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REVIEW ARTICLE

# Mobility assistive devices and self-transfer robotic systems for elderly, a review

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**Abstract** When mobility degrades with age, it is of great significance to develop devices which can support the elderly in their day-to-day life. With the usage of intelligent assistive robotic systems, elderly population can lead a better quality of life independently. This article is a review of various assistive devices for elderly focussing on mobility and self-transfer systems. The practical difficulties in walking and moving from bed to wheel chair or wheel chair to toilet seat affect the daily activities of aged people. Depending on caregivers to access toilets affects one's dignity. The review covers various advances that have been evolved in this area of research and addresses the limitations to be overcome.

**Keywords** Assistive robotics · Wheel chair · Self-transfer · Patient lift · Rehabilitation

## 1 Introduction

The population of the aged, around the globe is increasing and thereby introducing a wide array of challenges. Various surveys have been conducted by different agencies, which prove the drastic increase in population of elderly. Before exploring these surveys, let us see, at what age someone becomes old or elderly? As per Population Reference Bureau, USA, "older people" and "older population" refer to people who are aged 65 or older and people over age 80 or older are known as "oldest old". Population of the developed countries have been ageing for over a century. But the situation is different in developing and less developed countries that comprises majority of youth population at present. It could be said that the ageing process began recently in most less developed countries [1]. As per Youth Data Sheet published by Population Reference Bureau in 2013, the population of youth of age group between 10 and 24 around the world is 1,809.6 million, which constitutes to 25 % of the total population. The population of the youth of same age groups in developed countries is only 216.4 million which constitutes 17 % of total population [2]. The figures provided imply that by 2050, the current youth population in developed countries will become "older population", which comprises 27 % of total world population. This will affect the socio-economic development of these countries. A study by United Nations and Social Affairs points out that in 2011, there were approximately 647 million people in the world who come under "older people" category and this figure is expected to accelerate to 2 billion by 2050 [3,4]. Another survey by Population Division, DESA, United Nations, implies that the proportion of population over 60 years were 8 and 10 % in 1950 and 2000 respectively and is estimated to reach 21 % in 2050 [5,6]. In India the absolute population of elderly people was 76 million in 2001 and will touch 137 million mark by 2021 [7]. A report jointly brought out by United Nations Population Fund and Help Age International says that India has 100 million elderly at present which constitutes 7.2 % of total world population and the number is expected to increase to 323 million constituting 20 % of total population, by 2050 [8].

Given the fact that mobility degrades with age, it is of great significance to develop devices which can support the elderly in their day-to-day life. Mobility is a fundamental aspect of health, which leads to social integration and individual well-being. Mobility of a Wheel Chair dependent person can be

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regained by rehabilitation processes and they can be successfully re-integrated into a productive and active life. But most of the lower limb disabled and aged with lower limb incapability depend on wheel chairs for their mobility [9]. For aged, independent mobility increases their self-confidence, self-esteem and happiness levels due to self-reliance. Therefore, the role of intelligent assistive robotic systems takes an important place in improving the quality of life of the elderly.

Joseph F. Engelberger, the Father of Robotics and the man behind the first Industrial Robot in an interview given to *Business Week* in 2003 said that an Elder care robot can be developed at a cost of less than $700,000 using the then current technologies [10]. He also opined that the robot can be rented for $600 per month and operated at a cost of $ 1.25 per hour, resulting in a cost effective eldercare solution compared to healthcare home workers costing around $15 per hour. The Eldercare Robot that Engelberger visualized was a multipurpose one, for which he wanted to have technical partnerships with industrial giants in healthcare products apart from financial investment. Engelberger's vision is not yet realized, as researchers are working on various elder care robots in labs around the world. These products are emerging very slowly and they do not address all the issues concerned.

Reduced mobility affects many other factors in daily life of an elderly. Pain, muscle weakness, osteoporosis, practical loss of motion or physical deformity of joint structure, etc. may restrict an aged person from walking. Another area of focus is the difficulty when raising to a standing position, as raising from a chair is a common but demanding activity involved in day-to-day life. The practical difficulty in walking and rising from sitting position affects other activities in daily life. Accessing toilet, moving to another chair, etc. are some of them. Assistance of a caregiver can be made use for achieving daily activities, but it has limitations. Every person desires to go to toilet by himself/herself because it affects his/her dignity. An aged person who needs human assistance while using toilet feels mental agony [11]. Thus, it is essential to develop a robotic system to assist elderly for independent living. This paper provides a study on assistive devices, focussing on wheel chairs and patient transfer systems.

This paper is organized in such a way that, Sect. 2 covers wheel chairs including both manual wheel chair and powered wheel chair categories. Section 3 focuses on patient transfer devices. Section 4 addresses wheel chairs with transfer modules. Further, major challenges to be overcome in future researches are mentioned in Sect. 5.

## 2 Wheel chairs

The first dedicated wheel chair, known as 'invalids chair' was invented far back in 1595 for Philip II of Spain [12]. The name of the inventor is unknown. Stephen Farfler built self-propelling chair on a three-wheel chassis in 1655. In 1916, the first motorized wheel chair was manufactured in London. It was in 1932, that the first folding, tubular steel wheel chair, similar to what is used today was built by Harry Jennings [12]. There have been a number of innovations in this field since then. Wheel chairs could be broadly classified into (1) manual wheel chairs and (2) powered wheel chairs.

### 2.1 Manual wheel chairs

Manual wheel chair requires human physical power to move them. These wheel chairs can be folded to smaller size for storage and are relatively light weight. There are two types of standard manual wheel chairs: self-propelling wheel chair and attendant-propelled wheel chair. A self-propelled wheel chair, as shown in Fig. 1, has large rear wheels which can be rotated manually by the user through a hand rim [13,14]. Figure 2 shows an attendant-propelled wheel chair which employs smaller rear wheels [14].

