Current use and possibilities of robots in care

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D.G.Bouwhuis. Current use and possibilities of robots in care. Gerontechnology 2016;15(4):198-208; doi:10.4017/gt.2016.15.4.003.00 **Background** Robots are seen as one of the possibilities to provide care to older people, especially when care by humans becomes scarce and too expensive. In the past sixty years, however, robots have diversified into many different types with a very broad range of functionalities. Despite this large variety of operational robots that have been developed in the past decades, the majority of existing types of robot will currently not be capable of carrying out reliably and effectively meaningful care tasks. For one thing, the communication between the more traditional types of robots and humans is severely underdeveloped. This is only logical as robots were intended to replace human practice in which human-robot communication was either undesirable or of limited value. **Aim** Fortunately, exceptions to this are increasingly appearing, and these will be treated. At this stage it will not be surprising that an overview of types of robots for care will be a categorization of types of robots, rather than types of care. As it is, current prototypes of robots for care also have different functionalities, and with those, also a very different architecture indicating that no single planned robot can perform all care tasks that are necessary or desired. This manuscript presents an overview of the main types of care robots that are currently under development, and partly even operative in actual care locations. **Results** It is evident that also the care robots in actual use still have quite limited capabilities, and, coupled with this, a short endurance of about an hour. Yet it also has to be concluded that even the simplest types of robots with a very limited behavioural repertoire can be successful with cases of cognitive decline and early dementia. In view of the potential capabilities of robots a categorization of care activities is proposed that can be stated as (i) physical assistance, (ii) social assistance and (iii) medical assistance. Physical assistance can be provided by relatively large and heavy-weight robots that can lift and transport people with limited mobility. For the great majority of care robots, social assistance is envisaged, to be realized by humanoid robots, looking like real humans but mostly half-size or less. Active research in this field is focusing on robot locomotion, gestures, speech recognition, understanding and production, face recognition and autonomy. Somewhat disconcerting is the observation that medical assistance robots are practically absent in current development efforts, though it can be argued that there are definitely many relatively simple and frequently occurring medical actions that could be successfully carried out by a robot.

Keywords: care robots, human-robot communication, telecare, humanoids

From 1950 onwards, when the first of what can be called autonomous robots appeared on the scene, the variety of robots has increased considerably, and with them the tasks that they are intended to perform. More or less in order of appearance they are:
(i) Industrial robots that are stationary and mostly used for assembly tasks;
(ii) Service robots, autonomously moving devices for goods transport and various maintenance and repair tasks in inaccessible places;
(iii) Medical robots, consisting of a master and slave system where the surgeon manipulates controls of the master, which actuates surgical instruments in the slave system for minimal invasive operation on patients;
(iv) Military robots, basically a spin-off from service robots, capable to move and climb in difficult terrain with long endurance capabilities;
(v) Situated agents, extremely simple autonomously moving robots, that give the impression of intelligent behaviour, operating on a subsumption architecture[1];
(vi) Domestic robots, mostly robot mowers and vacuum cleaners that operate autonomously;
(vii) Humanoid robots, that resemble humans, and are developed to get insight in human movement and balance, and also with the intent to deploy them as care providers; and
(viii) Care robots, designed to fulfil specialized care tasks.

Robots for care tasks

Despite this large variety of operational robots that have been developed in the past decades, the majority of existing types of robot will currently not be capable of carrying out reliably and effectively meaningful care tasks. Fortunately, there are some exceptions to this, which will be treated below. At this stage it will not be surprising that an overview of types of robots for care will be a categorization of types of robots, rather than types of care. Some types of care require activities that cannot be performed by robots that are operational now or in the near future; so robot capabilities have to be the basis for categorization.

The most complete overview to date of robots intended to assist in care environments, including medical treatment, nursing, therapy and in-home assistance, is presented by Agnihotri and Gaur[2]. Their overview is restricted to robots and devices that have been reported in the regular scientific literature, together with systematic evaluation trials. The current paper concentrates on the functional aspects of robots in various personal care situations, and describes a subset. Specifically, medical robots are not treated here, and of the above list only some domestic robots, humanoid robots and care robots will be described with regard to their functionality.

The list presented in the previous paper refers mainly to robot architecture which is a very diversified field. Consequently, different architectures can be deployed for specific care tasks, which is why this paper concentrates on a categorization of care tasks calling for specific types of robots. The combination of types of care and types of robots treated here are a diversification of prosthetic rehabilitation, self-feeding robots and behavioral therapy and special needs categories of Agnihotri and Gaur[2].

