et al., 2020).

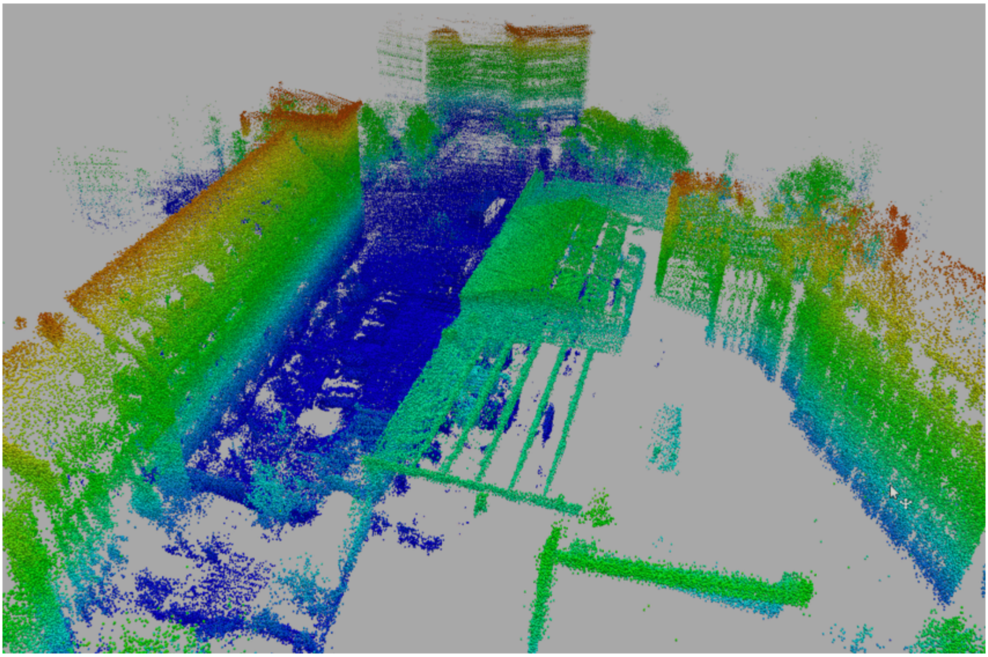

Figure 1.4: 3D map for navigation in dynamic, complex real-world applications (Besselmann et al., 2021). ©FZI Forschungszentrum Informatik

1.1.4 Object Recognition and Localization of Everyday Objects

Interaction with everyday objects like cups, bottles, trash, and many more things is an important skill for robots when operating in human-centered environments. Often it is desired to grasp, push, or move these objects. But before manipulation skills can be applied, it is necessary to detect and locate these objects. Therefore, extracting the depth information from LiDAR, RGB-D, or just RGB data is a key function. Flacco et al. efficiently derive the object's depth data from RGB-D sensors. This allows them to perform the necessary coordination transformation, detect collisions, and reliably locate the objects (Flacco et al., 2015). In the past, a lot of geometric approaches that, for example, fit virtual spheres or cylinders into the objects, were used for both localization and grasp planning (Nieuwenhuisen et al., 2012). Many current works rely on deep neural networks (DNN) with a focus on convolutional architectures like Mask-RCNN (Yu et al., 2019, Schwarz et al., 2015). Good performance is also shown by new DNN architectures such as Transformers, which rely on attention mechanisms for combined detection and pose estimation (Amini et al., 2023). In everyday environments, there are a large number of similar but not identical objects. Here, it is beneficial to add semantics to object recognition. The application of semantic segmentation can improve object detection, as both complement each other (Schwarz et al., 2018b). Other approaches include algorithms from the field of mobile mapping, such as Simultaneous Localization and Mapping (SLAM). As an example, the graph-based approach proposed by Salas-Moreno et al. enables accurate detection, tracking, and localization of many objects in complex scenes (Salas-Moreno et al., 2013). Open datasets of household objects are essential for the development and evaluation of object detection and localization approaches, regardless of whether the methods are based on machine learning or other algorithms. One of the first large object datasets was created by Kasper et al. with high-resolution 2D and 3D data of many typical everyday household objects (Kasper et al., 2012). Today, object datasets such as YCB and Washington play an important role in this field (Amini et al., 2023, Schwarz et al., 2015). In typical home or public environments, many objects have a soft structure and are transparent or deformable. These objects are not only difficult to grasp or manipulate, they are also more difficult to detect. Du et al. introduced a method to efficiently track deformable objects. A structure-aware hypergraph was developed to capture the higher-order dependencies needed to solve this tracking problem (Du et al., 2016). Other works focus on tracking textureless objects by fitting the model and the corresponding mesh to the current point cloud data from RGB-D sensors. The model takes elasticity as well as point-to-point correspondences and forces into account (Petit et al., 2017). Besides detecting, tracking and locating objects, it is important to do the same for humans when working with service and assistance robots.

Unlike rigid objects, people move, change shape, and vary greatly from person to person. Many works have addressed this challenge using different algorithmic approaches and sensors. Currently, RGB-D data and deep learning are the dominant key technologies in this field (Munaro and Menegatti, 2014, Nakano et al., 2020, Mathis et al., 2020).

There is also research into applications in domestic, retail, hospital, and public environments. Domestic environments are very challenging for robots as they are dynamic, have many different types of objects, and require repeated interaction with the occupants. For the acceptance of service robots in these environments, it is important to provide efficient and reliable performance in mobile manipulation tasks like object segmentation, collision-free grasp planning, or navigation (Stückler et al., 2013). Large human-like robots like PR2, HRP-4, or ARMAR-6 have great potential to help with daily chores and enable an aging society to stay independent in their own home longer (Yamazaki et al., 2012, Asfour et al., 2019). Current works show high robustness in laboratory environments and early field tests. In many cases, though, researchers try to address more complex scenarios while the robots could already reliably support simple, common tasks. Blackman motivates to use more analogies to existing products in everyday life than to laboratory or industrial robots and to bring the first service robots to the mass market sooner rather than later (Blackman, 2013). The design of the BratWurst Bot followed this mindset, combining off-the-shelf robotic components with reusable open-source software (ROS) to create an interactive, simple, yet robust sausage grilling and serving robot (Mauch et al., 2017). Some of the first consumer service robots, such as lawnmowers or vacuum cleaners, have been hugely successful and are showing increasing sales volumes. Other robots are still struggling with this new market, industry fragmentation, and complexity. However, as Gates already noted in 2007, breakthrough robotics technologies are available that will enable more and more service robots to support everyday life: "... the birth of a new industry"(Gates, 2007).

Proactive robots need to select the appropriate moment to start the interaction to achieve high acceptance. The ‘openings’ are crucial and should be developed as a stepwise and coordinated process. Gehle et al. demonstrated that this approach works well in an environment like a museum with random visitors (Gehle et al., 2017). Navigation in complex, dynamic urban areas comes with many challenges for mobile robots. One of the early large-scale field tests in Freiburg, Germany, from (Kümmerle et al., 2015) demonstrated how it is possible to create robust robot navigation by developing precise SLAM methods and considering the traversability, types of terrain and humans in the path planning.

But mobile robots cannot only assist in outdoor environments. They can also guide in

Figure 1.5: Service robot in a hotel lobby as part of the BMBF-funded project AuRorA.

large buildings such as hotels, airports or stores. How these robots can interact with blind people and guide them through buildings effectively is discussed in Azenkot et al. (2016). The socially compliant interaction is especially important with this user group but also for all other groups. These social aspects were the focus of the SPENCER project, which targeted an application at a large airport. The researchers developed methods to perceive, learn and model human social behavior as well as detect and track individuals and groups. With this knowledge, the robot could then plan the next actions in this complex, dynamic scenario (Triebel et al., 2016).

However, the aspect of interaction and its importance for the acceptance of service robots is somewhat lacking in many works. Above all, it is necessary to take a deeper look at the special requirements and social implications of Human-Robot-Interaction with regard to individual domains. The focus should be clearly on the human when it comes to everyday life. In contrast to industrial applications in production and logistics, other human-centered aspects play an important role in addition to the primary economic considerations. The Ethical, Legal and Social Implications (ELSI) have to be part of the design already and also have to be considered throughout the rest of the development process.

