10

Applications

What is covered in this chapter:

- The diverse areas of robot applications where human–robot interaction (HRI) is an important component;
- Applications beyond robots that are studied in a research context;
- Possible future applications;
- Potential problems that would need to be solved when HRI has a larger role in our society.

Human–robot interaction (HRI) has numerous applications expected to make a positive difference in people's lives. HRI is increasingly getting traction in the technology market, and although most applications are still being developed in the academic sphere, adventurous start-ups have popped up that are developing and selling HRI applications, and established information technology (IT) industries are keen to understand and develop technologies that allow robots or robot technology to interact successfully with people. Not all of these enterprises turn out to be successful. Sony, for example, was one of the pioneers of commercial robotics with its Aibo (see Figure 10.1) and Qrio (see Figure 10.2) robots, only to stop its efforts in the field in 2006. However, Sony's efforts were recently rekindled, with a new Aibo appearing in 2018 (see Figure 3.2). Another example is the Bosch company, which initially supported Mayfield Robotics in developing the Kuri home robot but stopped the project before the official product launch.

A successful HRI application means something different depending on the perspective one takes: the notion of what constitutes success is very different for a researcher compared to an entrepreneur. Whereas a researcher will be interested in measurable outcomes of the robot's use and usability, an entrepreneur might be less concerned about the effectiveness of the robot and will be happy with a "good enough" technical solution that can be brought to market, thus preferring sales figures over scientific figures. Some may even develop unsuccessful applications

Figure 10.1 The Sony Aibo ERS-7 (2003–2005) with the Nao (2008–present) robot.

on purpose for the entertainment value or to inspire people to think more critically about the uses and design of robotic technology (see the accompanying text box for examples).

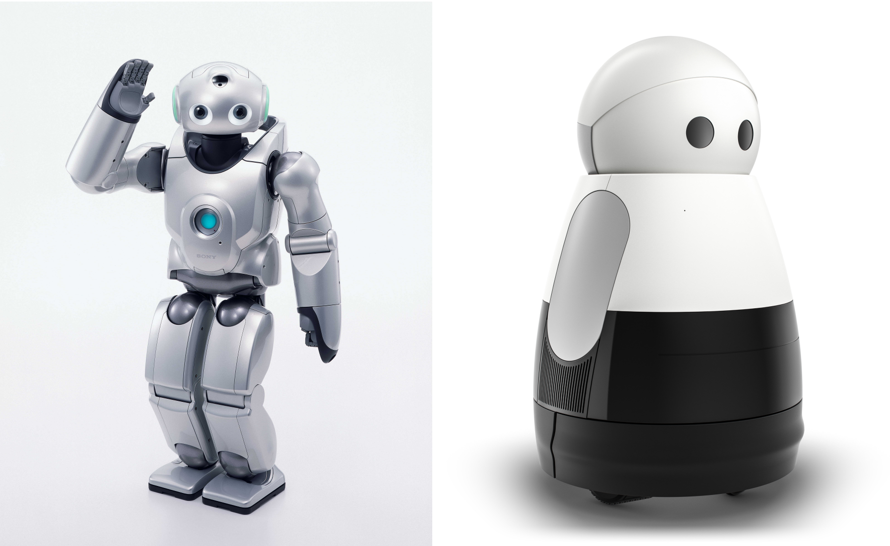

Figure 10.2 Sony's Qrio robot (left) (2003–2006) (source: Sony) and Mayfield Robotics' Kuri (2016–2018) (source: Mayfield Robotics)—two robots that never made it to the consumer market.

The self-crowned "Queen of Shitty Robots," Simone Giertz is a nonengineer robot enthusiast who designs service robots that usually perform poorly in their intended application. Her videos on the testing of her different creations not only have entertainment value but also demonstrate how designing robots for seemingly simple tasks can prove to be quite challenging.[a] White's "Helpless Robot," on the other hand, is a machine with a passive personality that asks people to move it around the room, opening up questions about the meaning of machine autonomy and whether our machines serve us or whether it is the other way around.[b]

[a] https://www.youtube.com/channel/UC3KEoMzNz8eYnwBC34RaKCQ/
[b] http://www.year01.com/archive/helpless/

For now, most robot applications remain at the research stage, but this is expected to change rapidly. The first wave of commercial success in robotics took place in automating industrial production; the next wave of commercial success is expected to come from introducing robots in dynamic and open environments populated by people in customer service, companionship, and socially and physically assistive roles. It is here that HRI has its major role to play: a solid understanding of how robots should behave around people, and how people respond to and benefit from robots, is needed to make the next robot wave a success (Haegele, 2016). The following sections provide an overview of the various types of robots that have been tested in the lab and in the field, starting with service robots.

10.1 Service robots

A novel robot often attracts people's attention; in public spaces like shops, visitors become interested and approach, and children crowd

Figure 10.3 The Robovie robot as a museum guide (2006).

around it. This makes robots an ideal asset for customer service settings. Many such applications have already been successfully tested in field research and have been deployed in grocery stores or bank branches (e.g., Pepper providing service at HSBC in the United States).