Robots for care tasks include:
(i) Lifting robots: lifting, carrying and laying down patients from and on beds, seats, or in and out of baths;
(ii) Exoskeletons: devices mounted on the body to aid locomotion;
(iii) Assistive robots: fetch and take away objects, medication, clothes, opening and closing doors;
(iv) Companion robots: social communication, information, instruction, contact with caring staff and relatives;
(v) Talking robots:
(v.a) Therapeutic robots, used for autism and depression treatment;
(v.b) Conversation robots, against loneliness;
(vi) Emotional communication robots: non-talking robots that behave like understanding animals;
(vii) Service robots

Figure 1. The lifting robot Ri-Man[4], carrying a mannequin (drawing by the author)

Figure 2. The lifting robot RIBA II[6] lifting a real person (drawing by the author)

Lifting robots

Of the types of robots mentioned lifting robots are most closely related to humanoids, but are only similar from the trunk up. As they have to remain absolutely stable while lifting a human being, they are much heavier than humanoids and move on wheels, rather than legs. In the past decades, mobility aids of various kinds have been developed, with the wheelchair as the best-known example. However, transfer from bed to chair, or in and out of bath has up to now required quite a variety of complicated and heavy contraptions[3] that have to be controlled and manoeuvred by another person.

Table 1. Properties of robots that can lift and transport patients; RI-MAN can lift 12 kg, but was planned to lift 70 kg; Robear is essentially the same as RIBA, but with lower weight, improved dynamics and extensible feet. RoNA (Robotic Nursing Assistant) has an articulated body, but in normal operating mode its height is approximately 170 cm

Characteristic	Robot type			
	Ri-Man[5]	RIBA[6]	Robear[7]	RoNa[9]
Institute	RIKEN	RIKEN & Tri	RIKEN & Sumimoto Rikoi	Hstar Technologies
Height, cm	158	140	140	Max ≈200
Weight, kg	100	230	?	?
Payload, kg	12 (70)	61-80	80	140-230
Degrees of freedom	?	22	24	23
# of sensor elements	320	436	436	?
Operation time, min	?	60	?	?

Table 1 shows the main characteristics of four lifting robots. RI-MAN[4,5], developed by the RIKEN Research Institute, Japan, was presented in 2006 and featured a soft silicone skin that also fully covered

the joints. As its lifting capability was only 12 kg, trials were performed with a mannequin. Especially high was the number of sensor elements that were necessary to avoid bodily discomfort to the carried patient, but that also served to steer the arms under the back and legs of the patient (*Figure 1*).

In a cooperative research effort with Tokai Rubber Industry RI-MAN was followed by RIBA[6] that was much heavier, and had a larger amount of sensor elements, both of the capacitance and of the resistance type. Both robots had simple hands without thumbs or fingers. Ri-Man was fitted with two scent sensors that were omitted in RIBA II (*Figure 2*). The advantages of wheeled locomotion are improved manoeuverability and stability that are specifically useful in this care application. The latest version of RIBA was Robear[7], with more responsive dynamics and much lighter. It had extensible horizontal feet that improved balance and allowed greater manoeuvrability. The lifting robot project was formally closed December 2015.

Another lifting robot is the American-built RoNa[8,9], that is four-wheeled and under control of a nurse, and therefore not autonomous. It has 23 degrees of freedom and can lift up to 225 kg; the first commercial version is due in 2016. In a planned military version it is moving on tracks in order to cope with rough terrain.

Exoskeletons

Exoskeletons are devices that are attached to the human body enabling the limbs and the trunk to make those movements that the person is not able to do anymore due to dysfunctions of various kinds. The exoskeleton has two functions: it provides rigidity of the body parts that are affected and it amplifies, or vicariously supplies the force that is needed to make desired movements. Strictly speaking, exoskeletons have a very long tradition, especially in the treatment and recovery of broken bones, where e.g. broken legs were tied to a long stick, while currently plaster casts are universally applied. Such casts, of course, do not supply any power, but may well serve to use the affected limb as a support.