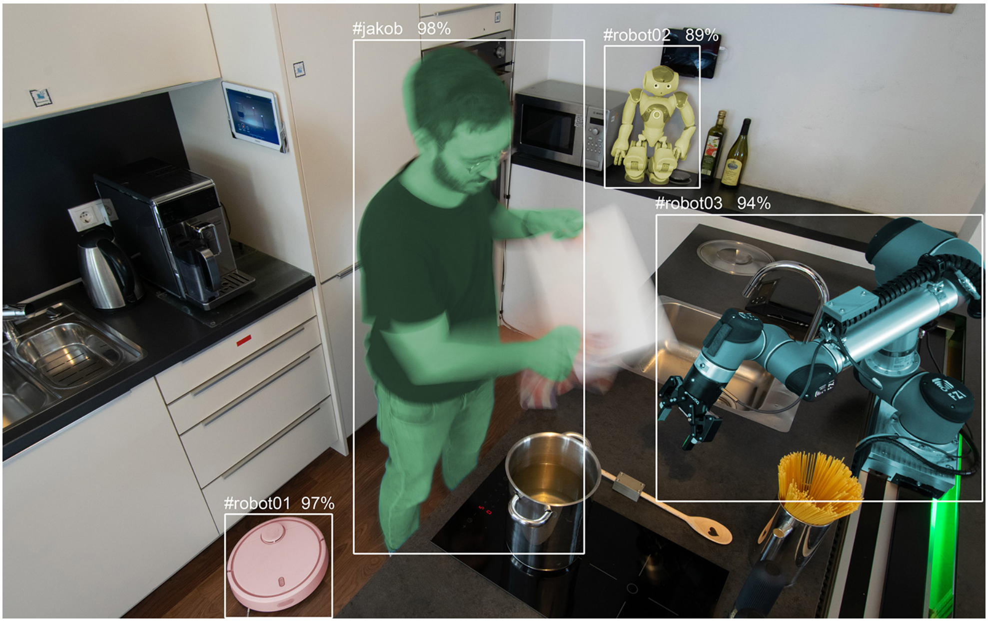

Figure 1.6: Human and robots working together in an AI enhanced kitchen environment. ©FZI Forschungszentrum Informatik

Furthermore, there is no simple roadmap on how to get from the idea or the first good research results to a real robot in the field. For this, not only the evaluation in practice under real, hard conditions but also legal requirements such as safety regulations play an important role. Finally, a new robotics idea needs a working and scalable business model to create impact and change. All these aspects are not sufficiently taken into account in much of the current work, with the result that few new service robots make it to the market, especially in Europe.

This work is intended to support the development of service and assistance robots for everyday life and to bring them towards market entry in terms of robustness, sustainable development, safety and business models more quickly. In the following, different approaches that support this will be presented. However, the literature has no uniform delimitation or definition of service robotics. Therefore, the authors propose the following definitional classification for this collection of studies:

The field of service and assistance robots in everyday life encompasses the everyday environment of people in both private and public spaces. Therefore, collaborative robots in indoor as well as outdoor household areas (including home care and therapy) are considered. Robots in public spaces include, among others, public authorities, stores, banks, airports, gastronomy, as well as research. Service and assistance robots in everyday life can act both stationary and mobile and involve human-machine interactions. This can take place with or without a manipulator. The operation should be intuitive and possible without prior training. A clear delimitation of the fields of application can be made by excluding, in particular, robots in the contexts of military, medicine, production and logistics, road traffic and space travel.

The collection of studies from the RA3 funding initiative of the German BMBF[1] on 'Robots for Assistance: Interaction in the Field' will be summarised and discussed. In this collection, the focus is on interaction and, therefore, on humans. The extensive individual studies provide detailed information on exciting domains and challenges for service and assistance robots in the real world. The respective authors contribute to the development of the field of service robots for everyday applications. Unfortunately, the full studies are only available in German, but they are briefly summarised in English within this preface article. In this way, the core contributions of the 15 studies are made accessible on an international level.

Following this introduction, the chapter is structured as follows. Section 1.2 presents approaches and methods for transferring research and development results into practical service robot applications. Different aspects are addressed, including safety, cost-effectiveness, business models, reusability, and performance metrics such as benchmarks. Section 1.3 then summarises the 15 comprehensive HRI studies on

[1]BMBF - Federal Ministry of Education and Research of Germany.

’Robots for Assistance: Interaction in the field.’ Section 1.4 compares and discusses the different challenges and approaches in these studies, summarises the results, and describes planned further activities and work.

1.2 Approaches for More Service Robots in Everyday Life

This work follows the aim to support the introduction of more robots into everyday life. More precisely, the focus is on service and assistance robots. For this purpose, it should first be defined which types of robots are to be considered as service and assistance robots in this work. But the range of this type of robot is very broad and difficult to delineate. One obvious common feature is that all these systems should be able to provide a service or assistance to humans. Systems that cannot do this will, therefore, be excluded and not considered. Further, only robots and not automatons or simple machines are to be taken into consideration. Here, the definition of a robot by Guizzo in the IEEE Robots Guide will be followed (Guizzo, 2018): Ä robot is an autonomous machine capable of sensing its environment, carrying out computations to make decisions, and performing actions in the real world."Furthermore, a more precise definition in this work can be made by considering the application area – everyday life.

Therefore, industrial robots on assembly lines, AGVs in warehouses, and robots in pick-and-place applications are not among the systems considered here. The human interaction with the robot should not be part of a regular work task. Of interest is the interaction in everyday life. This refers to random, spontaneous, but also regular encounters with robots in a public or private context that, therefore, do not take place in a work-related context. It also depends on the human interacting with the robot. The operator of a professional cleaning robot interacts differently with the same robot than a random pedestrian passing the robot in a parking lot. Everyday life thus encompasses a large number of areas: home, public spaces, supermarkets, train stations or airports and many other areas. A number of challenges need to be addressed in order to bring more robots into daily lives.

1.2.1 Robustness or Technical Readiness Level (TRL) of Service and Assistance Robots

The Technical Readiness Level (TRL, see also table 1.1) was first defined in the space domain by NASA (Mankins et al., 1995), but is now being used in a wide range of technical fields to describe the maturity and robustness of a technology. It has been extended to hardware, software, services and datasets (The-Human-Brain-Project, 2023). The different TRLs are used to create an objective scale for the development process, from the basic principle to the final product or system being used in the field. The TRL scale is also known and used in robotics but is not fully established yet. One reason may be that the TRL scale was defined to bring new technologies to real applications, meaning here to the market as products/services. Therefore, TRL is a scale more suitable for commercial and industrial research than academic research at universities. Not all research in robotics is dedicated to creating new robots or technologies targeted to a market. Many works are focused on more fundamental research questions with the aim to create general advances in the field and not particular for one system or technology.

Level	Description
TRL 1	Basic principles/functions observed and reported
TRL 2	Robot concept and/or robotic application formulated
TRL 3	Experimental proof-of-concept of core components
TRL 4	First validations of robot components in simplified laboratory environment
TRL 5	Advanced validation of robot components in realistic environment
TRL 6	Robot components demonstration in a realistic environment (for short time)
TRL 7	Robot prototype operating in a real-world environment (for long time)
TRL 8	Actual robot or robotic application completed, complying to legal regulations, test and demonstration in real-world environment
TRL 9	Actual robot or robotic application proven as product in real-world environment

Table 1.1: Technology Readiness Levels for Service and Assistance Robots

In this work, the target is to bring more service and assistance robots to the market. Therefore, it is mandatory to put a strong focus on robustness. Hence, the TRL scale is well suited to support this task. The following TRL scale was taken from Mankins et al. (Mankins et al., 1995) and adapted to the field of service and assistance robots with a focus on everyday environments.

Most robotics research projects are in the TRL 2-5 range. It is at these levels that important scientific advances can be made most effectively. The effort required to verify the results is reasonable and can be well invested by researchers. At higher TRLs, there is a high technical effort for further improvement, which in most areas leads to little or no new scientific contribution. Some research and development activities, particularly in the context of international competitions such as the DARPA Subterranean Challenge (Rouček et al., 2020), the ANA XPrize (XPRIZE, 2023, Behnke et al., 2023), the ESA and ESRIC Space Resources Challenge (ESA/ESRIC, 2023), or large-scale field test missions (DLR, 2023) also advance into the TRL 5 or even TRL 6 range. Such applications require unusually high efforts to bring the robustness of robotic systems to this advanced level. However, these great efforts do not have to be carried out by a single research group, company, or institution. The efforts can either be spread iteratively over the years or be shared by an active community. However, the named issues have reached the attention of German policymakers. The German Federal Ministry of Education and Research (BMBF) has launched the so-called "RA3"funding initiative to address these challenges. Fifteen consortia have conducted feasibility studies on how research projects should be designed to close the gaps and foster the acceptance of robots in everyday life.

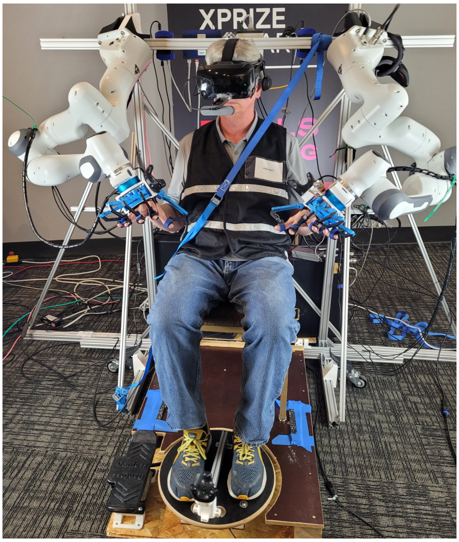

Figure 1.7: Operator of the winning team NimbRo during the ANA Avatar XPRIZE Finals (Lenz et al., 2023). ©Rheinische Friedrich-Wilhelms-Universität Bonn

These studies are published in this collection. Three of the ideas have been selected by

BMBF for funding and were further developed as competence centers: rokit, RuhrBots, and ZEN-MRI. These centers are supported by a transfer center for robots in everyday life (German: Transferzentrum Roboter im Alltag – short RimA). The feasibility studies focus on different use cases in everyday life, but in all cases, there are big challenges for software and technology development that all of them are concerned with.

