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Telepresence Robots for People with Special Needs: a Systematic Review

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Abstract Telepresence robots are increasingly used to support remote social interaction. Telerobots allow the user to move a camera and a microphone at a remote location in real time - often with a display of the user's face at the robot. These robots can increase the quality of life for people with special needs, who are, for instance, bed bound. However, interface accessibility barriers have made them difficult to use for some people. Still, no state-of-the-art literature review has been made of research on telerobots for people with disabilities.

We used Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for a review. *Web of Science (WoS)*, *ACM Digital Library*, *IEEE Xplore*, *PubMed*, and *Scopus* were searched and a supplemental by hand examination of reference lists was done. The search includes studies published between 2009 and 2019.

A total of 871 articles were included in this review, 42 of which were eligible for the analysis. These articles were further characterized in terms of problems addressed, objectives, types of special needs considered, features of the devices, features of solutions, and the evaluation methods applied. Based on the review, future research directions are being proposed, addressing issues like: use-cases; user conditions; universal accessibility; safety; privacy and security; independence and autonomy; evaluation methods; and user training programs.

The review provides an overview of existing research, a summary of common research directions, and a summary of issues, which need to be considered in future research.

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1 Introduction

The concept of *telepresence* [1] introduces the possibility of providing a person the feeling of actually being present at a remote location. With the continuous development of robotic technology, robotic telepresence has now been realised to some degree [2]. It enables the operator to be placed effectively "on-the-scene" by mapping the operator's visual, tactile, motor and cognitive functions to a remote robot [3]. Social robotic telepresence is a major field of application, providing social interaction at a distance [2].

A number of studies have put a special focus on the potentials of telerobots supporting people with special needs, e.g., distant communication for patients [4], support of older adults with dementia [5,6], distant learning for home-bound students [7], caring for children with cognitive disabilities [8], and independent living for seniors [4]. User engagement with telepresence robots has been either as the local operator (teleoperator); or as participants in social events including a telerobot. In this review, we only focus on the first role.

Literature on general usages of telepresence robots has been reviewed by [2]. Telepresence robots to enhance social connectedness for older adults with dementia have been reviewed by [6]. A systematic review of research into how robotic technology can help older adults was conducted by [11]. However, these reviews only considered telepresence robots for either typical

Fig. 1 Left: Two typical commercial telepresence robots (*Double* [9] and *Beam* [10]). Right: A pair of experimental telepresence robots from *Orihime* where people with disabilities are serving in a cafe.

users, or for a very specific user group. Hence, there is a need for of a systematic review of the recent literature on telepresence for people with special needs, including people with disabilities, seniors, and patients, who could potentially all increase their quality of life by using telepresence robots.

Consequently, the purpose of this review is to perform a systematic review and showcase the academic research work published in the telepresence robots domain for people with special needs, and to identify new areas of research.

The paper is organised as follows: Section 2 describes how telepresence robots have been used by people with special needs and states the research questions for our review. Section 3 presents the methods used for the systematic review. Section 4 describes results based on the review. Section 5 presents answers to the research questions, and suggests research directions and issues to be considered in future research. Section 5.12 identifies some limitations of our review. Finally, in section 6, conclusions are drawn.

2 Telepresence robots and special needs

2.1 Telepresence robots

Telepresence robots are utilised for, e.g., collaboration between geographically distributed teams [12], at academic conferences [13], for relationships between long-distance couples [14], by people with mobility impairments [15], and for outdoor activities [16]. During the Covid-19 pandemic, telepresence robots support healthcare personnel by providing remote patient communication, clinical assessment and diagnostic testing [17].

Social robotic telepresence has formed the basis of several new companies introducing commercial products, like *Double Robot, Beam, Giraff, Padbot, and VGO* (see Fig. 1).

Different terms have been used for telerobots in the research literature, for instance: remote presence system [18], mobile robotic telepresence system [2], virtual presence robots and remote presence robots [19]. They are often explained as a video conferencing system mounted on a mobile robotic base [2], with a popular phrasing of "skype on wheels" [20].

Commercial products usually feature: i) two-way audio and video communication between remote parties; ii) a video screen where the operator's face image is shown; and iii) mobility controls for the path of motion, - of which the two-way video communication feature is considered essential [21].

Communication via a telepresence robot can be defined as robot-mediated communication [22]. Using telepresence robots involves different types of interactions occurring simultaneously [2]. When using the robots for social interaction, besides the human-robot interaction mentioned above, human-robot interaction occurs between the remote robot and the remote people. The interaction between local users and remote persons is human-human interaction via the robot.

We define *telepresence robots* as robotic devices, by which an operator can overcome physical distance for the purpose of telepresence. In this review we include both commercial products, experimental (i.e., prototype) robots made for research, and commercial telerobots modified for special needs.

2.2 Accessibility and universal access

Accessibility describes the degree to which an environment, service, or product allows access by as many people as possible, in particular people with disabilities [23]. Accessibility and high quality of interaction for everyone, anywhere, and at any time are fundamental requirements for universal access [24]. Universal accessibility is typically considered for special populations including seniors and people with disabilities [25].