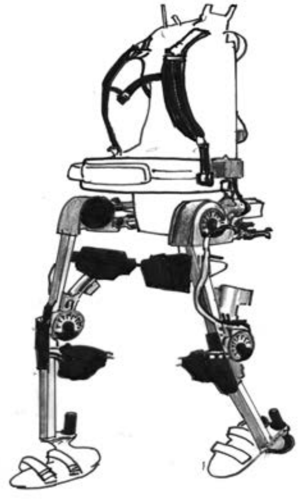

Figure 3. The Mindwalker exoskeleton[10] enabling paraplegic persons to walk. The torso is held by the two shoulder straps and the horizontal belt. The mechanical legs are fixed to the legs of the patient by means of the black straps on the upper and lower legs (drawing by the author)

One of the most complex exoskeletons is the Mindwalker[10] (*Figure 3*) that is intended to restore walking capability to patients with spinal cord injuries. In this project victims of serious traffic accidents have been participating. Walking control took place in two ways. In the first patients could initiate a forward step by turning their torso. In the second, based on a Brain-Neural-Computer Interface (BNCI), a cap with electrodes was worn on the head, with which brain signals were registered that controlled the movements of the exoskeleton. With the body-turning control walking looks decidedly unnatural, unlike the BNCI control, though the latter proceeds very slowly as the preparation for each step takes rather longer than the step itself. The Mindwalker is rather heavy at 30 kg.

Somewhat simpler systems for rehabilitation of spinal cord injury patients are the lighter ReWalk[™,11], at 23 kg, including batteries, of which various versions are available; the latest being the ReWalk Personal 6.0 for personal use[12]. Just as for walking humanoid robots, the normal walking speed of patients with the exoskeleton is 1.4 km/h, though velocities of 2.6 km/h have been attained. Patients can walk for five minutes continuously, and up to 30 minutes with breaks after every five minutes. The Ekso exoskeleton[13], which is of similar size and weight, and produced in a number of versions, like for mountain climbing or carrying heavy loads, is called by its manufacturer more euphemistically a wearable bionic suit. A still lighter system is the Indego[14] weighing 12 kg, which still is a considerable weight for paraplegic patients. The Indego system is modular and consists of six parts that have to be pushed and clicked together and secured by means of adjustable straps, which does not seem to be particularly easy. Especially mounting the part that fits on the back requires a remarkable agility. All of these systems require the use of two crutches or a walker to retain balance and walking is not considered very easy. On the positive side it is found that exercising with the exoskeleton creates considerable improvements in gait, and a decrease of neuropathic pain.

In fact the exoskeletons for walking are derived from Reciprocating Gait Orthoses (RGO's) that feature a similar mechanical construction but which are unpowered, and cannot be called robotic. They require residual muscle power, and RGO's are more functional for a stable stance than for locomotion.

Far more wearable walking assistance can be provided by a system that is a spin-off from research on the Asimo robot[15], and which is called Stride Management Assist. It enables the walker to make larger steps and so walk faster and farther with less fatigue than when unaided. Studies with the Tokyo Metropolitan Institute of Gerontechnology found allegedly that seniors, averaging 78 years of age, improved their walking speed by around 30% after using the Stride Management Assist.

Another spin-off of Asimo is the Bodyweight Support Assist[16]. It consists of a small saddle to which two slender metal legs are attached that are driven by battery-powered motors. The walker straddles the saddle, and the two artificial legs are moving between the true biological legs. The main function is to support the body weight during walking, useful in stair climbing, and particularly helpful in crouching.

In contrast with the lifting robots, where the patient is entirely passive, exoskeletons require that the user does actively control movements, or they assist the existing, perhaps weakened forces exerted by the user. At this point in time it does not seem that older people would benefit much from the exoskeleton in order to walk again when suffering from paraplegia or hemiplegia. Exoskeletons are rather heavy, mostly difficult to don, and BCNI's do not yet operate sufficiently reliable or effective. Walking with two crutches does not make the usage of the bionic suit much easier, especially as the walking process is experienced as exhausting.

It might be that in terms of size and simplicity the Bodyweight Support System and the Stride Management Assist are much better suited to older people to which they have been targeted. Unfortunately, no details are available concerning weights and battery life and neither are there scientific publications describing performance.

Assistive robots

Assistive robots are primarily intended to carry out physical tasks in the home of the client. This may include fetching medication, personal objects, drinks, and clothes, but also setting the table, opening and closing doors or adjust temperature and ventilation. Robots of this kind need not specifically be humanoid, but most humanoid designers state that they will be better accepted when looking that way[17]. Actual empirical research on this issue with random control trials, i.e. comparing reactions to humans, humanoid robots and non-human like robots is very scarce and so far there are no unambiguous results[18]. One study[19] reported little anxiety for humanoid robots in the older population. Biological movement increases acceptance[20]; a point strongly reinforced recently[21]. However, human-like robots can also lead to negative reactions instead[22]. Acceptance of Humanoid robots has been found to depend more on perceived usefulness and skills, but also that less human-like looks were preferred[23]. Considering that the assistive robot has to move around it