In the leveraged freedom chair (LFC), shown in Fig. 3, the user swings the levers on both sides of the chair, which are connected to the gear-wheel mechanisms that propel the wheel chair. Torque change is achieved by sliding user's hand up or down the lever. For higher torque, user needs to slide his/her hands up the lever away from the pivots. For lesser torque and higher speed, user needs to move his/her hand closer to the lever pivots. Advantages of LFC include efficient and quick travel on smooth and flat roads, and maintaining enough torque to conquer steep hills and soft ground [15].

**Fig. 1** Self-propelling wheel chair

**Fig. 2** Attendant-propelled wheel chair

**Fig. 3** Leveraged freedom chair

## 2.2 Powered wheel chairs

Electric-powered wheel chairs or Motorized wheel chairs are propelled by the means of electric motors, instead of manual power. It was invented by George Klein during World War II. Powered wheel chairs also incorporate various sensors and control systems to guide themselves to achieve intelligent navigation. Various electrically controlled wheel chairs and automated guided wheel chairs (AGW) have been developed around the globe. Most of the electrically controlled wheel chairs are manipulated using joystick. More care, skill and practice is needed to control wheel chairs using joystick as even a slight movement of joystick may cause quick turn, which may result in loss of control. The sub-sections below address various powered wheel chairs with different navigation schemes.

### *2.2.1 Wheel chairs with automated navigation*

AGWs are guided by several means; the most conventional method being sensing reflective tape markers on the floor using photo detection sensors installed on the Wheel Chair [16]. Other techniques of Automated Guiding are visual machine guidance, in which a painted track is picked up using a video camera mounted on the wheel chair and buried-wire guidance system [16,17]. The major disadvantage of these guidance systems is that the tape markers or the painted tape may get dirty, which makes the photo sensors or video camera almost impossible to pick up the lines. Buried-wire guidance systems fail to work, if the wires are damaged. As a solution for these problems magnetic ferrite markers are used for guidance purposes. Wheel chair guided by magnetic ferrite marker follows a magnetic line, sensed using a magnetic line sensor placed under its foot rest [16]. SENsor-Aided intelligent wheelchaiR navigatIOn (SENARIO) is a European project that provides high level navigation aid to wheel chair users with two modes of operation. In semi-autonomous mode the user controls the wheel chair using voice commands or joystick, where as in fully autonomous mode the wheel chair follows recorded paths [18]. Figure 4 shows, VAHIM,

**Fig. 4** The VAHM wheel chair

a Robotized Wheel chair which has three operating modes: manual mode, a classic powered wheel chair control with anti-collision system; assisted manual mode, that makes use of wall following or obstacle detection; and automatic mode, in which the wheel chair makes use of globally planned paths [19]. Wheelesley [20], another robotic wheel chair, is shown in Fig. 5. This is targeted to persons who have difficulties in controlling a wheel chair with a joystick. The user gives commands through graphical user interface; the command is executed and at the same time it avoids obstacles on the path. To achieve this, the wheel chair is equipped with various sensors like infrared sensors, laser range sensors, wheel encoders and hall effect sensors. Navchair [21], SIAMO and Rolland [22] are other wheel chairs with automated navigation systems.

Almost all researches on autonomous wheel chair navigation are based on Simultaneous Localization and Mapping (SLAM). It is a process of building a map of an unknown environment for navigation within the environment. Extended Kalman filter (EKF) is the heart of this process. It employs range measurement devices like Laser Range Finders, Sonar or vision sensors and odometry sensors like wheel encoders. Using wheel encoders, the exact position of the wheel chair in the environment is determined. But using these data alone may cause erroneous results. Hence, laser scans are used to correct position of the wheel chair. Exact position is determined by extracting environmental features and re-observing, as the wheel chair navigates. EKF is used to update the position, based on these features [23–26].

**Fig. 5** The Wheelesley wheel chair

### *2.2.2 Wheel chairs following caregivers*

Many researches on wheel chairs have focused on reducing the load on caregivers and assisting them. Wheel chair that moves along with the caregiver like the one shown in Fig. 6 is an example. The laser range sensor employed in the wheel chair observes the position and orientation of the caregiver and moves side by side. Various situations like the caregiver stepping forward to open a door, stepping aside in narrow corridors to give way for other pedestrians, wheel chair waiting for the door to open, etc. were being addressed by Kuno et al. [27,28].

### *2.2.3 Wheel chairs with intelligent user interaction*

Researchers have also been thinking on how to avoid conventional joysticks for controlling the wheel chair. One of the methods is to use gaze direction for commanding 'left' and 'right'. It is a sort of imitation of joystick operation, but in a natural way, as it reflects the human behaviour while changing direction during walking [23]. In this work, the gaze direction is detected using a web camera. Wheel chairs could be controlled using vision-based passive motion tracking or active motion tracking. In passive motion tracking camera is placed in front of user's head to pick up head movements.

**Fig. 6** Concept of wheel chair moving side by side

Whereas in active motion tracking, camera is mounted on user's head and it captures user's field of view [29].

Another method is based on electrooculography (EOG). EOG is the process of recording the activities of eye movements and eye positions. The signal obtained known as electrooculogram is the potential difference between two electrodes placed on the skin on either side of the eye. Four to five electrodes are placed around the eyes. Both horizontal and vertical movements of the eyes are detected using these electrodes to obtain different EOG signals. There are a total of three eye movements namely, right gaze, left gaze and blinking of eyes. Two electrodes are placed on left and right of the outer canthi and a reference electrode on the forehead. When the person looks at right, the voltage between the electrode in the right and reference electrode will be high, similarly during left gaze the voltage between the electrode in the left and reference electrode will be high. For vertical movement detection a pair of electrodes is placed on top and bottom of the eye. With respect to these signals the wheel chair navigation is accomplished [30,31].