1.2.1.1 Continuous Open Source Software Development

In order to focus efforts on new service robots, sustainable software development with continuous progress is desirable, rather than recurrent redevelopment of the same functionalities. A distinction should be made between scientific contributions, which can be ensured through reviews of scientific articles and discussions at conferences, and the generally available state-of-the-art (SoA). This will be further elaborated in the context of the Simultaneous Localization and Mapping (SLAM) challenge in robotics. SLAM was scientifically addressed in early work around the mid-1980s and has been extensively derived, algorithmically described, and further developed in numerous other works (Durrant-Whyte and Bailey, 2006). Despite all these research works, SLAM was not an available technology for decades. Only in recent years the SLAM technology has become widely available through powerful open-source stacks such as hector_slam (Kohlbrecher et al., 2011), GMapping (Grisetti et al., 2007) and Cartographer(Hess et al., 2016).

Today, numerous commercial mobile robot systems such as the MIR100 (Cartographer, 2018), TIAGo (ROS.org, 2023), Toru (MAGAZINO, 2023), and many more rely on these open source software stacks and achieve a TLR 9 in real-world applications. The issue of modularity and reusability is thus primarily defined by the use of open-source software. ROS, ROS 2, and ROS Industrial are the driving forces in the robotics community. However, numerous independent open-source tools and libraries such as PCL (Rusu and Cousins, 2011), Gazebo (Koenig and Howard, 2004), OpenCV (Bradski, 2000) play an equally important role. In the field of Artificial Intelligence (AI), many publicly available deep neural network architectures, pre-trained networks, training data, and learning frameworks are important for everyday robotics applications when it comes to recognizing objects or people. The continuous, community-driven development of high-quality, high-performance algorithms has been the main driver of robotics research in recent years. However, with such fragmented, distributed development, it is essential to ensure comparability of performance and results.

1.2.1.2 Competitions, Challenges, and Benchmarks for Robotic Systems

Competitions and challenges play a vital role in advancing robotics research (Behnke, 2006). They define common goals and benchmarking procedures and allow for a direct comparison of different approaches outside of the participants' own lab. In contrast to approaches tested only under laboratory conditions, robot competitions deliberately take place in realistic environments with complex tasks and thus represent an important link between research and application. Competitions such as the DARPA Challenges (Buehler et al., 2009, Krotkov et al., 2017, Kottege et al., 2022) and RoboCup (Gerndt et al., 2015) have been instrumental in shaping the autonomy of mobile robots. As they are often accompanied by a scientific workshop or symposium, they foster the exchange between participants and have an innovation-driving impact on the community. Robot competitions cover a wide range of application fields. For example, the European Robotics Challenges (EuRoC) (Siciliano et al., 2014) focused on new industrial applications for micro aerial vehicles, mobile manipulation robots and stationary manipulators. The Amazon Picking and Robotics Challenges (Schwarz et al., 2018a) focussed on cluttered bin picking and stowing. Directly targeted to assistance robots for everyday environments is RoboCup@Home (Stückler et al., 2016). Some competitions, such as the DARPA Challenges and the Mohamed Bin Zayed International Robotics Challenge (MBZIRC) for a team of UAVs (Beul et al., 2019) and UGVs (Schwarz et al., 2019), support developments of selected participant teams towards challenge tasks with sponsoring or grants. Also, a significant prize purse, such as the 10 Million US$ offered by the ANA Avatar XPRIZE competition, can focus the development of top research labs towards the competition goals (Schwarz et al., 2021). As the performance level of the participating robot systems rises, the competition rules must be developed to keep the challenges challenging. For competitions to be successful, it is important to ask for skills meaningful for many research groups. The skills to demonstrate must be challenging but not too difficult, as a hopeless challenge will not attract participants. Thus, there is a need for intensive exchange between the organizers of the competition and the participants. Naturally, robot competitions evaluate entire systems. Thus, when observing a performance difference, it is frequently unclear to which component of the systems it should be attributed to. Hence, it is desirable to include specific tests for subsystems, such as locomotion, manipulation, or Human-Robot-Interaction.

Benchmarks and performance metrics serve an important role in standardized evaluation not only in competitions but also in research labs. Some of these focus on subsystems, such as perception or planning. For perception, annotated data sets with evaluation procedures, like SemanticKITTI (Behley et al., 2021) or YCB-Video (Xiang et al., 2018), are widely used. Other benchmarks focus on individual skills, such as interactive navigation (Xia et al., 2020) and general object grasping (Fang et al., 2020). For benchmarking of complete systems, simulations have been increasingly used in recent years, which, in contrast to real-robot tests, do not require material and logistical effort and increase comparability by providing controlled conditions (Makoviychuk et al., 2021). Simulated benchmarks for assistance robots that evaluate different aspects of their performance are emerging (Erickson et al., 2020), but especially benchmarking Human-Robot-Interaction remains challenging (Aly et al., 2017).

1.2.2 Economic Efficiency and Business Models for Service and Assistance Robots

Regarding service and assistance robotics, many impressive ideas, as well as proof-of-concept developments in the field of academic research, have not yet made the transition to a product, service or applications in real-world settings. The consideration of economic efficiency and potential business models is a key challenge. Therefore, it is crucial to sensitize and qualify projects at an early stage in order to consider and systematically develop exploration and exploitation capabilities with regard to conceivable application scenarios for the use of robots. For this purpose, established methods from the fields of IT entrepreneurship and service engineering for different application contexts of robotics in everyday life are made available. Additionally, web-based toolboxes are provided, benchmarks of typical profitability parameters are analyzed, and their application is taught via interactive tutorials and competitions. This includes, for instance, the context- and target group-adjusted development of value propositions for potential application scenarios (i. e. with an adapted "RimA Value

Proposition Canvas") as well as the development of potential business models based on these (i. e. with an adapted "RimA Business Model Canvas"). This also includes the estimation of important cost and revenue assumptions as part of an encompassing "RimA Business Planning Toolbox". The goal is to empower every robotics project to reflect relevant economic options of their application during core ideation, development and scaling phases. Teams will be able to communicate business options with reference to benchmarks at any time. Furthermore, important contributions are also made to the development and establishment of a knowledge platform, which supports the projects from the beginning in actively designing the translation of economic exploration and exploitation results into the community.

1.2.3 Safety Regulations and Requirements for Service and Assistance Robots

Proof-of-Concept (POC) studies in the laboratory are an important part of the development and evaluation of new robotic technologies. Especially if these new technologies are to be used in everyday life, extensive field trials with feedback from external users are essential. However, especially in Europe, many legal regulations and standards simply do not allow the direct use or even evaluation of new technologies with untrained people in private or public environments. For a successful transfer from a POC in the lab through realistic field trials to a real system in everyday life, it is essential to address safety issues and legal constraints as early as possible.

Service and assistance robots are caught between technological progress, legal requirements, and user acceptance. On the one hand, technological progress makes it possible to use robots for tasks that were unthinkable until recently. On the other hand, legislation and technical regulations are lagging behind. While manufacturers and operators of industrial robots can already rely on a wide range of existing regulations and established procedures, standards for mobile service robots are still being developed. Manufacturers of service robots are, therefore, faced with the question of which specific requirements they need to meet in order to be able to sell legally compliant products on the European market, for example, and are faced with the problem of selecting the regulations applicable to their product from the multitude of regulations.

Figure 1.8: Safety regulations and requirements enable collaboration with service and assistance robots. ©FZI Forschungszentrum Informatik

The currently valid legal regulations essentially already take account of new technological developments. They are, therefore, valid in the absence of product-specific requirements. However, these safety objectives are generally formulated in the directives and laws. The technical requirements are only specified in the technical harmonized standards, which are to be observed on a voluntary basis. As a result, the laws and regulations give manufacturers a certain freedom of interpretation but also a greater responsibility for their technical solutions. This freedom and the lack of product-specific safety standards unsettles many manufacturers of service robots, as they expect and need specific requirements for the design of their systems.

The transfer center RimA addresses this area of conflict and seeks to resolve it throughout the process lifecycle, from the specification of regulatory requirements (directives, laws, regulations) to risk assessment methods, verification, and validation of product conformity. In particular, new issues need to be considered and integrated into the already established methods and procedures for service and assistance robots. Important requirements and regulations are the new Machinery Regulation, which is expected to replace the Machinery Directive 2006/42/EC (Directive, 2006) in the year 2024 (Commission, 2022, 2021), as well as regulations on data security (EU General Data Protection Regulation – GDPR (GDPR, 2023)) and cybersecurity

(Commission, 2AD, 2023b, BSI, 2021) as well as the expected legal framework for Artificial Intelligence (AI)(Commission, 2023a,c) and the yet to be developed requirements for the acceptance, function and safety of service robots. There are many other issues to consider. For example, the impact of digitalization (e.g., Internet of Things, Industry 4.0) and new business models and their influence on the limits of service robots, additional hazards and risks, as well as the availability of data – in particular external access to personal data. Communication, interoperability, and availability in the context of product safety are also challenges for the development of new service and assistance robots. Last but not least, there are many socio-technical aspects and criteria that need to be considered, like:

- ethics and morality of decisions made by robots,
- acceptance of the solutions in everyday work,
- transparency of the decisions made,
- possibilities of influencing and correcting AI decisions,
- collaboration with users,
- and many other aspects.