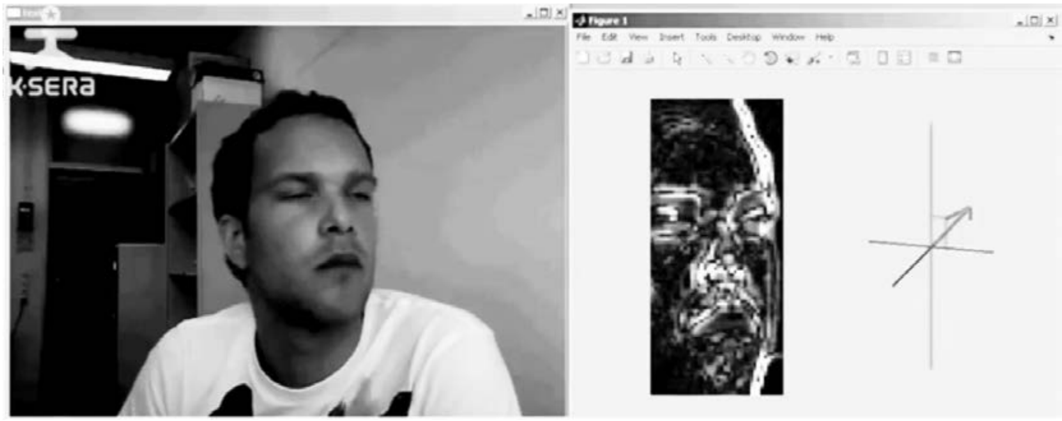

Figure 4. Picture of the user (left panel) that is registered by NAO's cameras, in which the face is recognized. The right panel shows the filtered image of the face, which is used to compute in real time the looking direction of the user's eyes, indicated by the arrow. In this way, NOA does not only 'know' where the face is, but also whether the older client is watching NOA or not, and can take appropriate action (The research leading to these results is part of the KSERA project (http://www.ksera-project.eu) funded by the European Commission under the 7th Framework Programme (FP7) for Research and Technological Development under grant agreement nr: 2010-248085.)

will be fitted with walking legs, and also it must have articulated hands with fingers and an opposing thumb for grasping and releasing objects.

When moving around in the home, and interacting with the client-owner, a number of non-trivial behaviours must be realized. First, the robot must 'know' the layout of the home, in order to go for example from the kitchen to the living room. In going from one place to another it must avoid obstacles that have to be spotted by means of sensors, it must also negotiate elevated thresholds, curled up carpets and connection cords lying across the floor. So far, irregular surfaces have been a source of difficulty for walking humanoids, and mostly it is proudly claimed that they may be unfazed by height differences of one cm, which is not impressive compared with humans.

For interaction with the client, visual recognition is important, as the robot should recognize its owner among lifeless objects and especially among other persons in the room. In addition to this type of recognition the assistive robot should fixate the owner when speaking or listening, and thus be capable of following the fixation direction of the owner.

Speech recognition, and to a certain degree speech understanding will be necessary as well, while in addition its speech output should be clear and intelligible.

Stairs are somewhat problematic, inasmuch as only few humanoid robots can climb stairs; conversely the robots should not fall down the stairs and to this end be capable of detecting the stairwell.

In actual studies on assistive robots, NAO[24] is most frequently represented, partly because it is much cheaper than most other humanoids, but mostly because of its open software architecture, which makes it possible to add functionalities that suit the specific application. In the Ksera project[25] navigation behaviour in the home was optimized in the sense that, when called, NAO would approach the owner via the shortest route, taking obstacles into account, and stop at a distance and azimuth angle that the owner felt to be optimal. NAO was also programmed not only to detect the face of the owner, but also the direction of looking of the owner. In other words, NAO can recognize whether the owner looks at it, or not. *Figure 4* shows a still from video footage depicting the real-time computation of the orientation of the head and the looking direction. While the reasons for employing NAO as an assistive robot in evaluation studies are obvious, NAO is not an optimal assistant inasmuch it has only limited object manipulation capabilities, and would therefore function better as a companion robot, for which purpose another robot, called Pepper[26], is under development. As regards assistive robots the replacement of NAO is planned to be Roméo, likewise under development and started in 2009. Roméo[27] is a biped of 147 cm, weighing 37 kg, and therefore much larger than NAO, while its proportions are more humanlike (*Figure 5*).