2.3 Telepresence robots and special needs

More than 190 million people worldwide are estimated to live with disabilities [23]. Auditory disabilities, motor disabilities, and cognitive disabilities are the main types of disabilities, while 39 million people are classified as legally blind [26]. In particular, people with motor disabilities may benefit from telepresence robots to overcome mobility problems, especially those with servere motor disabilities, for instance cerebral palsy [8] or Amyotrophic Lateral Sclerosis (ALS/MND) [27]. The most commonly used control method for telerobots is hand control. However, motor impairments may limit the use of hands, causing, for instance, limited gripping, fingering or holding ability. Visual and auditory sensing also play important roles in the experience of telepresence [21]. Impairments of sensing may have severe negative impacts on the experience of telepresence, or even make it impossible to experience the remote place.

Telepresence robots have been used by families and caregivers to support remote relationships with children who have cognitive challenges from Autism Spectrum Disorder or Cerebral Palsy [8], and have been used as a communication tools for people with dementia [5]. However, due to their cognitive challenges, independent use of telepresence robots can be problematic [25]. Finally, older adults and hospitalised or home-bound patients have been considered as beneficiaries of telerobots.

Telepresence robots may have particular impact on hospitalised or home-bound children, who experience not only poorer health, but also limited opportunities for education [28]. Likewise, children with disabilities experience poorer health, limited opportunities for education, and they encounter greater inequalities than children without disabilities [28]. Mobility problems may lead to psychological problems, for instance, feelings of emotional loss, reduced self-esteem, isolation, stress, and fear of abandonment [29]. Overcoming part of a mobility problem may provide new daily opportunities, reduce dependence on caregivers and family members, and promote feelings of self-reliance [30]. Telepresence robots thus have the potentials to improve their quality of life by supporting social activities and building networks to others. For instance, telepresence technology can reduce loneliness among older adults with mobility impairments, supporting their ageing-in-place while remaining socially connected to friends and family [31].

2.4 Research question

A systematic literature review was performed to collect, comprehend, analyze, synthesize, and evaluate recent relevant literature. The seven research questions (RQ) addressed in this review are:

- RQ1 Which relevant studies have been published from 2009 to 2019?
- RQ2 What are the special user conditions considered for the design of telepresence robots?
- RQ3 What are the use-cases addressed for people with special needs?
- RQ4 Are current telepresence robot systems accessible for people with special needs?
- RQ5 How have telepresence robots for people with special needs been evaluated?
- RQ6 What are the potential impacts on quality of life for the proposed solutions?
- RQ7 What should be addressed in future research?

We aimed to provide an overview of the studies focused on the telepresence robots for people with special needs by answering RQ 1. This research question is the base for answering the other research questions. Regarding people with special needs, we attempted to know which exact conditions were focused on in these studies to answer RQ 2. RQ 3 attempts to inform readers about the use cases in which telepresence robots were applied for people with special needs, in contrast with general use cases. Then, we attempted to have an overview of the accessibility of the telepresence robots to answer RQ 4. In addition, we aimed to get more details about the selected studies where the evaluation was a key issue to answer RQ 5. As improving the quality of life was a common goal of the studies, we investigated the potential impacts of the solutions in RQ 6. Based on the review, we tried to summarize the research gap, which should be addressed in future research, thus answering RQ 7.