In order to be able to solve these demanding tasks for the benefit of everyone involved, intensive and goal-oriented coordination and cooperation between research, development, certification and application is required. RimA transfer center intends to make a major contribution to creating these conditions and the necessary framework.

1.2.4 Acceptance of Service and Assistance Robots

The aspects described above can help to ensure that robustness, safety, and economic feasibility are considered as early as possible in both scientific and technical development in order to establish new systems in real-world environments. However, success in this area depends mainly on the acceptance of non-expert users. If the robots are not accepted and, therefore, not wanted, they will be damaged, deliberately disrupted, and eventually banned from all public applications under public pressure. Without a high level of acceptance, service and assistance robots will not be successful because, in this field, it is not only economic aspects that decide whether a robot application is continued or perhaps extended to other locations. It is well known that acceptance is primarily based on positive, successful human interaction with robots.

Interaction is a multidimensional, complex action that can be conscious or unconscious. It is not limited to speech, facial expressions, and gestures but can take place with all the senses. The key point is that interaction always takes place in a context and, therefore, has social, ethical, and legal implications. How to achieve positive, successful Human-Robot-Interaction in the field is the central research question in the collection of studies. Therefore, reference is made here to the summary of the studies in Section 1.3 and to the full German studies in the following chapters of this book.

1.3 Studies on Robots for Assistance: Interaction in the Field

1.3.1 AixistenzRobotik – Aachen Competence Center for Interactive Robots in Health, Care and Assistance

Full approach is described in detail in Chapter 2 (in German, Rosenthal-von der Pütten et al. (2023)).

1.3.1.1 Objectives

AixistenzRobotik focuses on assistance robots for professional healthcare applications that can really support patients and nurses. The authors build their idea on the issue that many systems initially developed for healthcare do not even make it into the initial field tests in real environments. The main reason identified for this is that the technical developments cannot yet master the complexity of real healthcare applications. The authors want to test existing assistance robots for professional healthcare under realistic conditions. The following key aspects are identified: interaction, usability or acceptance, as well as the technical properties of the systems, the integration in work processes and team structures, as well as their influence on care relationships.

1.3.1.2 Contribution to the Field

Moreover, the authors stress the need to put nurses in leading positions to help shape the future, as nursing professionals uniquely understand the complexity of the healthcare environment. Nurses know the needs and demands, what actually works in practice, and how to improve patient experience and healthcare results. AixistenzRobotik views it as essential to develop and research assistance systems in the sense of co-design with care professionals and with the involvement of other scientific disciplines, aiming at an interdisciplinary competence development. This can lead to a paradigm shift away from the development of care solutions and towards participatory co-design with people in need of care and their nurses.

AixistenzRobotik can contribute to the establishment of an approach to develop robotic systems that really meet needs and can be successfully integrated into existing care structures while combining interdisciplinary perspectives and methods like real-life testing, interviews and surveys. AixistenzRobotik conducted a first feasibility study to address these challenges.

1.3.1.3 Scientific and Technical Approach

The authors propose testing three different types of existing robotic assistance systems:

1. robotic developments that support actual care and/or therapy activities (e.g. robot-assisted rehabilitation, exoskeletons),
2. robotic systems that promote individual health and provide personal assistance, and
3. robotic systems that support care tasks (e.g. specialized pick-up and drop-off services for care stations).

A total of 22 field studies are planned, ranging from a minimum of one week (for preliminary studies) to up to three months in the regular operation of a university hospital and at least one nursing home. This will allow an unprecedented amount of data to be collected in just three years. They plan to develop use cases and benchmark scenarios in order to standardize individual basic or special assistance robots in a standardized and comparable way.

1.3.1.4 Transfer and Outreach

AixistenzRobotik can really make a difference with the participatory co-design approach. To this end, it is planned to build up interdisciplinary competence and enable structured knowledge acquisition on the above-mentioned scientific questions concerning a) acceptance, usability and user experience, b) ethical aspects, c) group and team dynamics in human-robot teams, d) technical benchmarks for, for example, control technology and dialogue systems, e) new types of data-driven business models and f) beneficial institutional, organizational and personal factors in relation to the sustainable implementation of assistance systems in care facilities.

1.3.2 CeRA4HRI – Everyday Assistance Robotics Lab

Full approach is described in detail in Chapter 3 (in German, Beetz et al. (2023)).

1.3.2.1 Objectives

CeRA4HRI focuses on the use of existing living labs for long-term studies. The approach is to investigate all necessary aspects for the use of robots for everyday assistance, to evaluate application scenarios in long-term studies and comprehensively investigate them with regard to economic connectivity and social acceptance.

1.3.2.2 Contribution to the Field

By using existing research robots and application-oriented use cases, a holistic approach is introduced. The authors analyze the current state of the art in the everyday use of robots for assistance functions and which technical and non-technical measures are necessary to enable everyday use. The main aim is to establish benchmarks or comparative values for the evaluation of robots in the area of everyday assistance. The authors identify the use of photorealistic virtual environments with physical simulation (so-called "digital twins") as a key technology to implement new application scenarios quickly, cost-effectively and safely.

With its living labs, the approach can contribute to research on robotics in everyday life via four unique points:

1. the living labs with their technical equipment,
2. the research robots,
3. the digital twins of both the robots and the living labs, and
4. the comprehensive know-how and experience with the extensive collection of open-source software tools for controlling and interacting with the robots in the real and virtual living labs.

The authors aim to demonstrate through long-term studies how people without expert knowledge fulfill their desired tasks with the support of assistance robots – safely and in consideration of ethical, legal and social aspects.

1.3.2.3 Scientific and Technical Approach

The authors emphasize the need to conduct long-term studies in living labs that can be transferred into practice. For example, in areas of flats and supermarkets, experiments should not only be evaluated in terms of user experience but also accompanied by social and behavioral science. For the purpose of differentiating the systems, general evaluation approaches for assistance robots for task fulfillment and interaction quality are to be created as a basis for decision-making. The process and outcome evaluation are to be supplemented by systematic behavioral observation, measurement of physiological parameters, assessments to record attitudes, values and norms, as well as qualitative interviews. Questions concerning Ethical, Legal and Social Implications (ELSI) should go beyond the approach: clusters of ethical, social and legal attitudes are to be identified using quantitative and qualitative methods. These clusters can rely on empirical and representative survey studies on the basis of access panels for market research. The goal is to record the population's value orientations regarding assistance robots and possible business models.

The approach can, therefore, be a holistic evaluation of solutions that specifically help people with support needs. Existing open-source software and open research methods from the field of machine learning can be used for intention recognition, contact situation classification, knowledge representation and reasoning, and plan-based assistance. In this way, people without expert knowledge will be able to use existing research robots in the long term, taking into account ethical, legal, and social aspects.

1.3.2.4 Transfer and Outreach

All in all, the existing living labs can answer the question of how people can use technology to support their everyday lives or maintain their independence and autonomy, based on extensive experience with user-centered design and user experience. In order to ensure the transfer to the general public, the authors propose a digital learning platform that teaches the basic concepts of cognitive Human-Robot-Interaction (HRI) with online learning materials, interactive tutorials and training, as well as making the existing demonstration scenarios available as open-research examples for future application scenarios.

1.3.3 CONSAS – Competence Center for Construction Robotics in Civil Engineering

Full approach is described in detail in Chapter 4 (in German, Kuhn et al. (2023)).

1.3.3.1 Objectives

CONSAS focuses on assistance robots in the construction industry. It, therefore, uses a different, more industrial approach to "robots in everyday life" than most of the other works in this collection. The CONSAS concept highlights the construction industry's key function in central social issues and areas of innovation in Germany. The authors see the construction industry as the basis for innovative and resilient cities, efficient renovation of sustainable buildings, solving the housing and rental problem, high-quality hospitals, schools and retirement homes, and the necessary measures in the COVID-19 context, and many other aspects.

1.3.3.2 Contribution to the Field

The authors claim that a center of excellence for construction robotics does not yet exist in Germany. Even on an international scale, there are only a few places in the world where the conditions are similar to those of the CONSAS approach, which has a unique set of technology and production-related stakeholders. The approach is a pilot project for the entire construction sector. The special selling points are the many realistic tests of the assistance robots on real construction sites with a focus on health, especially physical and mental stress, as well as the technical robotic and construction challenges, while also taking into account the economic limits.

1.3.3.3 Scientific and Technical Approach

The approach develops a systematic, integrative approach to the use of assistive robots on construction sites, involving all stakeholders in the field of construction robotics. The authors plan to gather structured experience with mobile robot assistants (cobots) and motion-supporting robots (exoskeletons). In order to test construction-specific robotic solutions, research is to be carried out in situ. At the same time, research will be carried out in a laboratory environment to enable widespread use.

The first feasibility study between March and July 2021 aimed to scientifically verify the approach for assistance robots in the construction sector. It validated the methodological approaches and helped to define the qualitative and quantitative objectives. The core of the study was an analysis of the emerging works and activities in building construction and the technical and economic application potential of assistant robots. Based on stress analyzes of individual activities, profiles were created that provide information on the degree of physical stress of the workers and clarify the need for ergonomic or assistive technical support systems.