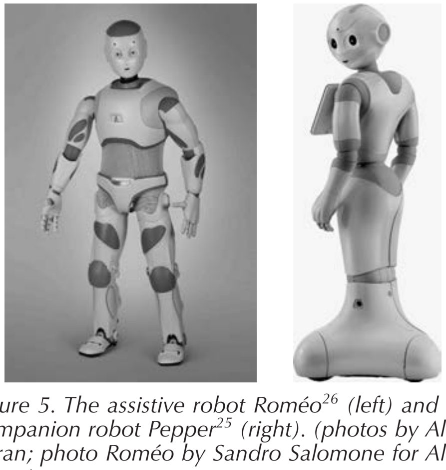

Figure 5. The assistive robot Roméo[26] (left) and the companion robot Pepper[25] (right). (photos by Aldebaran; photo Roméo by Sandro Salomone for Aldebaran)

Also Roméo's behaviour is more humanlike, it can seat itself on chairs, and walking is relatively natural with only a slight 'stalking' posture, but as slow as its colleague humanoids. Most of its functionalities are in the research phase, so definitive technology choices have not been made, but the research activities give a good overview of the main capabilities that are planned for an assistive robot.

The visual system enables the robot to recognize objects, human gestures and navigate successfully in its environment. An interesting development is that ocular information is used for gait control, e.g. in the case of floor irregularities or circumventing walls or objects. Making use of multisensory perception functions can be integrated which improves the interaction with the end user and its environment.

Special effort is spent on communication with the end user, for which state-of-the-art speech recognition and synthesis have been adopted. Roméo[27] can engage in 'small talk' as it can make use of on-line information bases, and relate this to the situation of the end user. Not only can it express emotion, which is controlled by a decision making tool, it can also detect and recognize the emotion of its interlocutor. The explicit target of Romeo is people with reduced autonomy, which places it directly in the field of gerontechnology. On the other hand, both implementations of functions and the integration of those which will be necessary will at least require a few years before successful operation will be possible.

Companion robots

Companion robots do have a more limited action repertoire than the assistive robots in that they do not perform any physical actions. Their main activity consists of communication with their owner. Currently the best example of a working companion robot is Pepper (Figure 5, left)[26], closely related to Romeo, but with significant differences. As it performs no physical tasks its locomotion can be restricted, and Pepper moves on three wheels, which lends it greater stability than walking robots, while dispensing with all software and hardware for two-legged locomotion. Curiously enough it features five fingers on each hand, unlike Romeo which has four, and which are deemed useful for expressive gestures.

During communication Pepper can recognize facial expressions, emotions and choice of words that betray emotions, and react to those in an appropriate way. Pepper is slightly smaller than Romeo, at 120 cm, and weighs 28 kg. The battery lifetime is 14 hours; Pepper monitors the battery state, and is capable of finding a power source to recharge. Currently Pepper is operating in two of Japanese companies and a French supermarket chain, where it more or less operates as a receptionist, intending to draw curious customers.

In a care context a companion robot would of course concentrate on the well-being of the user, checking medication, food and drink intake, and would function as a messenger in emergency cases. The fact that it can display text information on a tablet screen mounted on the chest makes it suitable for hard of hearing persons, but also takes care of message back up.

Talking robots

Talking robots do even less than the companion robot in that they are intended to give the older user a talking and listening partner with the main aim to combat loneliness. Talking robots do not need any technology for locomotion, and also the gestural functionality may be limited, as its main aim is talking and listening.

Therapeutic robots

A good example, though not in the area of gerontechnology, is the robot KASPAR that was designed to communicate with autistic children[28]. It is termed 'minimally expressive' and this feature, together with the repeatability of its behaviour is supposed to put autistic children at ease. By means of the ensuing dialogue the communication skills of those children would improve, and the deployment of KASPAR would have a therapeutic effect. KASPAR can move his arms and eyes, and only sits – walking is not possible. Regarding this potential therapeutic role, it has been suggested to employ similar instantations of robots for relieving feelings of depression in older people. Such robots do not have to perform any physical tasks but should be able to entertain verbal communication with older people and show emotions, and preferably detect these in their users. Such robots are called 'conversation robots', while robot that do not speak but only show emotions are 'emotional robots'. Both are described below.

Conversation robots

In the Netherlands an analogous conversation robot, called Alice[29], also non-walking, has been the object of a study in the homes of a number of older women. Alice is about as tall as NAO, but with a realistic face and hands and was constructed by Hanson Robotics. The face can assume various expressions, realized by 16 motors that also move the lips in a convincing way. The role that Alice is envisaged to play is to entertain a conversation, asking questions, commenting on the living situation or pictures in a photo album, and supplying information like addresses and phone numbers of friends and relatives. No scientific publications on Alice have been released. Under the name of Zora[30] the NAO robot is fulfilling a similar function in over 160 nursing homes and hospitals in Belgium, the Netherlands, Norway and Sweden and some other countries[31]. Zora has of course the same movement repertoire of NAO in that it can walk, move its arms, hands and head. Its facial expression repertoire is, however, much more limited as it can only light up its eyes, also in different colours, and look at an interlocutor. *Figure 6* shows Zora interacting with older ladies in a care home in Vught, the Netherlands.