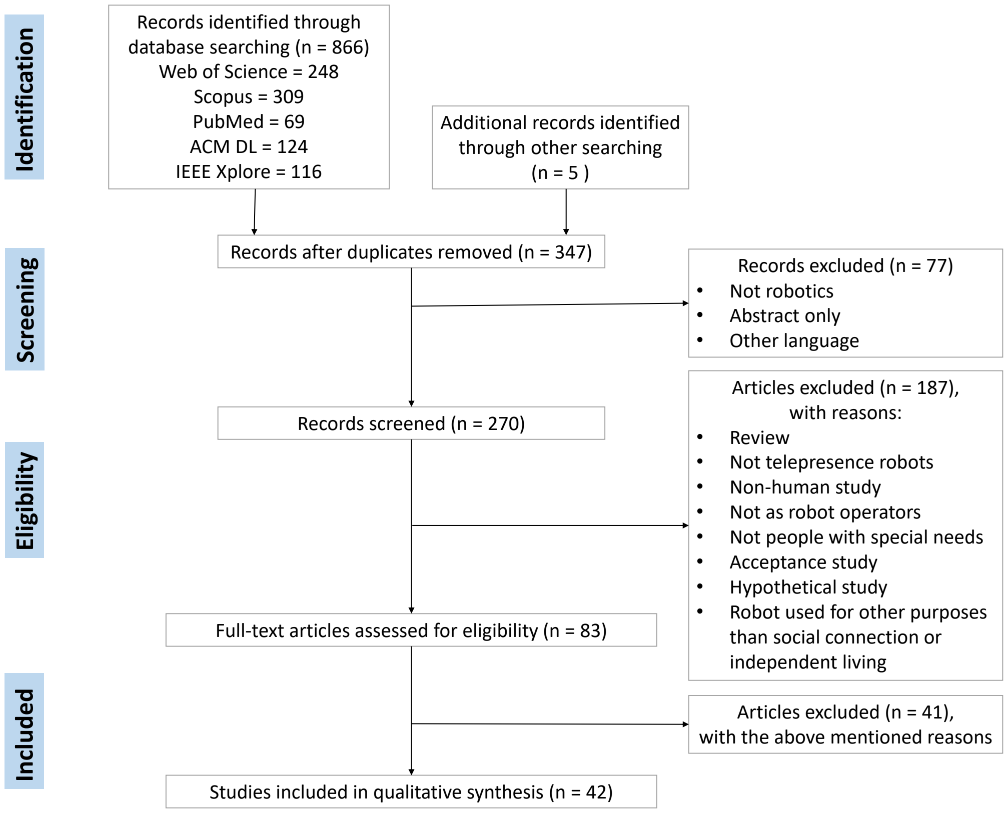

Fig. 2 PRISMA flow diagram illustrating the number of reviewed articles through the different phases.

3 Method

The methodology used for this systematic literature review is detailed in the following sections. We conducted and reported the review according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses Statement (PRISMA) [32]. A flowchart of the process is shown in Fig. 2.

3.1 Search terms

Based on our research objectives, we defined the search terms to match the research questions. The topics of the terms chosen were the purpose (i.e., *telepresence*) and the possible fields of use (i.e.,*accessibility, inclusive design, universal design, special needs, disabilities, hospital, care home*). Instead of the specific term "telepresence robots", a broader database-specific search term "telepresence" was used.

The expression used in the search process was: *(accessib* OR assistive OR inclusion OR "inclusive design" OR "universal design" OR "special needs " OR disabilit* OR impair* OR deficit OR ill* OR hospital OR "care home") AND (telepresence OR tele*presence)*

3.2 Identification of databases and search engines

The search engines and bibliographic databases were selected to cover both healthcare and technical-scientific literature. *IEEE Xplore* covers technical fields, including electrical engineering and computer science [33]. *ACM Digital Library (ACM DL)* is a premier database for computer science literature [34]. PubMed [35] covers healthcare-related literature. This database was considered an optimal tool in biomedical electronic research [36]. *Web of Science (WoS)* and *Scopus* cover most of the scientific fields. Both databases have their own advantages [36]. Therefore, *IEEE Xplore*, *ACM DL*, *PubMed*, *WoS*, and *Scopus* were chosen. We searched the databases in December 2019.

Title	Types of Special Needs	Ref.
A cloud robotics system for telepresence enabling mobility impaired people to enjoy the whole museum experience	Motor disabilities	[37]
A Step towards a Robotic System With Smartphone Working As Its Brain : An Assistive Technology	Motor disabilities	[38]
A study to design VI classrooms using virtual reality aided telepresence	Homebound children with disabilities	[39]
A Telepresence Mobile Robot Controlled With a Noninvasive Brain-Computer Interface	Motor disabilities	[40]
A telepresence robotic system operated with a P300-based brain-computer interface: Initial tests with ALS patients	Motor disabilities	[27]
Accessible Control of Telepresence Robots based on Eye Tracking	Motor disabilities	[41]
Accessible Human-Robot Interaction for Telepresence Robots: A Case Study	Motor and cognitive disabilities	[42]
An Eye-gaze Tracking System for Teleoperation of a Mobile Robot	Motor disabilities	[43]
Assistant Personal Robot (APR): Conception and Application of a Tele-Operated Assisted Living Robot	Older adults	[44]
Brain-Computer Interface Meets ROS: A Robotic Approach to Mentally Drive Telepresence Robots	Motor disabilities	[45]
Brain-controlled telepresence robot by motor-disabled people	Motor disabilities	[46]
Comparison of SSVEP BCI and Eye Tracking for Controlling a Humanoid Robot in a Social Environment	Motor disabilities	[47]
Design and Optimization of a BCI-Driven Telepresence Robot Through Programming by Demonstration	Motor disabilities	[48]
Designing speech-based interfaces for telepresence robots for people with disabilities	Cognitive and/or motor disabilities	[49]
Driving a Semiautonomous Mobile Robotic Car Controlled by an SSVEP-Based BCI	Motor disabilities	[50]
EEG-Based Mobile Robot Control Through an Adaptive Brain-Robot Interface	Motor disabilities	[51]
Effect of a Click-Like Feedback on Motor Imagery in EEG-BCI and Eye-Tracking Hybrid Control for Telepresence	Motor disabilities	[52]
Evaluation of an Assistive Telepresence Robot for Elderly Healthcare	Older adults	[53]
Eye-Gaze-Controlled Telepresence Robots for People with Motor Disabilities	Motor disabilities	[54]
Gaze-controlled Laser Pointer Platform for People with Severe Motor Impairments: Preliminary Test in Telepresence	Motor disabilities	[55]
Going to school on a robot: Robot and user interface design features that matter	Homebound children	[56]
Hand- and gaze-control of telepresence robots	Motor disabilities	[57]
Hands-free collaboration using telepresence robots for all ages	Older adults	[58]
Head and Gaze Control of a Telepresence Robot with an HMD	Motor disabilities	[59]
Human-robot cooperation through brain-computer interaction and emulated haptic supports	Motor disabilities	[60]
Measuring Benefits of Telepresence robot for Individuals with Motor Impairments	Motor disabilities	[61]
Mobile Robotic Telepresence Solutions for the Education of Hospitalized Children	Hospitalised children	[62]
My Student is a Robot: How Schools Manage Telepresence Experiences for Students	Homebound children	[7]
Navigation of a Telepresence Robot via Covert Visuospatial Attention and Real-Time fMRI	Motor disabilities	[63]
Real World Haptic Exploration for Telepresence of the Visually Impaired	Visual disabilities	[64]
Real-time Haptic Rendering and Haptic Telepresence Robotic System for the Visually Impaired	Visual disabilities	[65]
Robotics-based telepresence using multi-modal interaction for individuals with visual impairments	Visual disabilities	[66]
Social robots helping people with dementia: Assessing efficacy of social robots in the nursing home environment	Older adults (with dementia)	[67]
Towards Independence: A BCI Telepresence Robot for People With Severe Motor Disabilities	Motor disabilities	[68]
Telepresence heuristic evaluation for adults aging with mobility impairment	Older adults	[31]
Telerobotic haptic exploration in art galleries and museums for individuals with visual impairments	Visual disabilities	[26]
The role of shared-control in BCI-based telepresence	Motor disabilities	[69]
Towards designing telepresence robot navigation for people with disabilities	Cognitive and/or motor disabilities	[25]
Towards Independence: A BCI Telepresence Robot for People With Severe Motor Disabilities	Motor disabilities	[68]
Transferring brain-computer interfaces beyond the laboratory: Successful application control for motor-disabled users	Motor disabilities	[70]
Using a Telepresence Robot to Improve Self-Efficacy of People with Developmental Disabilities	Cognitive disabilities	[71]
Virtual inclusion via telepresence robots in the classroom	Homebound children	[72]
Virtual inclusion via telepresence robots in the classroom: An exploratory case study	Homebound children	[73]