10.1.1 Tour guide robots

One of the applications developed in the early years of HRI research is the tour guide robot (Burgard et al., 1998; Shiomi et al., 2006). Typically, a tour guide robot moves from one location to another while providing information about nearby entities; some of them take the user to a requested location. This robot application involves navigational interaction (e.g., the robot safely moving around in an environment it shares with humans) and face-to-face interaction with its users (see Figure 10.3).

There are many instances of successful tour guide applications. One such application is in a museum setting, where a mobile robot is left to autonomously navigate around. Visitors are invited to use a user interface on the robot to indicate whether they want to have a tour guide. Once a tour is requested, the robot leads the visitors to several exhibits, providing a brief explanation at each (Burgard et al., 1998). HRI researchers experimenting with museum robots have found that giving the robot the ability to display emotions can enrich the educational experience and allow the robot to better manage its interactions with people, such as getting them to move out of its way by expressing frustration (Nourbakhsh et al., 1999). An alternative application concerns the retail context, when a customer may want to know where in the store a specific item is kept, and a robot takes the lead to show him or her the way to the appropriate shelf (Gross et al., 2009). A final example is the airport, where a robot can escort travelers to the gate for their next flight (Triebel et al., 2016).

It is easy to imagine similar scenarios where robots would be helpful. For example, it is common for people to escort other people, either because they need physical assistance or because they want to be accompanied, in daily interactions. Robots could be used in this context in the future. One such application being developed by HRI researchers is a guide robot for individuals with visual impairments (Feng et al., 2015). Although the current limitations in robotic hardware and HRI capabilities prevent such uses in the present, technical advancements and further HRI research should enable us to have robots with faster velocity and better navigation capability in human crowds that can be applied for accompanying users in a broader range of environments.

10.1.2 Receptionist robots

Receptionist robots are placed at a reception desk and interact with visitors, typically offering information through spoken-language conversation. For instance, Gockley et al. (2005) studied people's interactions with a robot with a display for its head as a receptionist at a university (see Figure 10.4). The robot was able to provide directions and would share daily stories with people who came to chat with it. It also turned out that people were sensitive to the robot's moods, and the length of their interactions with it changed based on whether the robot displayed a happy, sad, or neutral expression (Gockley et al., 2006). Outside of the research setting, android robots have been used as receptionists in hotels. In this case, users use a graphical user interface (GUI) to proceed through the check-in process, attended by an android robot and a small humanoid robot that offers greetings to the visitors.

Figure 10.4
Receptionist robot.

10.1.3 Robots for sales promotion

Another straightforward application of service robots is product promotion in the retail context. In this setting, robots can function as proxies for store clerks, informing customers about the promotions offered by the store. Because people are naturally curious about robots, these robots can easily attract the attention of potential visitors, who will stop to listen and then look around. In Japan, Pepper is already used for this purpose. In the typical use case, robots are not necessarily proactive but instead wait for visitors to initiate interaction. In the research context, researchers study robots that proactively approach customers to offer promotions (Satake et al., 2009). For instance, the famous Geminoid android robot has been deployed in a shopping mall in Japan to boost sales (Watanabe et al., 2015).

10.2 Robots for learning

Social robots have been shown to be particularly effective for assisting in learning and education (Mubin et al., 2013). This should not be confused with the use of robots as an educational tool to teach mathematics, programming, or engineering, such as Lego Mindstorms. Robots can take on various roles in the process of learning: The robot can act as a teacher, taking the students through the curriculum and offering testing opportunities to assess knowledge. As a tutor, a robot would support the teacher in his or her teaching (Kanda et al., 2004). This role is actually preferred by teachers and students (Reich-Stiebert and Eyssel, 2016). However, the robot is also often presented as a peer. The peer-like robot has a similar level of knowledge as the learner, and the learner and robot take a learning journey together, with the robot adapting its performance to that of the learner. At the far extreme is the robot that needs to be completely taught by the student. This approach, known as a care-receiving robot or teachable agent, is effective for two reasons. First, teaching a subject often leads to mastery of that subject, and second, having a less knowledgeable peer can boost the learner's confidence (Hood et al., 2015; Tanaka and Kimura, 2010). Finally, robots could also be used as a sidekick for teachers. In this role, the robot spices up the lesson and makes the learning more entertaining, thus capturing student interest (Alemi et al., 2014).

Tutoring robots may take over specific tasks from the teacher. Because teachers typically deal with class sizes of more than 20 students, they are required to teach to the mean of the class using a broad rather than a personalized style. It has been shown that tutoring has a strong impact on learning. Bloom (1984) found that one-to-one tutoring resulted in a 2-standard-deviation improvement against a control group, concluding that "the average tutored student was above 98% of the students in the control class." Although research has since shown that the effects are not as large as first observed, there is nonetheless a distinct advantage to the one-to-one tutoring approach (VanLehn, 2011). Social robots in education capitalize on this by offering a one-to-one, personalized tutoring experience.