So far, conversation robots cannot maintain a meaningful conversation and normally can engage only in short and relatively predictable

Figure 6. Zora (in fact, NOA equipped with special software), functioning as a companion robot in a care center (Image: Omroep Brabant)

dialogues. All demonstrations of conversational robots nowadays are only simulations of some realistic verbal exchanges. Experimental studies on the psychological effects of conversation robots have therefore not yet been performed.

Emotional communication robots

Emotional communication robots are, with one early exception, the simplest types of all robots and only need little advanced technology to function. They consist of a replica of an animal that can show a reaction when being touched and displays some autonomous behaviour, like emission of various sounds and movements. The earliest example, which is also by far the most complex, was the artificial dog Aibo[32] developed by Sony, introduced in 1999 and marketed as an 'Entertainment robot'. In 2004 the robot dog has been applied first as a rehabilitation tool in the treatment of severely demented patients and was found clearly effective[33]. Most notably, patients communicated with AIBO and cared for it, which did hardly occur with toy dogs. Recently, results of an older study on the interaction of Aibo have been published[34] with 15 socially isolated adults (mean age 84) in an assisted living facility. After six weeks a significant increase in life satisfaction and morale was found, together with a significant decrease in depressive symptoms. More anecdotal information on this study was reported in 2004[35] in which it was observed that participants regretted it very much that they had to return the robot dog. Asked whether they would buy a new robot dog, some declined to do that, as it would not be the same dog which they had formed such a close bond. Apparently, the highly responsive behaviour of Aibo had made them believe that it had acquired a personality. Aibo was discontinued in 2006 but robot dogs reappeared with the introduction of Genibo[36] released by the Korean Dasa Tech company. Genibo in three versions looks much like Aibo, but can recognize some 100 voice commands and is more doglike in character.

Currently the most popular robot pet, however, is PARO[37], designed to look like a baby harp seal that comes in at 2.7 kg with a length of 57 cm. It is unique in the robot field that its behaviour is generated by only a single 32-bit CPU chip. It has actuators for the eyelids, the upper body, the front paws and the tail, totalling five degrees of freedom. It is touch and light sensitive and can recognize its (given) name. When stimulated or when virtually hungry it emits cries to attract attention. Currently thousands of PARO's have been produced and there are recent clinically documented studies on PARO's effectiveness in reducing Alzheimer effects and emotional complications after serious illness or injuries[38]. A Randomized Control Trial (RCT) experiment on 18 older persons has been performed that found after five weeks that the PARO group had higher quality of life scores, as well as lower anxiety scores[39.40,41]. Nevertheless, Moyle[38] states that further trials with more people over much longer periods of time are necessary to understand in more detail why PARO is effective. Another RCT study has been proposed recently in which 40 community-dwelling older Chinese adults (≥ 60 years) with mild to moderate dementia will be participating for six weeks[42].

Yet the success of this type of application suggests that several designs could be created that, given an appealing behavioural repertoire, would be as effective, or even more as the existing ones. Among the current instances are Smiby[43] from Chukyo University's robotics department, Japan that looks like a somewhat abstracted baby capable of making many different typical baby noises when handled. From Singapore comes Huggler[44], looking like a chubby monkey that vocalizes and shows emotions when being hugged by elderly. Perhaps the imitation of an animal would not even be necessary, as the only issue that matters is that the emotional communication robots improve the well-being of frail and older people.

A complete overview of evaluation studies on PARO can be found in Agnihotri and Gaur[2].

Service robots

Service robots used in care do not essentially differ from regular service robots, although some types do fit the living situations of older people quite well.

One of the first domestic service robots was the robot lawn mower of 1995 by Husqvarna[45], at the time part of Electrolux. It is interesting that its control software was similar to developments in the study of Life Forms[46]. This same form of control was later employed in the Trilobite, a robot vacuum cleaner introduced by Electrolux[47] in 1999. The big advantage of what can be called situated control is that it does not require complex computing of location on the basis of GPS coordinates and that memory for the patches already treated are unnecessary. Since then many other robot vacuum cleaners have entered the market, and have become a popular commodity. Not all robots operate with the same form of control: some orient themselves by optical scanning of the ceiling, which shortens the duration of the cleaning task, and precludes repeated treatment of the same places. Notwithstanding the ease of vacuuming, its operation is not without problems: the devices are rather sensitive to thick carpets and other floor irregularities, and can easily get entangled in wires and cables lying on the floor.