Table 1 Papers selected for analysis.

3.3 Inclusion and Exclusion Criteria

As we focused on the systematic review on the state-of-the-art in telepresence robots for people with special needs, we established the period from 2009 to 2019.

The number of articles after removing duplicates was 342 (see Fig. 2). The articles were screened for eligibility in two phases. In the first phase of filtering, we excluded results which had only an abstract. Since we used the broad term *telepresence* in our search, we also excluded the articles which did not include any robot or robot-like devices. The number of articles after filtering was 265. In the second phase, we filtered out 78 articles from the 265. This was done by one author going through titles, keywords, and abstracts. If eligible, the full-text of the articles were retrieved and reviewed. The following exclusion criteria were met: (1) Not telepresence robots; (2) Non-human study; (3) Review; (4) Robots with other purposes; (5) Not for people with special needs; (6) Acceptance study; (7) Hypothetical study; (8) Robot used for other purposes than social connection or independent living.

The resulting list of 39 articles was further critically investigated by both authors separately. The results were then discussed and 2 articles were finally excluded by agreement of both authors, ending with a total of 37 articles. By snowballing from the reference lists of the papers selected, we found 5 more key papers for our review, which were considered as additional records. Finally, a total of 42 articles (see Table 1) were included.

3.4 Data Analysis

The articles on the final list were characterized in terms of problems addressed, research objectives, types of user conditions, features of devices, features of solutions proposed, and methodology of the study. Data were extracted from the articles into one separate table by the first author in a predetermined format validated by the second author.

4 Results

A small majority of the articles were conference proceedings (24 papers, 57%) compared to journal articles (18 papers, 43%). There was a slight increase in the number of papers per year over the time period investigated. No publications were found from 2009, and the year with the highest number of publications was 2018 (8 papers, 19%). The number of publications in 2019 until the last date of searching in December was five.

Barriers and challenges of using telepresence robots due to specific disabilities were the most common problem statements (e.g., [55,65,64,25]). There were two goals which were most commonly mentioned as research goals: i) to improve the quality of life of target users with special needs (e.g., [69,45,48,42]) ; ii) to increase independence of the target users (e.g., [68]).

None of the selected papers were published in 2009. However, what is striking in Fig. 3 is the growth of papers afterward. Overall, the telepresence research in this area is keeping up with the tremendous amount of work done in the accessibility space in HCI in general [74].

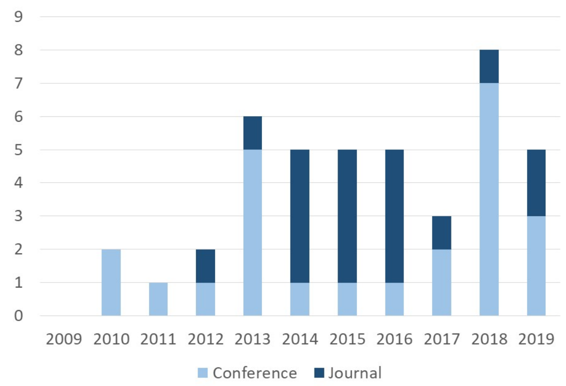

Fig. 3 Distribution of selected papers by their publication years.