Robots have been used to teach a wide range of topics, from mathematics to languages, both to adults and children. The main contribution of the robot seems to be that its physical presence promotes learning. Although computer-based tutoring programs, also known as intelligent

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tutoring systems (ITSs), are effective (VanLehn, 2011), the social robot adds to this through its social and physical presence. Studies have shown that robots offer a distinct advantage over on-screen social agents or ITSs, and the students learn faster and learn more when tutored by a robot as compared to alternative technologies (Kennedy et al., 2015; Leyzberg et al., 2012, e.g.). The reasons for this are still unclear: it might be that the social and physical presence of the robot engages the learner more than just on-screen delivery and feedback, or it might be that the learning experience is a more multimodal experience, thus resulting in a richer and embodied pedagogical exchange (Mayer and DaPra, 2012)—of course, a combination of these two is also possible. It may come as no surprise that socially supportive robots perform much better (Saerbeck et al., 2010). Some socially interactive behaviors can also backfire in learning contexts, leading the student to interpret the robot as a peer rather than a teacher and to engage with it socially rather than focusing on achieving certain learning goals (Kennedy et al., 2015). HRI research is therefore necessary to guide the development of robots that can effectively support learning.

10.3 Robots for entertainment

10.3.1 Pet and toy robots

Robotic pets and toys were among the first commercial robot applications for personal use. After the first doglike robot, Aibo (Fujita, 2001), appeared on the market in 1999 (see Figure 10.1), the development of many other entertainment robots soon followed. Compared to other robotic applications, entertainment robots have been easier to get to market because the functions they perform do not have to be as advanced, and they often use preprogrammed capabilities, such as dancing, talking, burping, and even seeming to develop their knowledge by simply starting to use more advanced preprogrammed skills after a period of time. Some of the most popular robotic toys over the years have been Furby, Sony's Aibo robot dog, and more recently, Cosmo. Lego Mindstorms was a market leader in the educational toy robot niche but has recently been followed by a slew of robots that allow children to learn how to code and think computationally, such as Dash and Dot and Ozobot, among many others. The WowWee company is another market leader, with many different robots, including the humanoid robots Robosapiens and Femisapiens and a mobile home robot. The company Sphero developed a robotic ball that could be remote-controlled; following the release of the new series of Star Wars films in 2015, the company amended the design to represent the BB-8 droid, which became one of the most popular holiday toys of that season.

Although most entertainment robots target children and adolescents,

Figure 10.5 Pleo Robot (2006–present). (Source: Max Braun)

many are also enjoyed by adults. The Aibo in particular was very popular with adults, who even started a "black market" of Aibo parts when the robot was discontinued by Sony in 2006. As mentioned earlier, Sony introduced a brand-new version of Aibo in 2018.

Pleo (see Figure 10.5), a camarasaurus rex robot platform, provides a similar complexity of interaction, with various modes of personality and behavior that adapt and change across time and users. These examples show that many robot toys are not necessarily social or humanlike in appearance, but they still elicit strong social responses in children and adult consumers alike.

Considering the variety of ways in which robots can provide entertainment and the popularity of robots among the public in general, it is not surprising that the market for toy robots has been and is expected to stay one of the largest for personal robots (Haegele, 2016).

10.3.2 Robots for exhibitions

Robots are often used in exhibitions and theme parks to entertain audiences. These often-animatronic devices are very robust; they must play the same animation script sometimes hundreds of times per day, with only a brief moment for maintenance between performances. Some robots intentionally look like robots, but others resemble animals, for example, dinosaurs (see Figure 10.6), or people. In these cases, the robot has a flexible latex skin, which has been carefully painted to reflect realistic skin coloration and patterns. Most of these animatronic robots have no autonomy: they play a prerecorded script of animation timed to a soundtrack. In rare cases, the robot may have limited autonomy, such as the ability to focus on members in the audience while

Figure 10.6
Animatronic robot.

speaking. A popular example of the use of animatronic robots is the Hall of Presidents located in the Walt Disney World Resort.

10.3.3 Robots in the performing arts

Robots are also sometimes used in the performing arts. One of the first robot performance art pieces was Senster, created in 1970 for Philips' Evoluon in Eindhoven, the Netherlands (Reichardt, 1978). Senster was an electro-hydraulic structure shaped after a lobster's claw, with six hinged joints. It registered and responded to sound and movement from the environment. It was on display until 1974, when it was dismantled. More recently, 20 Nao robots performed a synchronized dance recital for France Pavilion Day (June 21) at the Shanghai 2010 Expo.

Not all art applications have to be for a broader public. Home theater systems might soon become what their name promises. Imagine a future in which you download the theater script of *Romeo and Juliet* into your robots. You can then either watch the robots perform the play or join in yourself. It is important to note that a major use of robotics—both in the past and currently—is to automate tasks that we do not want to perform ourselves. Industrial robots, for example, were introduced to relieve us of difficult and repetitive manual labor. There is little use in automating tasks that we actually enjoy doing. This does not mean that there is no place for robots in the theater–plays that actually deal with robots should, of course, be cast with robots (Chikaraishi et al., 2017).

Furthermore, there are many ways in which robots can interact with people in art performances, to which the future social robots could contribute as a human counterpart. For example, Hoffman and Weinberg (2010) developed a marimba-playing robot that joins a jazz-like session with a human player. Kahn Jr. et al. (2014) revealed that a robot can partner with a human to enhance human creativity in the art-creation context. Nishiguchi et al. (2017) suggest that developing robots that can perform as actors in a play alongside humans can also be a way to develop more humanlike behaviors for robots.