Brain-actuated intelligent wheel chair makes use of brain commands to steer a robotic wheel chair [32]. Brain–computer interface is the back bone of the system which is used to interpret the user commands and determine paths to the predetermined goals. Brain commands are picked up as EEG signals using 12 passive electrodes positioned at various locations in subject's head. Researchers have also developed a system that is aimed to minimize the user involvement during navigation [33]. The wheel chair proposes actions to the user, based on environmental information collected through various sensors. User monitors the activities and rejects the prepositions that he/she disagrees. Upon rejection, the system has to take different decision based on this additional information. The workload of the user is reduced to simple 'yes/no' input.

## 3 Patient lift or transfer devices

Patient lift devices are used to transfer a wheel chair dependent or an elderly from one surface to another. It may be from a wheel chair to a bed, to a toilet commode, to another chair, to car, etc. Most of the caregivers suffer from musculoskeletal injuries that occur during patient handling, which includes, patient lifting and transferring. Health of the caregiver is also equally important. Hence, mechanical lifting devices have been introduced to reduce the injuries that occur during patient handling [34]. Patient lift devices could be classified into dependent lift devices and independent lift devices.

### 3.1 Dependent lift devices

As the name implies, the wheel chair user needs to depend on care givers for transferring to another surface. Patient pivot shown in Fig. 7 is an example of dependent lift device. The subject is strapped to the pivot and is rotated forward, allowing him to sit on another seat. The caregiver needs to apply a minimal force to rotate the subject [35]. Hoyer-Sling lifts have a hammock sheet that is placed underneath the subject while he or she is in bed. This fabric is then attached to a metal hoist and the subject is lifted up by manual means using arm cranks or by electrical/hydraulic power as shown in Fig. 8. Subsequently, the subject is swung and lowered onto wheel chair. The sheet stays under the person, while he/she sits on the wheel chair [36]. Figure 9 shows Arjo patient lift which is useful in reaching the floor to lift a person who has accidently fallen [35]. It can also be used for lifting from seats or beds.

Wall- and Ceiling-mounted patient lifts, shown in Figs. 10 and 11, are the devices that are being used in health care facilities. These devices have two degrees of freedom allowing lift of the patient in a sling and rotation about a horizontal pivot attached to the wall or a linear movement through a track on the ceiling [35]. A study shows that ceiling lifts are easy to use, consume less transfer time and more comfortable for the patient while compared to any other type of lift devices [34].

### 3.2 Independent lift devices or self-transfer systems

Independent lift devices or self-transfer systems assist an elderly or disabled to lift up and transfer to another surface without the assistance of caregiver. A simple device known as Trapeze lift, which can be connected to the bed or on a free-standing base, assists patients and elderly with some upper

**Fig. 7** Patient pivot


**Fig. 8** Hoyer sling

**Fig. 9** Arjo

body strength to lift themselves to facilitate the provision of bedpan or to reposition [37].

Figure 12 shows schematic diagram of a self-transfer system developed by Yoshihiko Takahashi et al. to facilitate self-transfer from a wheel chair to a toilet commode [11,38]. This self-transfer aid system consists of a robotic arm with a saddle on the top and a motorized horizontal rotation mechanism. The user places his/her abdomen onto the saddle. The robotic arm elongates when the drive motor rotates it, this straightens up the subject. The system turns 180° horizontally with the help of a motor and is stopped when the user is positioned towards the toilet seat. Then, the robotic arm is shortened to place the person onto the commode. The limitation of the device is that it is not compact enough and hence placing this system in front of the commode may cause disturbances for the other users.

National Institute of Standards and Technology (NIST), USA designed a patient lifter that allows a patient's upper body to be lifted and placed on bed, chair, wheel chair or floor [35]. The mobility could be achieved via three modes: self/caregiver powered, assist power and powered mode.

ROAD [39] robot is designed to assist the user in standing up, sitting down and locomotion. Like ceiling lifts, the robot is suspended from the ceiling and guided through predetermined tracks. Advantages of this robot compared to robots that move on floor are better balance, less risk of collision with the subject, no need of navigation system and less space utilization. A rail traction system on the ceiling supports the entire structure. The patient could navigate through a predetermined path only, and this is the major limitation of the system.

Apart from these, some advanced patient lift robot prototypes are also developed. Robot for Interactive Body Assistance (RIBA) is one such prototype developed by RIKEN-TRI Collaboration Center for Human-Interactive Robot Research (RTC) [40]. It is the advanced version of RI-MAN [41], which failed to lift up actual human because of lack of payload capacity, joint singularity and safety. RIBA is world's first robot which makes use of its strong and versatile human type arms to lift up a patient or an elderly from bed or a wheel chair and transfer to any other surface. Arms of RIBA are mounted with wide range of tactile sensors which could be used for modifying lifting trajectory, detecting caregiver's instructions and to ensure safety. Instructions to perform various actions are provided as voice commands, but the trajectories can be modified using tactile sensor data during