1.3.3.4 Transfer and Outreach

The authors plan the communication and transfer on different levels: Firstly, findings from evaluating the tested robot assistance systems can be transferred to the manufacturers and other stakeholders. Secondly, the results can then be communicated to the construction industry, e.g. in the form of training and workshops for SMEs and publications in business journals. Thirdly, scientific publications and academic teaching are planned. Fourthly, developing a public database on construction robots for interested companies and the general public is proposed.

1.3.4 KARoKAS – Competence Center for Human-Centered Assistance Robots in Disaster Management and Complex Emergencies

Full approach is described in detail in Chapter 5 (in German, Schischmanow et al. (2023)).

1.3.4.1 Objectives

KARoKAS focuses on the use of assistance robots in rescue missions. The authors note that, unlike industrial robots, assistance robots have not yet reached the same level of robustness and are, therefore, in many cases not yet ready for practical use. In particular, the development of assistance robots and their use in real disasters and complex incidents is still at a very early stage. Many issues, such as mission logistics, challenging environmental conditions, and enhanced reliability requirements, still need to be addressed. As a result, the first responders on the ground are still humans, as robots reach their limits in these scenarios.

1.3.4.2 Contribution to the Field

The challenges of developing, adapting, and evaluating assistance robots for use in complex disaster and casualty scenarios are identified in this work. The research approach focuses on the scientific evaluation of the Usability and User Experience (UUX) and Ethical, Legal, and Social Implications (ELSI) to promote the use of systems that are suitable and safe for Human-Robot-Interaction (HRI). According to the authors, this differs from the existing approach of the German Rescue Robotics Center (DRZ). The paper highlights five use cases in particular: search and rescue of lost persons after earthquakes, major damage after severe storms, forest and vegetation fires, terrorist attacks with mass casualties, and the case of large fires at industrial sites. The inclusion of police emergency responders is also relevant. Ongoing climate change and the associated increase in extreme weather events with heat and heavy rainfall, the resulting disasters, and the complex damage events of recent times create a clear need for assistance robots. These robots need to be expanded and developed to help save lives and reduce the burden on emergency services.

1.3.4.3 Scientific and Technical Approach

The core is the planned new approach with multiple, decentralized testing and evaluation facilities, where manufacturers can have their assistance robots for disaster management and complex emergencies evaluated under realistic operating conditions. These tests also include interaction, usability and user experience as well as social implications. As a result, the manufacturer will receive usability ratings, technology readiness levels and information on technology gaps and certifications from a user-centered research perspective. The five use cases identified will guide the development of this approach and help to set up the decentralized test and evaluation facilities. KARoKAS goes beyond the state of the art in science and technology by explicitly focusing on the evaluation of human-robot interaction. For this purpose, interaction strategies and process flows will be developed and specific evaluation methods will be applied and integrated into a new formalized evaluation process.

1.3.4.4 Transfer and Outreach

The decentralized testing and evaluation facilities create easy and direct access to the research of KARoKAS. End users can experience the systems in tasks and scenarios as close to reality as possible and evaluate the usability of new assistance robots together with experts. The approach creates awareness of the topic of Ethical, Legal and Social Implications (ELSI) by providing workshops and training. KAroKas uses a scenario-based approach to involve end users directly and continuously in the Human-Robot-Interaction (HRI) and usability and user experience (UUX) evaluation processes.

1.3.5 ProVeRo – Competence Center for Pro-Social and Trust-Building Robots

Full approach is described in detail in Chapter 6 (in German, Kühnlenz et al. (2023)).

1.3.5.1 Objectives

ProVeRo focuses on a robot-sharing concept for transport and shuttle services in public spaces. Currently, there is a demand for mobility-supporting assistance, especially in rural and peripheral regions. Using the example of the region of Upper Franconia, Germany, the approach can contribute to establishing systems for pro-social and trustful coexistence in the real world.

The vision is to make assistance robots accessible to the masses by using distributed, publicly available systems – e.g., "robot sharing."The development of an intelligent, pro-social, and trust-building control architecture is an important prerequisite for the establishment of a robot-sharing concept in real-world applications. A challenge is the availability of interconnected, inner-city demonstration sites, especially in regions with a difficult supply situation due to the existing infrastructure.

1.3.5.2 Contribution to the Field

Within this approach, an internationally unique urban distributed robot laboratory will be established, based on publicly available mobile robots and stationary systems, to investigate and promote pro-social and trust-based interaction and coexistence. The main contribution is the reduction of barriers to the use of robotic assistance in public spaces, which can enable future robot-sharing concepts combined with various services to make robotic assistance economically accessible to the general public. This contribution also includes acceptance and user experience, which can be improved through social-psychologically motivated adaptation methods and the integration of robot explanation strategies. To achieve this goal, structured test scenarios will be developed in a condensed and highly targeted manner. Corresponding metrics and benchmarks for quantitative evaluation, including user experience and acceptance, will play a prominent role. ProVeRo pursues an integrated concept with a novel robotic system that offers social interaction and accompanying services, such as carrying assistance in public outdoor spaces and with individual adaptation to the human user.

1.3.5.3 Scientific and Technical Approach

In the authors' vision, the real-world laboratory is divided into two research lines – a central line and a secondary line. They can be distinguished regarding the different levels of risk, which depend on the mobility aspects, the maintenance or the personal sphere of activity and physical limitations. The transport service as the central line serves to establish an accompanying inner-city carrying service for support in daily life, especially concerning the personal sphere of influence, as well as to support social interaction opportunities in public spaces. The shuttle service as a secondary line serves to establish an alternative to public transport. The approach is divided into three steps: First, the implementation and operation of a real-world laboratory for the inner-city, interconnected robotic assistance is required. Then, real studies with untrained users and robot ethics involve the general public. Finally, considerations of business models and services are made.

1.3.5.4 Transfer and Outreach

ProVeRo sees the acceptance of interactive service robots as an essential prerequisite for their successful long-term use in real-world environments. Its goal is establishing pro-social and trust-building methods for robots in public spaces.

ProVeRo has a unique character due to the planned real-world laboratory. In particular, the possibility of conducting long-term real-world studies in weakly structured public spaces in outdoor environments such as pedestrian zones is an excellent basis for research in this area. In addition, it will be possible to carry out experiments over long periods of time in conjunction with large-scale acceptance studies to investigate the evolution of public opinion, as well as the possibility of integrating other robots from possible industrial stakeholders.

1.3.6 KomPArob – Care-Supporting Assistance Robots

Full approach is described in detail in Chapter 7 (in German, Graf et al. (2023)).

1.3.6.1 Objectives

KomPArob focuses on the evaluation of product-like assistance robots in various care facilities. Today, the care sector faces major challenges in terms of demographic change and a growing shortage of skilled workers. KomPArob claims that the use of close-to-product assistance robots can support and relieve staff in residential care facilities. The approach differs from other formats, where often only one robot is tested, and the tests take place in a single facility. Multiple tests under realistic conditions in multiple facilities allow for comprehensive testing and investigation of relevant parameters. This is a novelty in the context of assistive care robots.

1.3.6.2 Contribution to the Field

The scientific goal of KomPArob is to investigate the potential positive impact of robots in nursing through a systematic and multidimensional evaluation concept. Various product-related robots are evaluated with relevant case numbers to identify underlying success factors. Another goal of KomPArob is to make the capabilities and possible applications of service robots known to interested users and to enable them to experience them themselves. The third goal is not only to motivate and support potential users to use robots in practice but also to open up the care sector as an attractive market for future manufacturers of assistance robots in Germany - including concepts for market entry and the implementation of technical solutions in daily care operations.

The pursued scientific approach differs from other formats, in which often only one robot is tested, and the tests only take place in a single institution. This approach brings together several research institutes and companies that provide robots that are close to a product and have already been tested in real-life applications. These robots can already be used in direct interaction with humans, and their robotic skills go beyond simple information support. In addition, several non-technical partners are involved who can scientifically investigate Human-Robot-Interaction (HRI).

1.3.6.3 Scientific and Technical Approach

The strength of the approach outlined here is, in particular, the wide range of robot solutions to be tested in practice combined with the wide range of applications. As a result, new findings for the design of assistance robots in the care domain are expected. In addition, many planned trials offer the possibility to develop robots iteratively and participative with potential users.

Each robot applied already has a high technical maturity. All the robots have already been tested in care facilities or clinics. However, only selected application scenarios have been implemented and analyzed in the past. Many technically feasible applications discussed with representatives have not yet been realized. The approach aims to evaluate three main aspects:

1. the usability, experience and expectations as well as acceptance and task characteristics of robots in nursing care,
2. the impact of service robots on care processes and
3. the economic aspects and models for the implementation in the regular operation.

1.3.6.4 Transfer and Outreach

The planned large number of trials will provide insights into the extent to which the technical challenges can be generalized. In addition, KomPArob investigates how the fields of application of the assistance robots, the interaction strategies, the different user groups, the care processes, and the economic efficiency can benefit. The potential applications will be presented to interested users, who will have the opportunity to gain experience in interacting with the robots. KomPArob aims to make the care sector more attractive for robot manufacturers and to make more robots available for everyday care.