10.3.4 Sex robots

Along with toy robots aimed at the child market, there are also embodied robots and virtual reality (VR) interfaces for the fulfillment of adult entertainment needs. Colloquially known as "sex robots," diverse robotic platforms offer varying levels of humanlike appearance and behavioral response. The Real Doll company, which develops hyper-realistic sex dolls, is working on adding robotic capabilities, including an emotive face and responses, to its base models. Several other producers have developed prototypes of sex robots, although none has yet come to market. It is envisioned that the sex robot industry will continue to grow over the coming years.

Levy (2009) provides a history of sex machines and speculates about our future intimate relationships with robots.

10.4 Robots in healthcare and therapy

Healthcare and therapy represent prominent domains of application for robotics. In these domains, social robots are used to offer support, education, and diversion to patients, with an eye toward improving healthcare and therapy outcomes. The practice of using social robots in healthcare is referred to as socially assistive robotics (SAR) (Tapus et al., 2007; Feil-Seifer and Matarić, 2011) and is often targeted to older adults (Broadbent et al., 2009; Broekens et al., 2009).

10.4.1 Robots for senior citizens

Although senior citizens and people with mild cognitive impairments are a key target audience for robot developers who want to offer technology-mediated social, emotional, and cognitive rehabilitation and diversion, there are other target groups that can benefit from social robots.

For example, the Paro robot is a seal-like robot equipped with sensors that allow it to detect when it is being picked up or stroked (see

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Figure 10.7 The ElliQ robot (2019–present) from Intuition Robotics is designed to interact with senior citizens. (Source: Intuition Robotics)

Figure 2.6). It can respond by wriggling and making seal-like noises. Paro has been used in a multitude of studies with elderly people, and positive psychological, physiological, and social effects of long-term interaction with the robot have been documented (Wada and Shibata, 2007). The robot is used as a companion in care homes and stimulates not only human–robot interactions but also interactions between the residents. It has been able to reduce feelings of loneliness and improve the residents' quality of life. Paro has been commercially available in Japan since 2006 and in the United States and Europe since 2009. It is interesting to note that although it is purchased by many individuals for home use in Japan, in Europe and the United States, the robot is almost exclusively purchased by healthcare institutions and companies. Furthermore, some robots, such as NEC's Papero (see Figure 10.8, have only ever been released in Japan.

Robots can also provide reminders for people to take their medications (Pineau et al., 2003) and can provide pre-clinic or tele-clinic support at home, thus reducing costs for medical services (Robinson et al., 2014).

10.4.2 Robots for people with autism spectrum disorder

Children and adults with autism spectrum disorder (ASD) are another group for which social robots are often developed and used. It has been shown that people with ASD generally respond well to robots, and there has been a large body of research looking into how robots can be effectively used to support ASD therapy (Diehl et al., 2012; Scassellati et al., 2012; Thill et al., 2012). Many types of robots have been used

Figure 10.8 NEC's Papero robot has been available in different versions, such as Papero R-100, Papero Mini, and Papero i (1997–present)

in a therapeutic context to support children with ASD (Robins et al., 2009; Pop et al., 2013) (see Figure 10.9). These include a wide range from humanoid robots, such as Kaspar and Nao, to zoomorphic robots, such as Elvis and Pleo. The predictable nature of robot behavior and the fact that robots are nonjudgmental have been credited as potential reasons why using them in interactions and therapeutic interventions with individuals with ASD is successful. The robots are either used as a focal point for the interaction between the therapist and the patient or

Figure 10.9 A range of robots used in autism spectrum disorder therapy. From left to right, Nao (2008–present), Elvis (2018–present), Kaspar (2009–present) and Zeno (2012–present). (Source: Christoph Bartneck, Bram Vanderborght, Greet Van de Perre, Adaptive Systems Research Group, University of Hertfordshire, Steve Jurvetson)

are used to train and improve children's social competences and their ability to regulate and interpret emotions.

10.4.3 Robots for rehabilitation

Robots are also used to support physical rehabilitation. This can be through offering physiotherapy, and through providing encouragement and mental support. Social robots have been shown to be effective in cardiac-focused rehabilitation by providing encouragement and social facilitation during cardiac exercises (Kang et al., 2005; Lara et al., 2017). Robots can also be used to encourage users to adopt healthy practices or to change unhealthy habits. For example, Kidd and Breazeal (2007) describe a robot that acts as a weight-loss coach, and Belpaeme et al. (2012) describe the use of a robot to support children diagnosed with diabetes. Kidd's early research developed into a robotic start-up and healthcare robot called Mabu.

Robots can also be used as orthotic or prosthetic devices. The restoration of the function of the lower limbs, arms, and hands through robotics has received considerable attention (Bogue, 2009). Although these developments are largely the concern of mechatronics, there is a role for HRI in the study of the acceptance and usability of robotic prostheses.

10.5 Robots as personal assistants

Smart-home assistants, unobtrusive devices that are placed in the home or the office and are often voice-operated, have been a recent and largely unexpected success of cloud-connected technology. Technology giants such as Amazon, Google, Microsoft, Apple, and Samsung have raced to build voice-operated assistants, and some offer hardware products that are built around this technology. Amazon's Alexa, Apple's Siri, Microsoft's Cortana, and the Google Assistant have found embodiment on a range of devices, with shapes and sizes ranging from a hockey puck to a shoe box. These devices offer a vast range of services, but they are most often used to request simple information, such as the time, weather, or traffic, or to stream music. These devices can engage

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Figure 10.10 Personal assistant robots: from left to right, the Jibo robot (2017–2018), the Nabaztag (2009–2011) robot, and the Buddy Robot (2018–present). (Source: Jibo Inc., Blue Frog Robotics)

in only very short social exchanges, often limited to chitchat, such as telling a joke.