One other effortful household job is window cleaning, which at first sight seems quite difficult to automatize. Nevertheless there exists a number of devices that do exactly that. The Winbot[48] appeared in 2010 and consists of two parts on either side of the window which are pressed on the glass by magnets. A further development is only one-sided, and is held on the glass surface by vacuum; it also has a memory for the surfaces already cleaned. The Korean PIRO[49] washer from 2011 cleans both sides of the glass simultaneously. Window cleaners sell for about $400 and so are reasonably affordable, unlike their big humanoid relatives, that might do the same thing, but also much more.

Considering the traditional view on robots, it is understandable that, their potential in care is almost exclusively seen as assistive: robots are not nearly as flexible, autonomous and knowledgeable as humans. Robots can carry out actions that the client is not able to carry out anymore, or only with great difficulty. This means that the actions are mainly in the physical domain, like lifting persons, aiding to walk, or fetching and discarding objects. To the extent that such robots only execute physical actions, they can be called 'physically assistive robots'. A great advantage of the robots in contrast to stationary devices is that they can be in the close vicinity of the human client, but also move around to open and close doors, windows or curtains, which gives the client real-time feedback about the action execution.

Some applications explicitly require close vicinity, like the spoon-feeding robots for people that are unable to use their hands and/or arms for eating. These are still stationary table top devices, and have to be controlled by push buttons or joysticks, that can be actuated e.g. by the mouth, knees, feet or chin, and can be semiautomatic. Two such commercial types that have been distributed in various countries are My Spoon by Secom, Japan[50] and Bestic from Sweden[51]. The manufacturer Bestic AB claims that the Return of Investment (ROI) time of its spoon-feeding robot is 212 days. The spoon feeder prototype iCraft, developed at Northeastern University[52] is entirely controlled by eye movements, enabling the user to select from various dishes or drinks. There are several such developments still in the laboratory phase, like a tremor-suppressing spoon for Parkinson patients, and a robot arm that feeds using chopsticks. As a rule, no spoken interaction takes place with physically assistive robots, though they may recognize simple spoken commands, like "Lift me", or "to bed".

The more recent trend is the development of robots that can engage in more or less natural modes of communication, for which the name 'socially assistive robots' is frequently used. These can be used to provide information, communication with care providers or family, to remind clients of medication, to play games, but also to serve as a companion to prevent loneliness. Physical assistance robots, and certainly exoskeletons, do not communicate verbally with their users, and are sometimes even experienced as extensions of the own body. Social assistance encompasses communication on a more mental level, rather than physical assistance that can by itself, of course, be quite satisfying.

An interesting counterpart to the spoon-feeding robots is the cognitive assistive device 'Brian' that encourages persons to eat and drink[53]. To this end Brian is equipped with a real-time monitoring system that tracks eating and drinking actions and it has sensors that determine the eater's visual focus of attention. The person does not have to wear any sensors while eating. Brian is designed as a life-like male upper torso, with arms that can point to eating trays or drinks, and can show various facial expressions. Brian produces synthetic speech reflecting different emotions, like sad, happy, and encourages the person to take bites from the food on the plates, or drink from a cup. In an evaluation study compliance to Brian's encouragements was 90% for eight participants, each in two eating sessions. While participants generally had a positive attitude towards the encouragement robot, perceived usefulness scored only average. Nevertheless, participants found the encouraging behaviour most helpful. What participants liked most were the human-like voice and the companionship that Brian offered. Now human-like voice can be realized partly by technical means, but companionship cannot be designed. It is an emergent property that ensues from the form of interaction and mutual understanding and not a component with technical specifications.

So, emotional communication robots also belong to this category; while their behaviour is much more simple than that of the talking robots, their interaction with the client has obvious social components. Inasmuch as they respond, even in a simple way, to human handling they appear to evoke caring behaviour and bonding, and in this way a form of intimacy. And again, intimacy is not something that can be designed, it is as well an emergent property of the interaction between the emotional robot and the person.