**Fig. 10** Wall patient lift

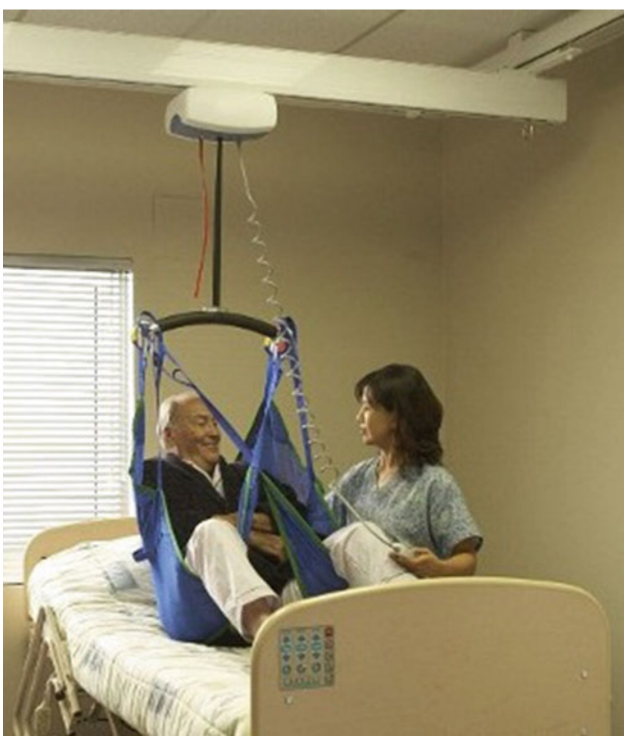

**Fig. 11** Ceiling patient lift

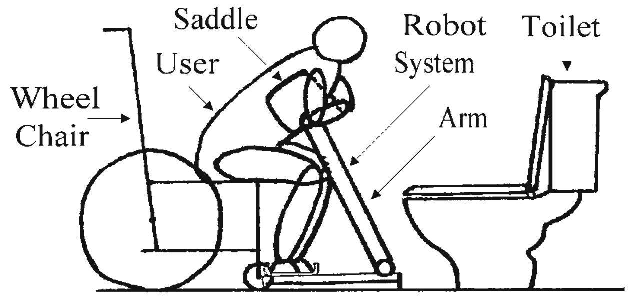


**Fig. 12** Schematic diagram of self-transfer facility developed by Yoshihiko Takahashi et al.

**Fig. 13** RIBA robot lifting a human

patient transfer activities according to changes in situations. Figure 13 shows a RIBA robot lifting a human using its arm. The major disadvantage of making use of human like arms for handling person is the risk of patient slipping through the arm and falling off [40].

Korea Advanced Institute of Science and Technology (KAIST) has developed an experimental smart home known as 'Intelligent Sweet Home' (ISH) for testing advanced concepts of independent living for the elderly and the disabled [42,43]. ISH is a broad concept which consists of several assistive robotic subsystems such as an intelligent bed, an intelligent wheel chair and a robotic hoist. An overall view of ISH is shown in Fig. 14. All components in the home are

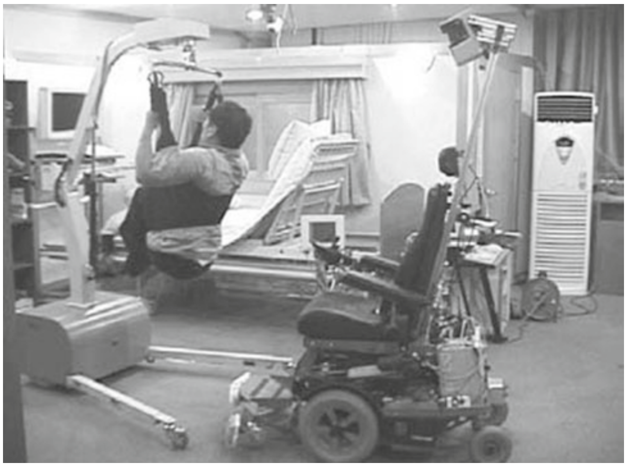

**Fig. 14** A view of intelligent sweet home

networked using communication modules and are controlled using a central control unit. Intelligent bed consists of an array of pressure sensors distributed over the surface of the bed to monitor patient's posture as well as motion on the bed and a supporting manipulator. User initiates a transfer task by voice commands or hand gestures. Posture and position information of the user is sensed by the pressure sensor array and with respect to the information received, the supporting manipulator assists him/her to change body posture in the bed. The control system analyses the posture and position information and the robotic hoist moves towards the bed and lifts the user. The intelligent wheel chair moves towards the hoist and docks itself with it. After docking, the robotic hoist lowers to place the user onto the wheel chair. Then, the wheel chair automatically navigates towards the destination provided. ISH also employs a steward robot '*Joy*' which reduces user's cognitive load and controls all the subsystems, within the ISH [44,45]. '*Joy*' controls the home appliances by communicating with a home network server within the smart house. The robot has two degrees of freedom for head motion, two arms of six degrees of freedom each with a mobile platform on two wheels. '*Joy*' is provided with learning function and human intent reading capability to handle uncertain services so as to avoid difficult situations faced by the elderly.

## 4 Wheel chairs with transfer modules

All the assistive devices discussed above are either to serve a single specific purpose or need multiple sub-devices to achieve locomotion and transfer task. Few researchers have attempted to address the issue of mobility as well as transfer task together. Mori et al. [46] had proposed a wheel chair with lifting function, shown in Fig. 15, that could assist a caregiver in transferring a wheel chair dependent. The lifting mechanism comprises a lifting frame, a sling seat and an electrically driven winch. The wheel chair employs front wheel drive and the seat could be folded, so that the user could approach a toilet commode or a bed from the rear. Sequence of transfer of an elderly from bed to toilet is as follows:

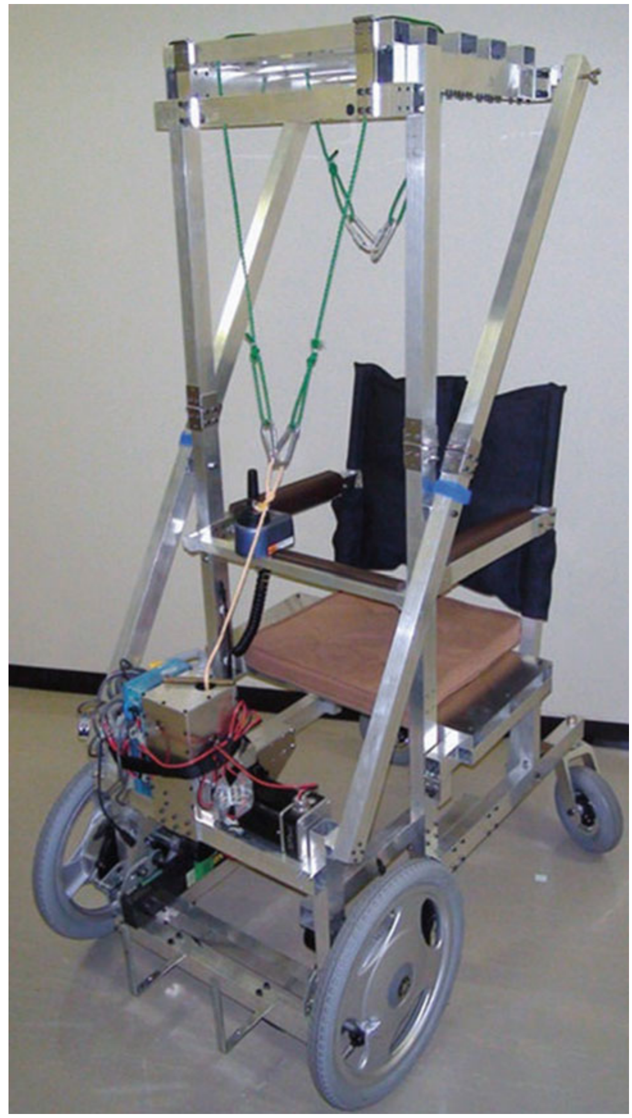

**Fig. 15** Wheel chair with lifting function

1. Seat, backrest and arm rest of the equipment are folded so that the subject could be accommodated into the equipment without any obstruction, through the rear of the device. The folded equipment moves towards the patient who is on the bed.
2. The subject wearing a sling seat is hooked up to the lifting cord and is lifted up from the bed using the winch.
3. The seat, backrest and arm rest are expanded and the subject is being seated on to the seat. He/she can be unhooked from the lifting cord.

4. The user can navigate to the toilet using joystick control.
5. At toilet the sling seat is attached back to the lifting cord and lifted using the winch.
6. Only the seat frame is folded.
7. The system is moved towards the commode in reverse direction and orients the subject above the toilet seat.
8. He/she is moved downward slowly and placed on top of the toilet seat.

The size of the chair when expanded is 100 (L) × 68 (W) × 162 (H) cm and while folded is 100 (L) × 68 (W) × 105 (H) cm. The dimensions of the device are satisfactory for a normal bathroom, but the position and orientation of the commode within the bathroom may cause difficulties for the chair to approach the commode. Moreover, the device has to be moved towards the commode in reverse direction, which would be difficult for an elderly to perform independently.

The Home Lift, Position and Rehabilitation (HLPR) Chair, developed by National Institute of Standards and Technology (NIST) USA, is a multipurpose self-assistance robotic chair that addresses locomotion, transfer to toilet or bed, lift assistance to access tall shelves and rehabilitation [47–49]. The back bone of the device is a sturdy fork lift. There are two inverted L-shaped frames. The outer L frame is fixed to the lift device. The inner L frame, which carries the seat, rotates within the outer L frame with point of rotation on the top point of the outer L frame. This allows the seat frame to be rotated 360°. HLPR chair has tricycle design, with two casters on the front and back wheel drive. The device could also be used as a smart walker for walking rehabilitation. Figure 16 shows a HLPR chair. Following are the steps to transfer an elderly from HLPR chair to the toilet commode:

1. HLPR chair navigates to the bathroom. Foot rest is folded up beneath the seat. Now the subject's feet are placed on floor.
2. The inner L frame is rotated, allowing the patient to be above the toilet.
3. Padded torso lifts on both sides of the seat, lifts patient from beneath the arms as in crutches.
4. The seat with foot rest is folded and is moved behind the patient's back, clearing the area beneath the subject and he/she is placed on to the toilet seat.

The graphical illustration of placing the subject on to toilet seat is shown in Fig. 17. Manual navigation of HLPR chair is achieved using joystick control. Further experiments were carried out for achieving autonomous navigation using various localization sensor technologies including RFID technology and Flash LIDAR [50]. Four-dimensional/real-time control system (4D/RCS) is the control architecture developed by NIST for intelligent machines and the same is experimented in HLPR chair. In 4D/RCS architecture, the environment around the robot is sensed and this information is placed onto a model map. The appropriate navigational paths are planned, generated and are provided as input to the robot's actuators in real time. The HLPR chair measures 109 (L) × 58 (W) × 178 (H) cm during normal mobility operation. Even though the width of the device is small enough to pass through the narrow corridors, length of the system may extend up to a maximum 145 cm during transfer, making it difficult to be used in smaller bathrooms.

**Fig. 16** HLPR chair

## 5 Challenges and issues

As already mentioned many of the assistive devices could perform only a single specific task or need multiple subdevices to achieve a particular task. Navigation of wheel chairs is a broad research area, where different new meth-