Recently, a number of commercial ventures have been launched that offer social robots as personal home assistants, perhaps eventually to rival existing smart-home assistants. Personal robotic assistants are devices that have no physical manipulation or locomotion capabilities. Instead, they have a distinct social presence and have visual features suggestive of their ability to interact socially, such as eyes, ears, or a mouth (see Figure 10.10). They might be motorized and can track the user around the room, giving the impression of being aware of the people in the environment. Although personal robotic assistants provide services similar to those of smart-home assistants, their social presence offers an opportunity that is unique to social robots. For instance, in addition to playing music, a social personal assistant robot would express its engagement with the music so that users would feel like they are listening to the music together with the robot (Hoffman and Vanunu, 2013). These robots can be used as surveillance devices, act as communicative intermediates, engage in richer games, tell stories, or be used to provide encouragement or incentives.

10.6 Service robots

Service robots are designed to help humans in various onerous, often called "dull, dirty, and dangerous," tasks. The tasks performed by such robots are typically simple and repetitive, and they often do not involve explicit interaction with people. HRI research considers such robots when they operate in everyday human contexts and therefore come into regular contact with people, including house-cleaning and delivery robots and robots that offer personal assistance.

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Cleaning robots

Cleaning robots are widely used in homes. The most well-known cleaning robot is Roomba; it is also the most commercially successful personal service robot to date. It is a small robot, approximately 30 cm in diameter, that has two wheels to enable it to move around, dust sensors to know where it needs to clean, cliff sensors to avoid falling down the stairs, and of course, vacuuming capability. It moves around randomly in a house, turning when it comes to a wall, and over a period of time, it manages to clean up the room. (In general, that is; pets can undermine this goal horribly. See the accompanying box). There are many other vacuum-cleaning robots for the home, as well as the mopping robot Scooba.

> Dreaded by every pet-owning Roomba user, the *Poopocalypse* is the unfortunate yet inevitable event where a pet leaves a dropping somewhere in the house, and the Roomba encounters it before the owner can clean it up, spreading it all across the house. These incidents are common enough that iRobot formulated an official response, warning Roomba users to not use their Roomba unsupervised if they own a pet (Solon, 2016).

Commercial service robots coming onto the market have provided HRI researchers with opportunities to study how people respond to and use such robots in everyday circumstances. Fink and Kaplan performed ethnographic studies of Roombas in user homes to identify common use patterns, and they also noticed how users prep their homes so that Roomba can do its job (Fink et al., 2013). Other researchers have found that users sometimes like to display Roombas as a sophisticated technology, whereas at other times, they try to disguise or hide them because they are deemed unsightly (Sung et al., 2007, 2009). Forlizzi and DiSalvo (2006) also explored how people's models of service affect the way they expect robots to interact with them, including how robots can best recover from mistakes made while providing services, such as bringing users the wrong drink.

Delivery robots

Delivery robots carry objects from one place to another. Amazon uses delivery robots in its warehouses. They are also used in other environments, such as the Aetheon TUG robot used in hospitals. Some hotels use robots to deliver goods from the service desk to guest rooms. More recently, mobile robots are now being used to make meal deliveries in San Francisco, California, through Yelp's Eat24 app. There are many start-ups that seek to provide delivery robots. Although perhaps desirable for the direct users, these robots sometimes turn out to be a nuisance for bystanders, who have to dodge them on already-busy city streets. Mutlu and Forlizzi (2008) showed that the workflow and patient profile of the hospital ward in which the Aetheon TUG delivery robot was deployed could make the difference between a successful and unsuccessful implementation.

Security robots

Robots are also commonly considered as potential providers of security in homes and public spaces. A robotic security guard, K5 (see Figure 10.11)) recently appeared on the market and has since been deployed at some shopping malls. It roams around the environment to monitor crime and alerts human authorities if it senses something suspicious. A prime example of a service robot that was not accepted by its environment, the K5 robot has fallen victim to a variety of abusive behaviors, ranging from an attack by a drunken man while patrolling a parking lot in Mountain View, California, to being tackled and covered in barbecue sauce while attempting to chase off homeless people from a nongovernmental organization's doorstep in San Francisco (see Figure 10.11).

Figure 10.11 Knightscope K5 (2013–present). (Source: Knighscope)

10.7 Collaborative robots

Collaborative robots are gaining importance in the automation industry. Traditional industrial robots typically are stiff, are strong, and have limited sensory capabilities. Because of this, humans are not allowed near a powered industrial robot. In contrast, collaborative robots—co-bots for short—have safety features and a mechatronic design that allow them to operate near people or even work together with people.

Some co-bots are equipped to interpret or produce social signals, such as the Walt robot, which has a face attached to its robotic arm (see Figure 10.12). The Baxter robot (see Figure 2.7) is a two-armed robot that is able to display a range of facial expressions on its screen, signaling various internal states. An embarrassed blush, for example, signals to the human co-worker that the robot is at a loss about what to do next.