1.3.7 OPERATE - Competence Center for Robots as Assistance for People with Disabilities

Full approach is described in detail in Chapter 8 (in German, Dalm et al. (2023)).

1.3.7.1 Objectives

OPERATE focuses on interactive assistance robots that support people with disabilities in sheltered workshops. The authors identify the overall societal benefits and social relevance in the area of inclusion and participation, as people with disabilities, in particular, often require a high level of support in working life, e.g., when handling parts. Assistance robots offer the opportunity to provide support while increasing the autonomy of people with disabilities. The integration of safe assistive robots in workshops allows them to better participate in working life.

1.3.7.2 Contribution to the Field

In OPERATE, methods, metrics, procedures, and approaches of interactive assistance robots are developed to support people with disabilities in sheltered workshops. The use of interactive assistive robots in this area focuses on three main criteria: the technical-technological side, the interactive approaches, and Ethical, Legal and Social Implications (ELSI) considerations.

Despite their great potential, interactive assistance robots are not yet widely available to support people with disabilities. OPERATE's vision is that interactive assistance robots will enable people with disabilities to participate more fully in working life and, in the medium and long term, in the mainstream labor market. In addition, the approach supports workshops for people with disabilities and later companies that want to support people with disabilities through interactive assistance robots in the design and implementation of such systems.

1.3.7.3 Scientific and Technical Approach

Three different use cases are analyzed, developed and implemented with the help of interactive assistive robots and systems in OPERATE. The use cases test and evaluate the systems developed in the workshop under realistic conditions. The solutions and strategies are then described in modular and tangible guidelines and published scientifically. Finally, they are extended by suitable business models and transferred not only to other workshops for people with disabilities but also to companies in other areas. Multiple use cases are defined in which the robots support the humans in the categories of functional safety, interaction, complexity and reproducibility.

The concepts for the different use cases are transferred to the application domain as early as possible. For this purpose, the robot systems are directly integrated into the sheltered workshops so that the developed prototypes can be tested and evaluated in practice on a daily basis. The evaluation will take place over an extended period of time, focusing on Human-Robot-Interaction through acceptance and usability studies.

1.3.7.4 Transfer and Outreach

In this work, the transfer strategy is based on the concepts of participatory design, community-based research and the potential transfer to other workshops and companies. The publications, guidelines and business cases, as well as the expertise gained from the evaluation of the use cases, will pave the way to enable others to integrate interactive assistive robots into sheltered workshops. Moreover, it is a bidirectional exchange that promotes engagement between the community (practice) and university (research), creating opportunities to contribute to solving complex problems with different resources. This enriches the research processes and outcomes, creates a community development strategy and improves community-academia relations.

1.3.8 KO:ROP – Competence Center for Robots and Interaction for Care

Full approach is described in detail in Chapter 9 (in German, Eichelberg et al. (2023)).

1.3.8.1 Objectives

KO:ROP focuses on assistance robots that can support caregivers and people in need of care in their daily care tasks. The approach shows how robotic components and systems can be integrated or adapted to routine care tasks. It will assess whether professional caregivers, care recipients, and carers can be physically and psychologically relieved of tasks and activities of direct and indirect care. According to the authors, it is crucial that the robotic systems respond appropriately to the typical requirements and needs of the different actors.

1.3.8.2 Contribution to the Field

The core research question is how to design situation- and person-specific interaction with a care robot in order to provide adequate support in everyday life. The basic aim is to support "good care,ï.e., care that is evidence-based and situation-, task- and relationship-oriented, and to make interaction with robots user-friendly in order to promote the general acceptance of care robots in practice.

For the practical implementation of care assistance robots, the KO:ROP concept addresses not only the current state of research but also issues of robot interaction, challenges of care practice, care science, and economic, social, and legal issues. The key research questions are:

1. Which prerequisites and conditions for success must be fulfilled for the use of robotic systems in nursing practice?
2. How can a safe, situation- and person-specific interaction between different groups of actors in nursing practice and robotic systems be technically realized?
3. Through which changes in nursing and work processes, IT support and data protection, as well as hygiene requirements, can demand- and user-oriented support be achieved by robotic systems and how can it be evaluated?

1.3.8.3 Scientific and Technical Approach

The KO:ROP concept will test robots in care support in acute inpatient, long-term inpatient, and outpatient care and will differentiate between task-oriented and relationship-oriented contexts. The aim is to put robots into practice in the six designed evaluation settings. In addition, the approach can support care, test and evaluate interaction concepts, and develop them iteratively.

The results of the first workshop with nurses from long-term inpatient, acute inpatient, and outpatient care showed interesting results. The theme of the workshop was "What forms of Human-Machine -Interaction (HMI) are suitable or necessary in the heterogeneous areas of care with regard to relevant care situations and currently available robotics?". The results showed that especially robotic lifting aids, robots for disinfection and cleaning, as well as logistics and transport systems, are helpful in supporting task-oriented care.

1.3.8.4 Transfer and Outreach

KO:ROP can provide information on how robotic components and systems can be integrated or adapted into routine care and whether professional caregivers, care recipients, and caring relatives can be physically and psychologically relieved of tasks and activities of direct and indirect care. The authors consider regular exchanges to promote cross-project collaboration and the establishment of a steering committee. Relevant cross-cutting issues with other stakeholders are technical implementation, open source strategy, integration and networking, evaluation, business models, security and liability, preparation of competitions, and public relations.

1.3.9 PosiBot – Center for Positive Service Robots in Customer Contact

Full approach is described in detail in Chapter 10 (in German, Pollmann et al. (2023)).

1.3.9.1 Objectives

PosiBot focuses on assistance robots for people with reduced mobility at airports. An EU regulation for airports from 2008 stipulates that people with reduced mobility must be provided with special services. The authors, therefore, identify this as an area of application for robots. PosiBot aims to include assistance robots in airport services increasingly to reduce the workload of airport staff and improve the service experience for passengers.

1.3.9.2 Contribution to the Field

An initial market study shows that service robots currently on the market provide a range of customer contact services (e. g. in retail, banking, cultural institutions, administration, transport, and tourism). These robots allow employees to focus more on customer communication and other issues. Robots also have the potential to take over tasks that workers often find less varied and less fulfilling. However, the authors also identify areas of concern: Companies using robots face the challenge of assessing the cost-benefit ratio. For robot manufacturers and system integrators, developing new robot applications is resource-intensive and only attractive if the business model works.

PosiBot will explore how barriers can be reduced. The result can support and enable German companies to overcome the identified hurdles and make greater use of service robots to relieve employees and positively influence customer service experience in the long term. To get there, human-centered-ethical development processes, insights into technology-sociological issues and public presentations of the tests and the results are considered.

1.3.9.3 Scientific and Technical Approach

The approach develops and tests the range of robot services iteratively. The development is carried out using a human-centered-ethical development process. Moreover, it is based on integrated research and combines ethical and technical-sociological approaches with those of user experience and application development. This can enable a holistic and socially sustainable view of the design and development of service robots.

In PosiBot, the focus is on the practicable and beneficial use of service robots in customer contact. The design and implementation of the service robot applications are oriented towards the wishes and expectations of the customers, as well as explicitly considered as part of the employees' work design. From the beginning, the technical capabilities of service robots available on the market are considered to achieve a high overall level of maturity of the solutions. In PosiBot, the focus is explicitly on developing a multimodal Human-Robot-Interaction (HRI). The approach is evaluated in an airport scenario with many inexperienced passengers.

1.3.9.4 Transfer and Outreach

The PosiBot aims to become an established point of contact in Germany for the practical use of service robots in customer contact. The service is intended to make it easier for application and development companies by adopting provided interaction modules. PosiBot aims to focus on interaction by creating a uniform interaction language. Moreover, PosiBot motivates manufacturers and system integrators of assistance and service robots to deal with aspects of trust building and acceptance promotion at an early stage in the design and development process of new robots and applications.

1.3.10 R-ITUAL – Robots: Interactive, Transparent and Adaptive Life Companions

Full approach is described in detail in Chapter 11 (in German, Herrnberger et al. (2023)).

1.3.10.1 Objectives

R-ITUAL focuses on assistance robots in a multi-generational home that support users in a private residential environment. While many assistance robots provide many functions reliably, they are often not yet able to interpret human emotions and behavior correctly. Therefore, they cannot interact with the user in a socially and situationally appropriate way. The approach aims to extend assistance robots with such characteristics in a focused, interdisciplinary, and structured manner. The social benefit is the potential increase in quality of life, autonomy and safety for all social user groups in everyday life.

1.3.10.2 Contribution to the Field

In recent years, the development of assistive robots has become an important, dynamic field, both in terms of product development and related research. Often, the functional or conceptual aspects are dominant and are considered in a laboratory-like environment or isolated from the environment. In this work, the intelligent interaction of assistance robots with humans plays a central role.

The long-term, large-scale use of assistance robots in society can only be successful and gain sufficient acceptance if the implementation of assistance robots is also tested and optimized in the domestic environment under realistic everyday conditions. For example, the recognition of human emotions is essential for the desired adaptive Human-Robot-Interaction (HRI). Systems currently available on the market are only capable of recognizing simple, basic emotions. In order to differentiate more finely between emotions and to react adequately, it is necessary to understand not only the emotion itself but also its origin.