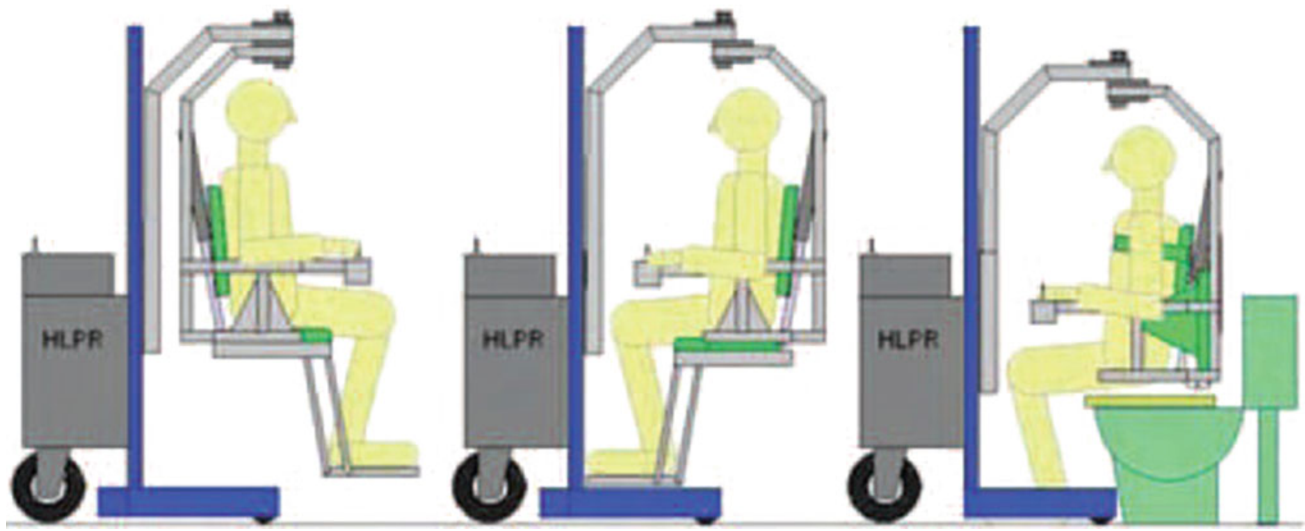


**Fig. 17** Graphical illustration of placing subject on to toilet seat using HLPR chair

ods are evolving. Many devices discussed like ceiling lift, ROAD, etc. need extra fittings on the ceiling for transfer and navigation purposes. These devices need infrastructural modifications before being put into use. Some modifications to the infrastructure to assist the elderly, like the device proposed by Yoshihiko Takahashi et al. may cause difficulties for other people using the same facility. Using of RIBA for transfer purposes, without modifying its arms is challenging. Psychological factors, like fear of fall, keep elderly away from using technology. So the ergonomic and aesthetic aspects of the device need to be improved. Intelligent Sweet Home is a broad concept which employs several robotic subsystems to achieve patient handling. Even with the presence of steward robot 'Joy', to control the subsystems, the elders may encounter difficulties in using the subsystems.

It is more convenient for an elderly or a paraplegic patient to use a device as a single unit and this is the key advantage of HLPR chair and the wheel chair proposed by Yoshikazu Mori et al. But these systems seem to be sophisticated, costly and designed as per the standards of developed countries. Size of the device is an important factor. The length of the chair should be within 100 cm range; else it would be difficult to accommodate wheel chairs within a normal bathroom. Moreover, these devices are still prototypes in laboratories and are not yet commercialized. Hence, it is clear that researches in this area are still wide open. Design of the wheel chair with transfer module should be in such a way that, whatever may be the position and orientation of the commode within the bathroom, the device should approach the commode and facilitate transfer. If more than one mobile robotic subsystems are used for assisting elderly, then several factors like localization of a particular robot within a multi-robot scenario, aligning of two robots and efficient docking need to be considered.

Another important issue to be addressed while using transfer facility is the psychological factor which may occur due to fear of fall. The device should be stable enough to avoid toppling, unnecessary jerking, unexpected movements, etc. during transfer process.

Appropriate safety measures should be taken to ensure that the user is comfortable with the device. Table 1 provides a comparison of Robotic Transfer systems discussed in Sects. 3 and 4.

One of the main challenges of a battery operated wheel chair or transfer system is the concern of battery life. It is necessary to identify the electrical components that consume less power and thereby increasing battery life. Another major challenge is the battery charging time. Batteries with less re-charging time to achieve full charge must be identified. Moreover, intelligent battery charge monitoring systems are required to convey the charge level to the user. The intelligence of the system could be taken into next level by implementing automatic recharging facility, where the assistive device will find out the nearest power source and charge itself without the intervention of the user, when once the battery level goes below a set value. This really helps the disabled and the elderly who live alone, as they do not need to bother about recharging of the device [51]. It is to be noted that the recharging should occur overnight. Recharging of battery is a time consuming process. In this case battery swapping system for the robots could also be considered [52]. When the robot runs out of power, it returns back to its home docking station, where the exhausted battery will be replaced by charged one.

**Table 1** Comparison of robotic transfer systems

| Sl. No. | Devices | Purpose | Sensors | Limitations |
|---|---|---|---|---|
| 1 | Transfer system by Yoshihiko Takahashi et al. [11,38] | • Self-transfer | Nil | Not compact |
| 2 | ROAD robot [39] | • Lift<br>• Transfer<br>• Limited locomotion<br>• Rehabilitation | • Pressure sensors | • Navigation through predetermined path only.<br>• Mostly aimed at lower limb rehabilitation<br>• Need Modifications to infrastructure |
| 3 | RIBA robot [40] | • Patient lift<br>• Locomotion<br>• Nursing care | • Tactile sensors<br>• Vision sensors<br>• Auditory sensors | • Risk of user safety<br>• Higher level of sophistication |
| 4 | Intelligent sweet home concept [42–45] | • Lift<br>• Self-transfer<br>• Locomotion | • Pressure sensors<br>• Cameras<br>• Laser range finders<br>• Auditory sensors etc. | • Higher level of sophistication<br>• Need modifications to infrastructure |
| 5 | Wheel chair by Mori et al. [46] | • Lift<br>• Transfer<br>• Locomotion | Nil | • Not a self-transfer system<br>• Position and orientation of the commode may cause difficulties for chair to approach the commode.<br>• Approaching the toilet in reverse direction will be difficult |
| 6 | HLPR chair [47–50] | • Lift<br>• Self-transfer<br>• Locomotion<br>• Rehabilitation | • 3D imaging camera<br>• Colour camera<br>• Wheel encoders<br>• RFID<br>• LIDAR, etc. | • Higher level of sophistication<br>• The extended length of 145 cm is a drawback during transfer operation when used in small bathrooms |

Wheel chairs and toilet transfer mechanisms are prone to be in contact with wet environments, like bathrooms. The electrical systems of the same have to be isolated from such environments by enclosing them in proper chambers so as to avoid damage from water spills.