The deployment of co-bots in industrial manufacturing contexts and the workplace in general may fundamentally change the notion of collaborative teamwork. In positive scenarios, co-bots should be able to help humans get more pleasure and efficiency from their work. In the worst case, collaboration with robots could backfire through a reversal of the roles of humans and robots, leading to humans serving robots rather than vice versa.

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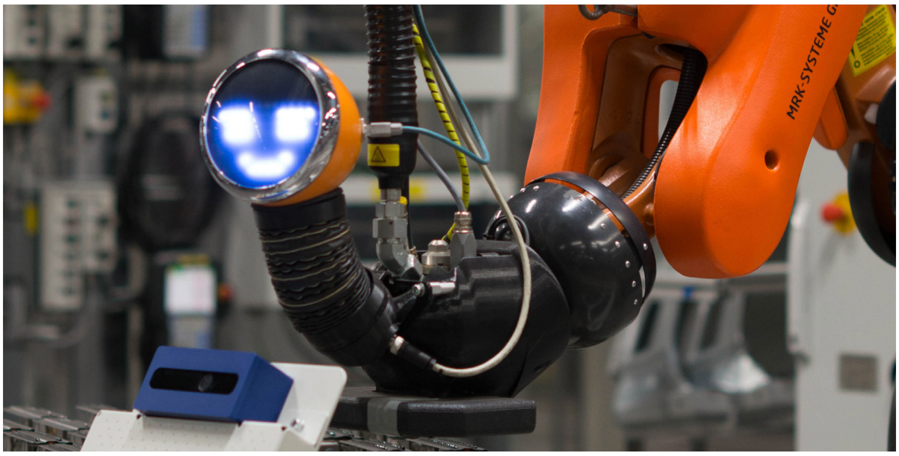

Figure 10.12 Walt (2017–present), a collaborative robot, working at the Audi car factory in Brussels to apply glue to car parts. It has a headlight-shaped head with an animated face to communicate its internal state to its human co-workers. (Source: copyright imec)

10.8 Self-driving cars

Self-driving cars are, in essence, robots in which the user is in the passenger's seat. Although autonomous cars are still not widely available, most cars now have some form of on-board advanced driver assistance technologies (ADAS), such as lane following, adaptive cruise control, automatic parking, predictive braking, pedestrian protection systems, and blind-spot warning systems. Many of these systems require an effective human–machine interface for the driver of the car. In addition, self-driving cars require interfaces allowing them to interpret the actions and intentions of other traffic users, and the car will need ways of expressing its intentions to other users. Car drivers use a wide range of signals to communicate their intent to others. For example, slowing down when nearing a crosswalk can signal to pedestrians that they have been noticed and that it is safe to cross. The Jaguar Land Rover developed a more explicit way of communicating with pedestrians by putting "googly eyes" on its cars to signify attention.

Interaction with the driver does not only happen through the car's interface but also often requires autonomous technology to communicate why a decision was made. Koo et al. (2015) show how a message that explains "why" an action was taken, such as automated braking, is preferred over a system that merely reports the action.

HRI studies can help understand how traffic users and passengers respond to autonomous cars. Rothenbücher et al. (2016) present a paradigm in which a driver is disguised as a car seat, giving the impression that the car is self-driving (see Figure 10.13). This deception allows for carefully controlled studies on how people perceive and respond to self-driving cars without the need for a fully self-driving car.

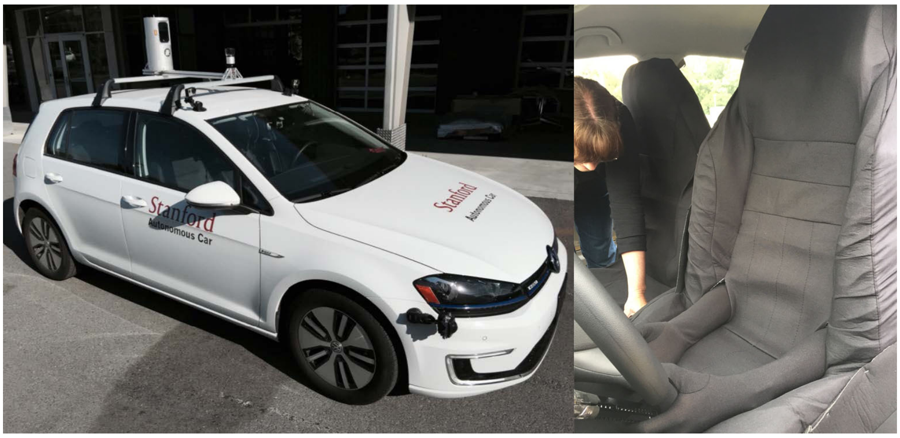

Figure 10.13 A mock-up of a self-driving vehicle, in which a driver is disguised as a car seat, used to study people's responses to the behavior of self-driving cars. (Source: Wendy Ju

10.9 Remotely operated robots

People in the military have reported becoming very attached to their robots, despite the fact that these were designed without any capability of social interaction. Military robots have been named, have been awarded battlefield promotions, and have received medals of honor from their human supervisors (Garreau, 2007).