Six of the identified articles have received 60 or more citations. Five of these focused on brain-computer interfaces (BCI) for people with motor disabilities, and one focused on healthcare of older adults.

4.1 Consulted source

Regarding the source of the paper selected, 61% of papers were found from *ACM DL* and *IEEE Xplore*. PubMed had 11 papers (26%), including 5 papers that also appeared in *IEEE Xplore*. After exclusion of all the papers from *ACM DL* and *IEEE Xplore*, a total of 7 papers (17%) were found from *Scopus* and *WoS*. The reference lists of all these 37 papers were examined and we found an additional 5 papers (12%) using the same inclusion criteria (see Fig. 2).

All papers from *IEEE Xplore* focus on accessibility and disabilities, especially motor disabilities. Most of these papers proposed a novel control technique or new sensing methods. PubMed also covered 5 papers from IEEE which focused more on medical and health

ID	Conference name	Total
C1	International Conference of the IEEE Engineering in Medicine and Biology Society	3
C2	ACM Symposium on Eye Tracking Research and Applications (ETRA)	3
C3	ACM SIGCHI Conference on Human Factors in Computing Systems (CHI)	2
C4	ACM/IEEE International Conference on Human-Robot Interaction (HRI)	2
C5	ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW)	1
C6	ACM SIGACCESS Conference on Computers and Accessibility	1
C7	Human Factors and Ergonomics Society Annual Meeting	1
C8	IEEE International Conference on Industrial Technology	1
C9	IEEE International Conference on Systems, Man and Cybernetics	1
C10	IEEE International Conference on Robotics and Automation	1
C11	International Conference on Human System Interactions (HSI)	1
C12	World Haptics Conference (WHC)	1
C13	International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)	1
C14	IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)	1
C15	IEEE International Conference on Design and Technology of Integrated Systems in Nanoscale Era	1
C16	IEEE International Conference on Advanced Learning Technologies	1
C17	International Conference on Rehabilitation Robotics (ICORR)	1

Table 2 Conferences

Journal	Journal title	Total
J1	*IEEE Transactions on Systems, Man, and Cybernetics*	2
J2	*ACM Transactions on Computer-Human Interaction (TOCHI)*	1
J3	*Artificial Intelligence in Medicine*	1
J4	*Assistive Technology: Building Bridges*	1
J5	*Brain Topography*	1
J6	*Computational Intelligence and Neuroscience*	1
J7	*IEEE Access*	1
J8	*IEEE Transactions on Haptics*	1
J9	*International Journal of Adaptive Control and Signal Processing*	1
J10	*International Journal of Intelligent Computing and Cybernetics*	1
J11	*Journal of Medical Systems*	1
J12	*Journal of Information Systems Engineering & Management*	1
J13	Paladyn, Journal of Behavioral Robotics	1
J14	*Perspectives in Health Information Management*	1
J15	*Presence: Teleoperators and Virtual Environments*	1
J16	*Proceedings of the IEEE*	1
J17	*Sensors*	1
J18	*The International Journal of Technologies in Learning*	1

Table 3 Journals

aspects, like hospitalized users or the use of special medical devices for control, for instance a functional magnetic resonance imaging (fMRI) device [63].

Regarding the source of journals and conferences, the selected papers were distributed in proceedings of 16 conferences (see Table 2) and 18 journals (see Table 3). The conferences were mainly organised by ACM and IEEE (15 conferences). Among them, the vast majority of the ACM conferences were fully or partly organised by Special Interest Group on Computer–Human Interaction (SIGCHI) (8 papers) focusing on human-robot interaction, and one paper was presented at the conference organised by Special Interest Group on Accessible Computing (SIGACCESS). The journal articles were distributed in a number of different journals, related to their specific topics.

This section has shown general features of the selected papers, regarding databases and types of publications. In the next sections, we focus on specific issues of telepresence robots for people with special needs.

4.2 Special needs and Application Areas

Firstly, we analysed the special needs addressed in the selected papers. Fig. 4 shows the distribution of types of special needs addressed. Disability was the most frequently considered use condition (31 papers, 74%). Motor disability (26 papers, 77%) was the most common user condition among the disability-related papers, while 4 papers focused on visual disabilities and 3 focused on cognitive disabilities. Most of them focused on just one type of disability, while two of them [49, 25] addressed a combination of motor and cognitive disabilities.