Another challenging area is interaction of the user with the device. Human–robot interaction for assistive application is still in its infant stage [53]. Various interaction schemes include joystick control, voice control, gaze control, gesture-based control, EEG-based control, etc. The interaction schemes should be simple for the elderly to use. Aged people may feel difficult to use sensory systems, which is in direct contact with their body, like the one used in brain-actuated intelligent wheel chair. The fear of using such systems may keep them away from using technologies that are beneficial to them. Advantage of voice- and gesture-based (using video input) interaction is that none of the sensors are in contact with user's body. But perfect filtering of the signals is required to avoid noises that may occur due to the aged person's shivering or unsteady voice, or due to unsteady gestures. If a front user display interface is used, special care should be taken to make it as simple as possible, so that it would convey the messages in an easily perceivable manner.

## 6 Conclusion

This paper covers a brief review on mobility assistive devices and self-transfer module for elderly. Wheel chair is the most commonly used mobility assistive device. By incorporating several intelligent features on to wheel chairs or employing intelligent sub-robotic systems along with wheel chairs, assistance for independent living could be provided to the elderly population to an extent. Sensors have an important role to play in assistive robotics area. Several algorithms and designs are evolving in various laboratories around the globe, but only a few of them are reaching commercial space. Cost of assistive robotic systems, complexity to use, fear of elderly to use a device, etc. are the main reasons. Providing pre-usage training to the elderly on assistive robotic devices that they are about to use can minimize problems like inhibition and fear to use smart assistive robotic devices.

Through technology, the quality of life of elderly could be improved by increasing their self-confidence, self-esteem and happiness levels and thereby making world a better place for them to live.

## References


1. Kinsella K, Phillips DR (2005) Global aging: the challenge of success. Popul Bull Popul Ref Bureau 60(1)
2. The World's Youth 2013 Data Sheet (2013) Population Reference Bureau. http://www.prb.org/pdf13/youth-data-sheet-2013.pdf. Accessed 04 June 2013
3. World population prospects: The 2010 revision (2011) United Nations, D. o. E., & Social Affairs, P. D. http://esa.un.org/wpp/. Accessed 04 June 2013
4. Chernbumroong S, Cang S, Atkins A (2013) Elderly activities recognition and classification for applications in assisted living. Expert Syst Appl 40(5):1662–1674
5. World Population Ageing:1950–2050 (2002) Population Division, DESA, United Nations. http://www.un.org/esa/population/publications/worldageing19502050/. Accessed 10 June 2013
6. Martins MM, Santos CP, Frizera-Neto A, Ceres R (2012) Assistive mobility devices focusing on Smart Walkers: classification and review. Robot Auton Syst 60(4):548–562
7. Jai Prakash Indira (1999) Ageing in India. World Health Organisation, Geneva
8. Ageing in the Twenty-First Century: A Celebration and A Challenge (2012) United Nation Population Fund and Help Age International
9. van der Woude LHV, Hopman MTE, van Kemenade CH (1999) Biomedical aspects of manual wheelchair propulsion: the state of the art II. In: Assistive Technology Research Series. IOS Press, Amsterdam
10. Tobe F (2012) Where are elder care robots?. IEEE Spectrum. http://spectrum.ieee.org/automaton/robotics/home-robots/where-are-the-eldercare-robots. Accessed 25 Jan 2013
11. Takahashi Y, Manabe G, Takahashi K, Hatakeyama T (2003) Simple self-transfer aid robotic system. In Proceedings of the IEEE international conference on robotics and automation, Taipai, Taiwan, September, pp 2305–2309
12. Bellis M History of the Wheel Chair. About.com guide. http://inventors.about.com/od/wstartinventions/a/wheelchair.htm. Accessed 4 June 2013
13. van der Woude LHV, de Groot Sonja, Janssen TWJ (2006) Manual wheelchairs: research and innovation in rehabilitation, sports, daily life and health. Med Eng Phys. 28(9):905–915
14. Green G, Young J (2011) The provision for wheel chairs for older people in the United Kingdom. Eur Geriatr Med 2(1):52–55
15. Winter AG, Bollini M et al. (2010) The leveraged freedom chair: a wheelchair designed for developing countries. In: Assistive technology research series, rehabilitation: mobility, exercise and sports, vol 26. IOS Press, Amsterdam, pp 54–56
16. Wakaumi H, Nakamura K, Matsumura T (1992) Development of an automated wheelchair guided by a magnetic ferrite marker lane. J Rehabil Res Dev 29(1):27–34
17. Jullieri M, Bazin B. (1988) Video guiding of an industrial cart. In: Proceedings of the 6th International Conference, AGVS-6, Brussels, Belgium. pp 171–178
18. Katevas NI, Sgouros NM, Tzafestas SG et al (1997) The autonomous mobile robot SENARIO: a sensor aided intelligent navigation system for powered wheelchair. IEEE Robot Autom Mag 4(4):60–70
19. Bourhis G, Agostini Y (1998) The VAHM robotized wheelchair: system architecture and human–machine interaction. J Intell Robot Syst 22(1):39–50
20. Yanco HA (1998) Wheelesley: a robotic wheelchair system: indoor navigation and user interface. In: Assistive technology and artificial intelligence. Springer, New York
21. Levine SP, Bell DA et al (1999) The NavChair assistive wheelchair navigation system. IEEE Trans Rehabil Eng 7(4):443–451
22. Lankenau A, Rofer T (2002) Mobile robot self-localization in large-scale environments. In: Proceedings of the IEEE international conference on robot and automation, pp 1359–1364
23. Tomaria MRM, Kobayashi Y, Kuno Y (2012) Development of smart wheelchair system for a user with severe motor impairment. Procedia Eng 41:538–546
24. Surmann Hartmut, Nüchter Andreas, Hertzberg Joachim (2003) An autonomous mobile robot with a 3D laser range finder for 3D exploration and digitalization of indoor environments. Robot Auton Syst 45(3–4):181–198
25. Durrant-Whyte H, Baily T (2006) Simultaneous localization and mapping: part1. IEEE Robot Autom Mag, pp 99–108
26. Cheein FAA, De La Curz C et al (2010) SLAM-based cross-a-door solution approach for a robotic wheel chair. Int J Adv Robot Syst 7(2):155–164
27. Yuki K, Elly T, Kobayashi Y, Kuno Y (2011) Situation-driven control of a robotic wheelchair to follow a caregiver. In: IEEE workshop on frontiers of computed vision, Korea, pp 1–6
28. Iwase T, Zhang R, Kuno Y (2006) Robotic wheelchair moving with the caregiver. In: Proceedings of SICE-ICASE international joint conference, pp 238–243
29. Alaa H, ur Réhman S, Li H, Anani A (2012) Active vision for controlling an electric wheelchair. Intel Serv Robotics 5(2):89–98
30. Rokonuzzaman M, Ferdous SM et al (2012) Design of an autonomous mobile wheel chair for disabled using electrooculogram (EOG) signals. In: Mechatronics: recent technological and scientific advances, pp 41–53
31. Barea R, Boquete L et al (2002) Wheelchair guidance strategies using EOG. J Intell Robot Syst 34(3):279–299
32. Lopes C, Pires G, Nunes U (2012) Assisted navigation for a brain-actuated intelligent wheelchair. Robot Auton Syst 61(3):245–258
33. Perrin X et al (2010) Brain-coupled interaction for semi-autonomous navigation of an assistive robot. Robot Auton Syst 58(12):1246–1255
34. Alamgir H, Li OW et al (2009) Evaluation of ceiling lifts: transfer time, patient comfort and staff perceptions. Injury 40(9):987–992
35. Bostelman R, Albus J (2006) Survey of patient mobility and lift technologies: toward advancements and standards. Internal Report No:7384, Intelligent Systems Division, National Institute of Standards and Technology
36. Stein J (2009) Stroke and the family: a new guide. Harvard University Press, Harvard
37. Bell F (1984) Patient-lifting devices in hospitals. CUP Archive
38. Takahashi Y, Manabe G et al (2006) Basic study on self-transfer aid robotics. J Robotics Mech 18(1):4–10
39. Carrera Isela, Moreno Héctor A et al (2011) ROAD: domestic assistant and rehabilitation robot. Med Biol Eng Comput 49(10):1201–1211