There are several application examples of remotely operated robots. Robots used for planetary exploration have some autonomous navigation capability but receive commands from human operators on Earth as well. Packbot (see Figure 10.15) is a scout robot used in a military context; a human operator tele-operates Packbot while it searches for bomb-traps, thus clearing the road for military vehicles. Also in the military context, a human operator can operate a drone from a faraway location during military operations. In search-and-rescue scenarios, an operator controls a robot that moves on the ground or through the sky to find a person in need. Telepresence robots have started to appear on the market as well and can be used, for example, to give a presentation at a remote place or to interact with people in a different location.

In these remote-operation scenarios, a human operator commonly needs to work with some level of autonomy in the robot. A robot may autonomously navigate around, but the operator may need to provide destinations for efficient use. The robot's capability of avoiding risks (e.g., collisions with obstacles or attacks from a hostile entity) can be poor, and hence the operator needs to intervene before the robots are seriously damaged.

Operators interact with remotely operated robots via a user interface (see Figure 10.14); here, there are many common HRI problems to address, as with other types of human–robot interaction. For instance, the robot system needs to acquire an appropriate level of trust from the operator, not too much, not too little. There are similar ethical issues to be considered. For example, if the autonomy system fails, who is responsible? Is it ethical to design a system that would allow such a failure of autonomy?

Figure 10.14 The T-HR3 robot (2017–present) can be remotely controlled using a dedicated user interface. (Source: Toyota)

Figure 10.15 Packbot (2016–present). (Source: Endeavor Robotics)

10.10 Future applications

Many of the applications introduced in this chapter are already available today. As technologies keep advancing, however, other types of future applications will emerge. For instance, researchers envision that daily appliances can be more automated and connected, as a network of devices within a smart home, for example. Several research groups also envision that individual robots can provide interfaces for such smart homes (Bernotat et al., 2016). Researchers have also started exploring how people might react to robotic furniture and appliances. Sirkin et al. (2015) studied how a robot ottoman should interact with people and also explored interactions with an interactive chest of drawers. Yamaji et al. (2010) developed a set of social trash boxes, which use social cues such as approaching and bowing to motivate people to throw away their trash; they also created a set of robotic dishes that can be summoned by a user by rapping on the table. Osawa et al. (2009) investigated how people may respond to home appliances being anthropomorphized, such as equipping a refrigerator with eyes or a printer with a mouth so that it can speak to a user.

Future developments of robots will also likely extend the capabilities within existing application domains. For example, healthcare robots are now being developed not only to provide companionship but also to monitor the behavior and health status of their users (e.g., Autom) and also possibly to assist with tasks of daily living (e.g., Care-O-Bot). Educational robots may take on more active roles in tutoring, particularly in domains such as second-language learning (Belpaeme et al., 2015). Following data-based applications in other domains, robots might also take advantage of their interactive capabilities to collect different kinds of information on users. We can expect robotic sensing and interaction capabilities to become more distributed in our lived environment, engaging with us through various everyday devices that may not immediately come across as robots.

10.11 Problems for robot application

There are various HRI problems that could prevent robots from being successful on the commercial market and as applications in everyday life. These include the potential for robot design to lead to misplaced and eventually disappointed expectations, overreliance on and addiction to robots, misuse and abuse of robots, and engagement with robots taking people's attention away from other concerns.

10.11.1 Addressing user expectations

Users often enter into interactions with robots with certain expectations, often rooted in exposure to specific conceptions of robots in the popular news media or fiction. The design and presentation of robots can also inspire certain expectations in users. For example, if a robot speaks in English, users will likely expect that it will be able to understand spoken English. The more humanlike the robot looks, the more human capabilities it may be expected to have. The cost of disappointing user expectations can be that the robot is perceived as incompetent, and people are therefore less willing to use it. Paepcke and Takayama (2010) showed that it is possible, however, to manage user expectations by describing the robot's abilities realistically; in fact, it is better to set expectations lower rather than higher. User expectations could also be managed through the design; for example, many social robots are designed with infant-like appearances to decrease expectations and increase tolerance for error.

10.11.2 Addiction

There is a concern that robots, and specifically social robots, will make people over-reliant on the social and physical interaction offered by robotic devices. One can easily imagine a future in which some people prefer robots as interaction partners, perhaps even as life partners, over humans Borenstein and Arkin (2016). A less extreme scenario would be where robots are preferred over people for some interactions. Although this is not necessarily cause for concern—many people already prefer online shopping over a trip to the store, for example—we should be wary of the negative consequences of substituting social human interaction with social "robot" interaction. One concern is that robots will be seen to offer friendship, a state that, of course, is artificial to the robot but might be perceived as genuine by the human user (Elder, 2017). Conversations with a robot could be pleasant, even cathartic, but there is a danger that because the robot panders to the user, offering an interaction that is pleasing, this might make the user over-reliant on the robot, causing the human to crave the robot's company. Because robots are most likely to be under the control of corporations, to some extent, there is a concern that dependence, and perhaps even addiction, will be a sought-after property in robots. Lessons should be learned from our interaction with connected devices when designing robots (Turkle, 2016).