Eleven papers targeted a particular age group, namely children (6 papers) and older adults (5 papers). Regarding the children group, one of the papers focused

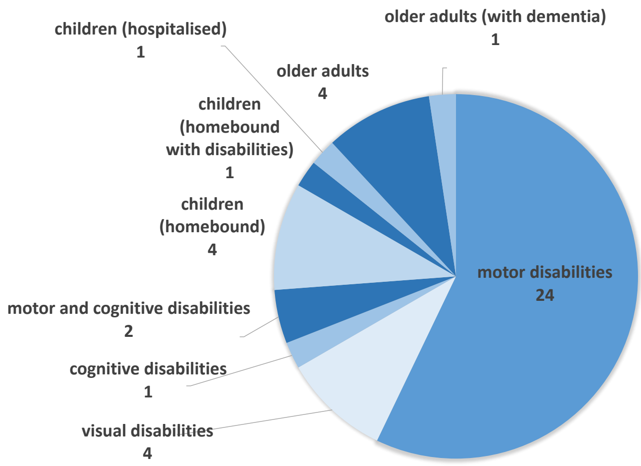

Fig. 4 Distribution of selected papers by types of special needs addressed.

on children with disabilities in general and the other five focused on home-bound or hospitalised children. For the older adults group, all papers were motivated by common problems faced by seniors aging-in-place, and one paper focused specifically on dementia. Figure 5 indicates a slight increase in the number of papers addressing disabilities, especially motor disabilities.

A majority of application areas were mainly applications for social interaction, social communication, and social engagements in general, mostly in the three main types of scenarios mentioned above. The application area of all selected papers about children was using the robots for education. One of the authors defined virtual inclusion in this use case as an educational practice that allows a student to attend school through a mobile robotic telepresence system in such a way that the student is able to interact with classmates, teachers, and other school personnel as if the student were physically present [73].

In summary, this section presents a brief overview of the special needs addressed and the areas where the telepresence robots have been applied.

4.3 Devices and Hardware

This section presents the analysis of devices and hardware used for the special needs addressed in the selected papers. The robots used in the selected papers may be classified into three categories according to their features: i) Experimental (i.e., prototype) robots; ii) commercial robots; and iii) adapted commercial robots. Robots mentioned in the study included commercial telepresence robots (like *VGO* [49], *Double* [56], *Padbot* [57]) and other types of robots for adaptation (like *LEGO Mindstorms NXT* [60], *NAO* [48], *Pepper* [45], *Robotino* by *FESTO* [63]).

All of the research papers addressing children applied commercial robots without adaptation, while most of the robots used in studies addressing disabilities were modified commercial robots or experimental robots. All three types of robots were used in studies regarding older adults.

Except for a stable robot used in [58], all of the robots featured mobility. Most of them were wheeled (38 papers), while 3 studies examined walk-able humanoid robots.

Camera features were not reported in a majority of the selected papers, or they just mentioned that a webcam or a notebook-integrated webcam was used (e.g., [49]). A few papers reported that they used a 360 degree camera [59,39,41,54], an HD-camera [55], a pan/tilt camera [37], or a stereo camera [64]. For studies of people with visual disabilities the camera was replaced by a RGB-D sensor (e.g., *Kinect*) [64,65,66,26].

Details about microphones or loudspeakers were not given in any of the selected papers. Commercial telerobots usually show the operator's face on a LCD display carried by the robot. Some of the experimental robots (e.g., in [67]) also provided a display, while a few papers state that the robot did not have a display. Information about the possibility to mute the displays or microphones was not given in any of the selected papers. Most of the commercial robots featured obstacle detection and avoidance (e.g., *Double*, *VGo* and *Padbot*).

A camera in front of the pilot is needed to display the operator's face image in the remote environment. Usually a webcam or a notebook-integrated webcam was used for this purpose (e.g., [68]). An LCD display was applied in the majority of studies in order to show the live video stream transferred from the remote space. Head-mounted displays were used in a few of the selected papers [39,41,54,57], usually connected with a 360 degree camera and sometimes used in combination with other built-in sensors for gaze- or head interaction. When the pilot uses an HMD it becomes impossible to show a live face image on the telerobot, because the HMD covers the face. This had a negative impact on the user experience reported by [75]. In all papers addressing visual disabilities [64,65,66,26], the display was replaced with a tactile device to sense the remote environment using hands.

Control devices varied depending on the control methods and robots used (see Fig. 6). Hand control was the most common one, performed with mouse and keyboard or via a touch screen [72,56,31]. Other control devices included BCI electrodes, fMRI, VR headset (with

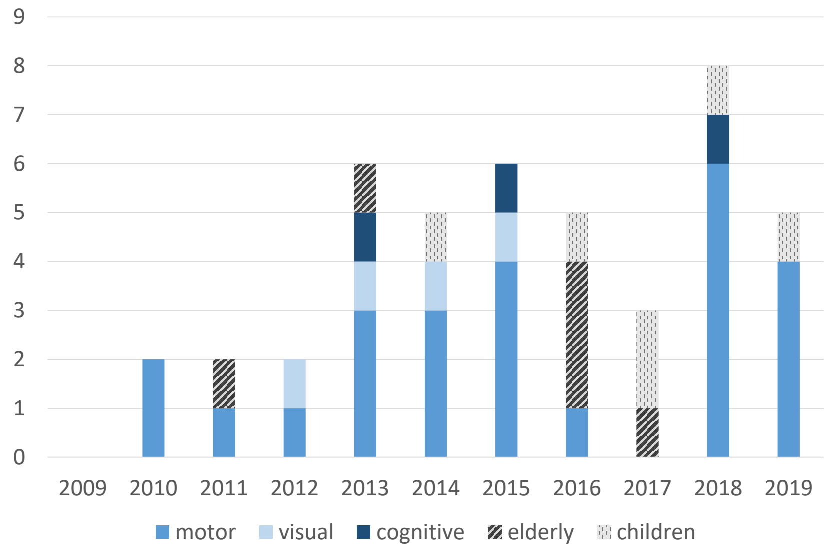

Fig. 5 Distribution of selected papers by years and types of special needs addressed.