1.3.10.3 Scientific and Technical Approach

R-ITUAL aims to establish an environment in which relevant research questions are analyzed and answered within a test scenario under realistic, everyday conditions. R-ITUAL will focus on onboarding, intelligent operation and the adaptation of assistance robot functionality and Human-Robot-Interaction (HRI). Independent of the general scientific aspects, however, the application in the domestic, private everyday environment is a key aspect – including all the associated technological, methodological, infrastructural, ethical and social challenges. In particular, R-ITUAL will investigate the use of near-product assistive robots in multi-generational households in order to draw general conclusions for improving and using such assistive robots in private spaces.

A significant focus of the R-ITUAL is the continuous improvement of understanding expectations and acceptance of assistance robots among different users through an iterative observation process. To achieve this, it is necessary that the sociological and technical experts communicate with each other. This is achieved through a continuous exchange of information and knowledge between the different partners.

1.3.10.4 Transfer and Outreach

In R-ITUAL, interaction strategies from robotics can be integrated into existing assistance robots, adapted to different user types and evaluated in long-term studies. The vision is to take a leading role in the application design, especially the introduction of assistance robots in the private residential environment.

The multi-generational house is highly relevant due to its cross-target group and already socially broadly designed characteristics. The findings can serve as a basis for expanding the application domains to areas such as villages, cities or larger residential complexes. R-ITUAL can be seen as a first step towards the intelligent digitalization of cities with new, semi-autonomous robotic services.

1.3.11 ROBO:REHKIDS – Competence Center for Interactive Assistance Robots for Kids in Rehabilitation

Full approach is described in detail in Chapter 12 (in German, Houta et al. (2023)).

1.3.11.1 Objectives

ROBO:REHKIDS focuses on assistive robots for therapy and support of children and young people with disabilities. According to the authors, interactive robots have the potential to become companions for this target group in two ways: both as assistance for disabilities that need to be compensated or supported and as companions for learning and therapy processes that are usually necessary throughout life for children and young people with disabilities. The intensified, self-determined and everyday use of such assistance robots offers promising opportunities to improve participation and the quality of care.

1.3.11.2 Contribution to the Field

The overall goal is to generate, bundle, and transfer knowledge and experience on the practical use of interactive assistance robots for the therapy and support of children and young people with disabilities. In order to unlock this potential, a competence network for the development and use of assistive robot technologies for the therapy and support of children and young people with disabilities is planned. The approach will also develop the organizational structures and methods for the use and application-driven development of such robotic systems. The scientific approach is based on a method tailored to the application domain, which also includes a socio-scientific and socio-political perspective. It analyzes the socio-scientific effects of Human-Robot-Interaction (HRI) and ethical implications as a basis for a value-oriented and sustainable design of assistance robots. This perspective includes the following aspects:

1. a health economic perspective – financial perspective,
2. a care process and user perspective – customer perspective,
3. a development and evaluation perspective – internal process perspective,
4. an innovation management and competence building perspective – learning and growth perspective.

1.3.11.3 Scientific and Technical Approach

The concept is based on three use cases. The first use case deals with interactive assistance robots as school and learning companions. The robotic assistants are intended to complement the existing learning companions in school and learning support against the background of the participation and self-determination of the children concerned, thus enabling new inclusive learning concepts.

The second use case relates to assistive robots in therapy and support of children with early childhood autism: According to the authors, robotic systems are well suited to support therapy. Moreover, robots can support autistic children because they can guarantee the safety of action, reliability and a high degree of repetition accuracy.

The third use case focuses on assistive robots as therapy companions or collaborators in neurological rehabilitation. With the increasing availability of safe, collaborative robots, it is essential to develop these systems that offer great potential for individualized and child-oriented therapy. However, the therapeutic requirements and concepts must be systematically combined with the technical possibilities.

1.3.11.4 Transfer and Outreach

The ROBO:REHKIDS concept combines interdisciplinary scientific and practical expertise in the field of interactive assistance robots for children and young people with disabilities. The combination of practice-oriented research on issues of interactive assistive robots with teaching concepts enables the inclusion of the latest research results into teaching. It, therefore, also allows the implementation of practice-oriented PhD research topics and the supplementation of practice-driven courses and seminars. This integrated teaching approach aims to advance research and development and expand the network.

1.3.12 rokit – Robots for Assistance Functions: Interaction in Practice

Full approach is described in detail in Chapter 13 (in German, Tariq et al. (2023)).

1.3.12.1 Objectives

The rokit project focuses on bringing mobile assistance robots and Human-Robot-Interaction (HRI) into public spaces. Public spaces, with their traffic, parks, and publicly accessible buildings, offer numerous fields of application for mobile robots. However, the integration of robots poses several specific challenges. On the one hand, interactions between humans and robots are remarkably diverse and often unpredictable: they involve safety risks that are often accompanied by unclear legal constraints. On the other hand, the public image of robots today is still very ambivalent and characterized by exaggerated expectations and fears of replacement.

1.3.12.2 Contribution to the Field

The resulting tension between technical, ethical, legal and design issues requires highly interdisciplinary strategies. The work in rokit is, therefore, dedicated to the normative design and evaluation of the practical and scientific issues of the use of mobile robots in public spaces. The approach addresses the use of and interaction with robots in public spaces and the resulting challenges of adapting existing robots to new use cases. The scientific mission of rokit is formulated in the following research questions:

1. Which social and individual expectations, needs and fears exist regarding robots, and what does this mean for the design of Human-Robot-Interaction (HRI)?
2. Which interaction strategies are suited for a good User Experience (UX) and high acceptance of robots in public spaces, and how can design guidelines be derived from this?
3. How can Human-Robot-Interaction (HRI) in public spaces be designed safely without compromising performance and usefulness?
4. What legal regulations enable or restrict the use of robots in public spaces?
5. What structured experiences can be derived concerning performance, (legal) security, Human-Robot-Interaction (HRI) and Ethical, Legal and Social Implications (ELSI) for assistance robots in general?

1.3.12.3 Scientific and Technical Approach

As a preliminary and preparatory step, three use cases are investigated as representative examples: The four-legged robot SPOT will inspect the area of a busy university campus, the robot MULI will help people to transport loads through a public building like a contactless handcart, and the robot from the company ANGSA will clean the areas of a public park together with employees of a city cleaning service. For research purposes, the approach consists of three elements: a think tank, a method workshop and a living lab. The integrative element of the structure is the rokit hub, which acts as a mediator and link within the cluster and as an interface and contact to the outside world.

In the long term, the available technology and expertise in assistive robots in public spaces are harmonized with social and economic requirements. The overall goal is to produce results that enable the meaningful, ethical, safe and economical use of robots in public spaces.

1.3.12.4 Transfer and Outreach

The authors are not aware of any other approach with a similar focus or comparable methodological and technical expertise. Moreover, they assume that existing consulting offers usually only focus on individual aspects such as usability, acceptance or security and are offered by single companies. In contrast, rokit aims to offer the added value of bringing together excellent partners from all decisive areas and dedicating itself to this challenging application domain. Moreover, rokit has identified many high-performant automation technologies for industrial and restricted areas. Adaptation to new use cases is an essential key to commercial success in the public sector. However, the transfer to this sector can only be successful if the relevant aspects identified in rokit are considered prior to deployment in public applications.

1.3.13 RuhrBots – Citizen-Oriented and User-Friendly Social Robots in the City Administrations of the Metropole Ruhr

Full approach is described in detail in Chapter 14 (in German, Straßmann et al. (2023)).

1.3.13.1 Objectives

RuhrBots focuses on assistance robots in the city to support visitors and staff. The focus is on libraries and museums, representing freely accessible meeting places with multiple uses. Robots can assist in searches, promotion, and education, as well as at return stations or cultural events.

Modern technologies, such as assistive robots, have a great leverage effect in the transition to a digitalized world, as urban institutions are meeting places and thus have both a role model and an educational function. Technical solutions are often not designed and implemented in a diversity-friendly way, so not everyone can or wants to use them. Municipalities are caught between rapid innovation and ensuring accessibility and diversity equity to ensure participation, accessibility, and acceptance for all.

1.3.13.2 Contribution to the Field

The scientific results show that, in addition to the design of the robot and its behavioral patterns, the human factor is highly relevant. In particular, expectations and fears play a significant role in the long-term use and acceptance of assistance robots. If people are unwilling to interact with and use robots because of fears, personal attitudes, and experiences, even the most functional and optimized robots will not reach their full potential.

The advantage of the RuhrBots approach is the combination of laboratory and field studies. These studies are based on the intensive participation of citizens and communities, with a continuous focus on the creation of an economic ecosystem. By locating the approach in the public space of the Ruhr metropolitan region, an ideal scenario is also created at the algorithmic level, in which the limits of existing systems are first made visible and then iteratively and continuously expanded in the direction of inclusion and adaptation. By locating it in the field and designing an individual human-robot-journey, the complete and complex interaction of the various sub-aspects of the socio-technical system becomes accessible for research.