10.11.3 Attention theft

As can already be observed with mobile devices, technology attracts our attention, and robots, too, could cause "attention theft." Neuroscience research has demonstrated that our attention is grabbed by motion and sound, and this is exacerbated when the sound and movement is lifelike and social (Posner, 2011). Robots pose an easy opportunity for attention theft, either unintentionally or by design. When designing and deploying robots, care should be taken that the robot has a mechanism to identify when not to engage with the user or draw attention through its actions, however unintentional. In particular, this should be carefully done in cases where the robot might attract attention away from a human interaction partner.

Gazzaley and Rosen (2016) provide an interesting read about the "dark side" of our high-tech age.

10.11.4 Loss of interest by user

The so-called novelty effect is frequently discussed in the HRI literature, suggesting that people pay more attention to a novel entity and

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express a preference to use it because it is unfamiliar; however, such effects are usually not long lasting (Kanda et al., 2004; Koay et al., 2007b). Researchers have tested various robot applications in research contexts and have revealed that the novelty effect lasted anywhere from a few minutes to, at most, a few months. Therefore, even if a one-shot experiment were to reveal positive outcomes regarding the performance and evaluation of a robot, we cannot be sure that the positive effect will prevail in the long run. Longitudinal studies are needed to provide further evidence for positive HRI over time. An important goal is to enable robots to sustain users' interest over time and across multiple interactions (Tanaka et al., 2007; Kidd and Breazeal, 2007; Kanda et al., 2007b).

10.11.5 Robot abuse

An aspect of HRI that came as a bit of a surprise to researchers in the field is robot abuse. It has been noted by various scholars that robots, when left unsupervised, sometimes get abused by humans (Brscić et al., 2015). Notably, the behavior that is generally displayed shares more similarities with intimidation and bullying than with vandalism. This makes sense, considering that robots are recognized as social agents by humans. Children seem especially prone to engage in robot-bullying behavior (see Figure 10.16), presumably due to their strong tendency to anthropomorphize and as part of developing their social skills. In a field experiment with a robot in a shopping mall, the abusive behavior of children became so disruptive to the robot's functioning that researchers eventually programmed the robot to avoid children, especially when they were gathered in a group (Brscić et al., 2015).

The fact that robots elicit abuse and that bystanders will unlikely intervene is a problem for their application in public spaces. For instance, in the retail context, robot abuse would disturb business; hence, store managers might be hesitant to have robots at their stores in order to avoid this problem. Visitors who witness abuse might feel sympathetic toward the robots in spite of being unlikely to intervene, which would result in a negative overall experience. So far, little experimental research has been conducted on the reasons why some people engage in robot bullying. A broader understanding of the phenomenon will likely help in the development of strategies to discourage robot abuse and thereby enable smoother functioning of robots.

Figure 10.16 A child kicking a robot in a shopping mall.

10.12 Conclusion

Markets for robots are growing (Haegele, 2016), but many of the robots that are available on the market still feature limited social interaction capabilities, for instance, pet robots and service robots. In the domain

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of navigation, great strides have been made, as documented by applications such as delivery robots and self-driving cars. Before deploying any such technologies, though, empirical research and evaluation studies need to be conducted in order to test and validate the new technologies and to get them ready for the market. With more research in open-ended, real-world contexts, it is likely that researchers will come up with new application concepts for robots and find novel niches that existing robotic technologies can successfully occupy.

Questions for you to think about:

- Try to think about a couple of new future applications that are not yet mentioned in the chapter. For each application that comes to mind, briefly describe possible technical problems and solutions.
- Suppose you would be able to prepare the technical solutions for your applications. Think about market potential: Who are the targeted users, how expensive will your robots be, and which consumers would be willing to buy the respective robots?
- Suppose your applications are successful in terms of technical preparation and the potential market. What problems might they cause? How would you avoid or at least reduce such problems?

Future reading:

- International Federation of Robotics. World Robotics Report. (Part of the report is free to download: `https://ifr.org/free-downloads/`).
- Joost Broekens, Marcel Heerink, Henk Rosendal, et al. Assistive social robots in elderly care: A review. *Gerontechnology*, 8(2): 94–103, 2009. doi: 10.4017/gt.2009.08.02.002.00. URL `https://doi.org/10.4017/gt.2009.08.02.002.00`
- Martin Ford. *The rise of the robots: Technology and the threat of mass unemployment*. Oneworld Publications, London, UK, 2015. ISBN 978-0465059997. URL `http://www.worldcat.org/oclc/993846206`
- Iolanda Leite, Carlos Martinho, and Ana Paiva. Social robots for long-term interaction: A survey. *International Journal of Social Robotics*, 5(2):291–308, 2013. doi: 10.1007/s12369-013-0178-y. URL `https://doi.org/10.1007/s12369-013-0178-y`
- Omar Mubin, Catherine J. Stevens, Suleman Shahid, Abdullah Al Mahmud, and Jian-Jie Dong. A review of the applicability of robots in education. *Journal of Technology in Education and Learning*, 1(209-0015):1–7, 2013. doi: 10.2316/

Journal.209.2013.1.209-0015. URL http://doi.org/10.2316/Journal.209.2013.1.209-0015

- Illah Reza Nourbakhsh. *Robot futures*. MIT Press, Cambridge, MA, 2013. ISBN 9780262018623. URL http://www.worldcat.org/oclc/945438245