built-in eye-trackers), screen-based eye-trackers, robot-integrated microphones, and smartphones with accelerators. Haptic devices were used for people with visual disabilities [64, 65, 66, 26].

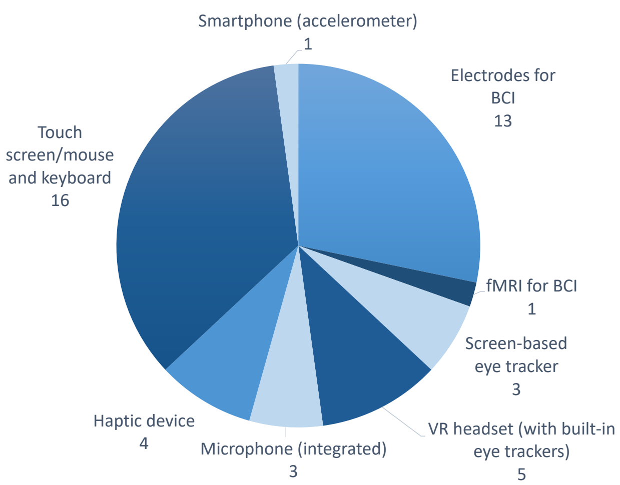

Fig. 6 Distribution of selected papers by devices used for controlling.

BCI was the most commonly used method in the selected studies addressing motor disabilities (14 papers). It does not rely on the brain's normal output channels of peripheral nerves and muscles. Therefore, it may become a valuable communication channel for people with motor disabilities, especially severe levels like ALS, brain-stem stroke, cerebral palsy, and spinal cord injury.

Eye-tracking-based methods were used in 31% of the studies focused on motor disabilities. Existing eye trackers are not cumbersome, and the increased accuracy of eye-tracking equipment makes it feasible to utilize this technology conveniently for users with motor disabilities. Besides screen-based eye trackers, some commercial head-mounted display (HMD) models with built-in eye-trackers were used (see Fig. 6). A solution combining eye-tracking with BCI [52] has the potential to solve a common problem of how to get user intention correctly when using eye-tracking-based user interfaces (UI) only. Eye-tracking was combined with head detection in [59]. Many partly paralyzed patients have preserved head movement, although they lack control over the rest of the body [47].

4.4 User Interface

The user interface is a key issue for persons with special needs when using telepresence robots. None of the papers used fully-automatic telepresence robots, hence they all required some degree of human piloting. Consequently, the target users were required to be the pilot. Some robots did not provide assistance for navigation [64, 57, 54], while most of the commercial products (e.g., [49, 31]) and the robots used in [27, 40, 67, 44] offered features such as obstacle detection, obstacle avoidance or semi-autonomous driving (e.g., [37]).

As listed in Tab. 4, control methods varied depending on types of special needs. For the group of older adults [31,67,44,53] and children [72,56,62,73], hand control was used. Two of these studies [39,58], applied head movement detection to change the field of view.

Motor disability was the user condition that most of the alternative control methods were proposed for, mainly to support navigation tasks. In total, 26 papers addressed motor disabilities [37,38,40,27,41,43,46,47,48,50,51,52,54,55,57,59,60,61,63,68,69,68,70,49,25], of which 2 papers [49,25] focused on both cognitive and motor disabilities. In addition to the hand control method, a number of other methods were proposed, c.f. Tab. 4. As previously mentioned, BCI was the most common alternative method (14 papers) [69,46,48,63,70,51,47,68,50,45,60,52]. In addition, eye-tracking was considered in 8 papers [47,52,59,43,55,41,54,57]. Speech-based control methods were used in 3 papers [49,25,42], of which two of them [49,25] addressed both cognitive and motor disabilities. Hand control via a haptic module was used in the four papers focusing on visual disabilities [65,66,47,26].

A large number of the selected papers focused on motor disabilities (see Fig. 4) using different types of body movements, and physiological signals and their UIs belong to the natural user interface category. All the solutions proposed for visual disabilities utilised haptic devices for sensing and control. Thus, their UIs belonged to a category of tangible user interfaces (4 papers).

An overview of the user interface was presented in this section, which attempts to provide some information regarding how to design telepresence robots to fit their special needs better.

The control methods were mainly for navigation tasks or for changing the field of view. Additional control tasks, for instance adjusting the height of robots, muting a microphone, or adjusting the volume of the loudspeaker, were not mentioned in any of the papers.