Three components of care

In fact the above is a different kind of categorization of care robots than has been presented before, and one that centres on the fields of application in care, or otherwise stated, the components of care. In fact, the task of care encompasses a

Table 2. Care robots as a function of type of assistance and of type of functionality; Robots mentioned in a cell are a single example of potentially many other robots; – indicates that no robot is available for the corresponding functionality and field of application; Robots in parentheses have only a minimal functionality in the area of assistance

		Area of assistance		
		Physical	**Social**	**Medical**
Robot type	**Lifting**	Ri-Man	-	-
	Exoskeletons	Mindwalker	-	-
	Assistive	(NOA)	NOA	(NOA)
	Companion	-	Pepper	-
	Talking	-	Zora	(Zora)
	Emotional	-	Paro	-
	Service	Roomba	-	-

number of different components: physical activities, social activities and medical activities. So it would seem that, in view of the still rather specialized nature of robots in general, the following types of robots can be distinguished:
(i) Physically assistive robots,
(ii) Socially assistive robots, and
(iii) Medically assistive robots.

In this way a matrix results of fields of application and type of robot, where in each field of application the type of robot may vary considerably (*Table 2*).

Robots between parentheses in *Table 2* are not fully representative of the particular area of assistance. Though NAO can indeed fetch objects, which is a physical action, the lifting capability is rather limited e.g. to medication or a small glass of water.

In the medical area Mindwalker can be used as a rehabilitation device, just as some other exoskeletons, but in most cases exoskeletons will function as systems enabling wearers to walk.

A popular activity of NAO -or Zora- is demonstrating fitness activities that care centre inhabitants have to imitate. On the generous quantity of video footage that is available it is clearly visible that the exercises are frequently executed with much less energy and amplitude than Zora[54] performs them. It would therefore be desirable that the robot exercise coach could perceive the extent to which the exercises are performed, and take corrective or encouraging action when indicated. As body movement tracking is nowadays feasible, it would in principle be possible to provide feedback to this end. Such an application cuts across the three areas of assistance, physical, social and medical. On the other hand, fitness exercises and rehabilitation activities are only bordering on medical practice.

Medical assistance robots

Currently the medical assistance field of robots is largely empty. There are several possibilities to deploy robots for medical practice though. A first example is administering medication, which entails choosing the right medication at the prescribed time, together with giving information about intake requirements, e.g. with water, or no food during the first 30 minutes.

A second example is taking blood samples. In many cases only a drop is needed, which is taken by means of a small lancet, e.g. for determining glucose or coagulation and a band-aid is applied afterwards. This may sometimes lead to a bloody affair, especially with diminished dexterity. Taking the sample requires precision as well as care, and this is exactly where industrial robots excel, which technology could be transferred to the care robot. Next examples are the administering of eye drops, or applying ointment on body parts.

Another activity in the medical field is monitoring the environment for health hazards. Of particular relevance for COPD patients is the quality of the air, which may be continuously monitored for dust content, including fine dust, humidity and temperature. Readings of these variables may prompt recommendations for ventilation and heating, for physical activity level, or relocation from the affected area to a specific room. Other monitoring might include detection of gas leaks, fire and CO_2 exposure.

The monitoring activity should not be restricted to the environment alone, but also include the body. Temperature measurement is an obvious task, but food and drink intake might also be monitored, in addition to physical activity, like walking and doing household chores. Transpiration could be assessed, but also smells. The lifting robot Ri-Man had two gas sensors in the left and right sides of the torso to detect important smells, such as urine, when carrying a patient.

An interesting property of the care robot is that none of the mentioned afflictions and situations, except fire, is applicable to the robot itself. It will not be inflicted with pests, bedbugs or rash, it will not catch cold or suffer from infections, it continues to operate in polluted air and it can grope harmlessly in even toxic dirt. In this respect the care robot is resilient and dependable. This is to a large degree offset by its limited time of operation between recharges, which reduces dependability considerably. This is doubtlessly an area where urgently technological progress is needed.

The downside of the low vulnerability of the care robot is the lack of its personal hygiene. As long as it touches food, medication or persons, its manipulators, hands and torso should be clean, so a self-cleaning procedure should inherently belong to its behavioural repertoire. So far, there is no robot development that has taken this issue into account.

Future robot tasks

While many of these observations point to a positive and constructive contribution by care robots, some activities are still beyond the care robots' power. Complex activities like putting on support stockings, a rather frequent event, will not be a possibility soon. Other activities like doing the laundry, ironing clothes, or preparing meals belong to an uncertain future. All of this belongs to situations with a large degree of unpredictability, and that is an area in which robots have not been successful at all. Unfortunately, the future of flexible care robots is unpredictable as well, and that is a problem where mankind, usually better equipped to deal with unpredictable events, will have to wait for progress, but also to realize progress in the technological and cognitive fields.

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