1.3.13.3 Scientific and Technical Approach

An iterative, three-stage qualitative approach is chosen as a human-centered design process. It ensures the development of accepted and realistic application scenarios. Several interviews and workshops with citizens and employees were organized to collect visions of use, feedback, and requirements for social robots. In addition, four exemplary personas emerged from the qualitative interviews.

RuhrBots enables municipalities to build and expand expertise regarding assistance systems and their practical application. Additionally, the approach aims to reduce psychological barriers and obstacles by making it possible to experience social robots in familiar areas of everyday life. Overall, the aim is to increase the competence of municipalities, whose employees and citizens can experience an increased awareness of diversity and self-determination in the context of digitalization through active participation in the development and integration of social robots.

1.3.13.4 Transfer and Outreach

The vision of RuhrBots is that social robots will be integrated into municipal administrations in a participatory way. The robots are integrated into the processes and designed to meet the different needs of the citizens. This allows all citizens to use them without fear, bad experiences, or reservations. The goal is that the robots adapt to the different needs and that the interaction is barrier-free, usability-optimized, intuitive, multimodal, and non-discriminatory. Only if social robots have a positive impact on all citizens (diverse characteristics) and can be used by all (barrier-free) can they be integrated into urban institutions in the long term.

1.3.14 ZEN-MRI – Ulm Center for Research and Evaluation of Human-Robot-Interaction in Public Space

Full approach is described in detail in Chapter 15 (in German, Kraus et al. (2023)).

1.3.14.1 Objectives

ZEN-MRI focuses on service robots for cleaning and transport in public spaces. Specifically, the authors evaluate Human-Robot-Interaction (HRI) in public spaces in order to derive, develop and evaluate different interpretations of robot behavior and robot interaction strategies, as well as measures for the integration of robots in public spaces. Psychological, social, ethical, legal and security requirements will be taken into account. The goal is to enable service and assistance robots to increasingly perform tasks such as cleaning and transport in public spaces.

1.3.14.2 Contribution to the Field

The ZEN-MRI authors identify the use of robots in public spaces, where they perform tasks in close contact with many people who are not involved in the actual task, as a unique feature. Most people they interact with do not directly benefit from the robots, for example, when they are cleaning a pedestrian zone. Therefore, in order to perform their task efficiently and safely, the robots need to interact with two different groups: their human team partners and uninvolved pedestrians. For example, the robots need to communicate their task and find a feasible path. Interestingly, in this scenario, new technical agents, the robots, enter an established, functioning system of social interaction in which humans have evolved strategies for responding to each other, communicating, and cooperating. The goal of ZEN-MRI is to enable a harmonious coexistence between humans and robots in public spaces, ensuring individual well-being for humans, efficient and sustainable task performance by robots, and consideration of Ethical, Legal, and Social Implications (ELSI).

1.3.14.3 Scientific and Technical Approach

To support the implementation of these requirements, the approach aims at an integrated, interdisciplinary and theory-based evaluation of design options, strategies and interpretations of HRI in public space. In addition, the ethical, legal and societal frameworks for the coexistence of humans and robots in public spaces are investigated, and possible solutions are developed.

In the targeted use cases, the robots will perform tasks in public spaces in realistic, practical scenarios and in coordination with their environment. The robots are intelligent and adaptable, responding to the needs of people around them and adjusting their interactions and behavior accordingly.

The primary research approach follows the concept of a real-world laboratory in which robots are integrated into the existing social structure of public space. A dynamic and ad-hoc usable testbed with several test areas will be developed in close cooperation with the city of Ulm to achieve this goal. This testbed will allow the seamless integration of the robots into the social structure of the pedestrian zone.

1.3.14.4 Transfer and Outreach

As part of the approach, new methods for involving stakeholders and the public (Stakeholder Labs, Robot Museum) will be developed to ensure the participation of the population in the integration process. By integrating new service robots into the established system of social interaction in the pedestrian zone, many pedestrians will participate in the research and ensure the development of efficient and ELSI-conscious robots. ZEN-MRI will contribute its technical expertise to all activities for networking, knowledge transfer, and sustainable performance to increase the number of available service and assistance robots in everyday environments, with a special focus on public spaces.

1.3.15 ZENT-AUR – Competence Center for Flexible Autonomy in Telerobotics

Full approach is described in detail in Chapter 16 (in German, Weber et al. (2023)).

1.3.15.1 Objectives

ZENT-AUR focuses on flexible autonomy for telerobotics. The objective is to develop a safe and intuitive interaction strategy for Human-Autonomy-Interaction (HAI) in telerobotics, which is evaluated in areas of everyday assistance and surgery. The approach is based on the lack of hybrid solutions in which robot autonomy and telerobotics complement each other. Where human skills are required, they can be integrated with telerobotic solutions where the human can directly control the robot manually. Telerobotics thus combines the strengths of humans (e.g., decision-making ability) with those of robots (e.g., precision), opening up a wide range of applications in many areas of everyday life, far beyond today's applications (e.g., agricultural robots or telesurgery).

1.3.15.2 Contribution to the Field

The following scientific questions are addressed in three application scenarios: How can Human-Autonomy-Interaction (HAI) be implemented intuitively, safely, and appropriately? For example, how can human intent or dangerous situations be detected and appropriate function allocation proposed? How can HAI be designed so the teleoperator develops high situational awareness and trust in the system? What are valid metrics and benchmarks for evaluating the overall socio-technical system? In principle, flexible function allocation in HAI raises many questions about who should propose or initiate transitions from one control mode to another. Therefore, the central goal is to develop a holistic solution of flexible, scalable autonomy that opens up a wide range of interaction possibilities. Such versatile solutions are needed in view of the growing shortage of skilled workers and cost pressures in care, nursing, and medicine. ZENT-AUR also meets the social requirements for interactive assistance robots.

1.3.15.3 Scientific and Technical Approach

ZENT-AUR plans to evaluate the interaction approach of flexible autonomy in three applications, which allows switching between different degrees of autonomy from manual control to partial to full autonomy. The ZENT-AUR concept is intended to open up a new field of action for assistance robots. Many applications could benefit from this approach, from autonomous driving to robot-assisted surgery, from satellite construction in orbit to nursing robots. The human-centered approach creates a flexible autonomy that enables continuous switching between control modes – from manual control to complete robotic autonomy. ZENT-AUR develops a modular, generic toolbox for flexible autonomy. This toolbox is extensively evaluated in three application areas with different requirements, robot systems, and users. The contribution of ZENT-AUR is the integration of human competence into robotic autonomy. This is in contrast to previous research and development efforts in assistive robotics, which have undoubtedly focused on the integration of fully autonomous robots into people's everyday lives.

1.3.15.4 Transfer and Outreach

ZENT-AUR opens up a new perspective on Human-Robot-Interaction (HRI) because in addition to humans interacting directly with robots, teleoperating humans now play a key role, and ZENT-AUR will focus primarily on this interface with humans. The current limitations of assistive robots can be overcome by connecting humans teleoperatively and simultaneously using the local robotic autonomy functions. This is a unique attempt in robotics, and ZENT-AUR proves that the approach of flexible autonomy can be successfully applied across systems, user groups, and domains. ZENT-AUR thus avoids the isolated consideration of individual application areas and offers a versatile, modular, and customizable approach.

1.4 Towards More Robotic Assistance for Everyday Life

In recent years, more and more service and assistance robots have been introduced, reaching out to new areas of application. New robotics start-ups are entering the market and exploring the possibilities of robots in everyday life. Not all of these ideas are successful yet, but there is a noticeable increase in interest. It can be said that the big breakthrough that will bring service robots into everyday life is still to come. However, the current performance and flexibility of the latest robot technologies are paving the way for this upcoming change in our society. Today, there are still several challenges: safety, legal regulations, reliability, reusability, and business models must be considered within the unique, dynamic, and challenging conditions in everyday life environments.

The acceptance and interaction between humans and robots are central to the success of service and assistance applications. This preface summarises the state of the art in the scientific fields that must be considered to enable the everyday use of robots: From manipulation tasks in everyday environments to Human-Robot-Interaction with non-experts or navigation in dynamic complex real-world use cases as well as object recognition and localization. The following key concepts have the potential to stimulate and accelerate the implementation of new service and assistance robot applications:

- continuous open-source software,
- periodic robot competitions and challenges,
- openly available benchmarks and datasets,
- new service and business models, as well as the
- safety, legal and regulatory framework

for service and assistance robots. All in all, the issues addressed are necessary to improve the acceptance of service and assistance robots in Germany, to ensure robustness, safety, and economic feasibility, and to establish new systems in real-world environments. If the robots are not accepted and thus not wanted, they will be damaged, deliberately disrupted, and ultimately banned from public use under public pressure. Without a high level of acceptance, service and assistance robots will not be able to become a success because in this field, not only economic aspects decide whether a robot application will be continued, rolled out to other locations, or even transferred to new domains.

It is well understood that acceptance is based primarily on positive, successful human interaction with robots. With their new research questions, innovative approaches, and interdisciplinary results, the 15 feasibility studies published in this collection contribute to increasing the acceptance of robots in our daily lives. It is, therefore, to be hoped that this collection will bring more and more fascinating service and assistance robots into everyday life in Germany in the near future.

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