40. Mukai Toshiharu, Hirano Shinya, Nakashima Hiromichi, Sakaida Yuki, Guo Shijie (2011) Realization and safety measures of patient transfer by nursing-care assistant robot RIBA with tactile sensor. J Robotics Mech 23(3):360–369
41. Mukai T, Onishi M, Odashima T, Hirano S, Luo ZW (2008) Development of the tactile sensor system of a human-interactive robot 'RIMAN'. IEEE Trans Robotics 24(2):505–512
42. Park K, Bien w, Lee J et al (2007) Robotic smart house to assist people with movement disabilities. Auton Robots J 22(2): 183–198
43. Jung J.-W, Do J.-H et al (2005) Advanced robotic residence for the elderly/the handicapped: realization and user evaluation. In: Proceedings of the IEEE international conference on rehabilitation robotics, Chicago, USA, pp 492–495
44. Bien ZZ, Lee H.-E et al (2008) Intelligent interaction for human-friendly service robot in smart home environment. Int J Comput Intell Syst 1(1):77–93
45. Bostelman R, Albus J (2008) A Steward robot to help daily activities in a smart house environment. In: Proceedings of the 17th world congress of international federation of automatic control, Seoul, Korea, pp 11738–11743
46. Mori Y, Sakai N, Kaoru K (2012) Development of a wheelchair with a lifting function. Adv Mech Eng 2012:1–9
47. Bostelman Roger, Albus James (2008) obotic patient transfer and rehabilitation device for patient care facilities or the home. Adv Robotics 22(12):1287–1307
48. Bostelman R, Albus J (2007) A multipurpose robotic wheelchair and rehabilitation device for the home. In: Proceedings of the IEEE/RSJ international conference on intelligent robots and systems, USA, pp 3348–3353
49. Bostelman R, Albus J (2008) Robotic patient lift and transfer. Serv Robot Appl, InTech, pp 1–20
50. Bostelman R, Albus J (2008) Sensor experiments to facilitate robot use in assistive environment. In: Proceedings of international conference on pervasive technologies related to assistive environments, Athens, Greece
51. Ren CL, Chung TL, Kuo LS, Kuei CL (2005) Automatic docking and recharging system for autonomous security robot. In: Proceedings of the IEEE/RSJ international conference on intelligent robots and systems, pp 2953–2958
52. Juan W, Guifang Q, Jian G, Hongtao S, Guangming S (2012) Automatic battery swap system for home robots. Int J Adv Robot Syst 9
53. Tapus A, Tăpuş C, Matarić MJ (2008) User-robot personality matching and assistive robot behavior adaptation for post-stroke rehabilitation therapy. Intell Serv Robotics 1(2):169–183