Control Method		
For motor disabilities		
BCI	13	31%
eye tracking	6	14%
eye tracking and BCI	1	2%
eye tracking and head detection	1	2%
head detection	1	2%
speech-based	3	7%
hand	2	5%
For visual disabilities		
hand (via a haptic module)	4	10%
For cognitive disabilities		
hand	1	2%
speech (for motor and cognitive disabilities)	2	5%
For children		
hand	5	12%
hand and head detection	1	2%
For older adults		
hand	4	10%
head detection	1	2%

Table 4 Distribution of selected papers by control methods used.

4.5 Types of Research

Regarding features of the research, different types of research were conducted in the papers selected. Applying the classification scheme suggested by [76], the papers selected can be characterized as: i) evaluation research (14 papers); ii) proposal of a solution (6 papers); or iii) validation research (22 papers). Some of the selected papers (14 papers) only focused on the evaluation of existing products (mainly commercial products). The other papers selected (28 papers) propose novel control methods and perform evaluation of the methods. If the evaluation was conducted in a lab environment, they are considered to be validation research (22 papers). The other papers (6 papers) performed the evaluation in a real environment, and they are considered to be a proposal of a solution. Validation research (53%) is thus found to be larger than the other two types.

In summary, all studies involve the evaluation of telepresence robots. Their main difference lies in whether they are based on novel or existing robots and the environments for evaluation. A summary of the evaluation methods, together with design methods, is provided in the following section.

4.6 Design and evaluation methods

The most common interaction design approach was user-centered design (UCD), taken by e.g., [51]. Participatory design was also reported by [49,25]. The evaluation research papers which focused on usability issues for hospitalised children (e.g., [62]) or older adults (e.g., [53]) considered specific use cases, for instance education [7] and social interaction [67]. Papers conducting a validation or proposing a solution mainly focused on exploring a novel approach for a specific type of disability. Their research questions were usually focused on challenges or uncertainty when using the new method.

Table 5 reveals that 18 of the selected papers did not involve target users. In the studies that did include participants from the target group, three of them [70, 39,56] had more than 5 participants, namely 17, 41 and 22 participants, respectively.

Table 6 shows that the number of studies conducted in a lab setting was slightly larger than those in a realistic scenario. The realistic test environments were education scenarios (e.g., classrooms [72]); cultural sites (e.g., museum [37]); health care environments (e.g., care-homes [67] and hospitals [62]). Papers with a focus on special needs addressed independent use in general, and did not explore specific application areas, except for a few papers addressing an art gallery scenario [42], museum and archaeological sites [37], or virtually inclusive classrooms [39].

Target users as participants	number	%
None (other participants only)	18	43%
Both target users and others	5	12%
Target users only	17	40%
Not mentioned	2	5%

Table 5 Distribution of types of participants.

Test environment	number	%
Lab	22	52%
Realistic scenario	19	45%
Not mentioned	1	2%

Table 6 Distribution of test environments.

The majority of techniques used in the selected papers were experiments (74%). Case studies (i.e., [42, 77, 78, 73]), heuristic evaluation [31], and interviews (e.g., [7]) were also occasionally used. These widely used methods in the selected papers were similar to the most popular study methods of general accessibility [74].

The main tasks for evaluation were navigation (e.g., by [38, 64, 57]). Task completion time was commonly used as a metric for evaluation. [68, 26, 38, 57, 66]. *NASA TLX* [79] was applied in a few studies [68, 57, 71]. Number of collision times were counted by [53, 69, 57, 54]. Descriptive analyses, like mapping of robot movements, were presented by [42, 70, 57] and heat maps of the robots' movement trajectories were made by [42]. The *Technology Acceptance Model* (TAM) questionnaire was also used in a study with senior participants [80].

Social Telepresense interaction occurs between a local target user and the remote site [2]. However, all of the studies focused only on the local part in their evaluation.

Visual and auditory experiences play essential roles in the experience of telepresence but this was ignored in the evaluation, and information about the devices used for social interaction (e.g., cameras, microphones, and loudspeakers) was missing in the selected papers.

Three main areas for future work were suggested by some of the papers: i) to involve target users in the research [40, 26, 57, 55]; ii) to test the proposed application in a more challenging real case scenario [37]; and iii) to improve the system [64, 37, 38].

Thus far, the subsection has shown key features of design and evaluation methods, including participants, test setting, and tasks.

5 Discussion

In this section, research directions and research considerations are discussed.

5.1 Goals and use-cases

Compared to the research of telepresence robots in traditional usages, the goals in the selected papers focused more on improving the quality of life of people with special needs. Most of the selected papers on children had a common goal of virtual inclusion [72] via using telepresence robots. This goal could also be addressed by future research for other groups of people with special needs.

Most studies in the field of proposing new solutions for people with disabilities did not focus on a specific application area. Application domains of the evaluation research (with existing products) had similarities with the research of traditional telepresence robots [2]. There was a lack of evaluations with our target users outside laboratory environments. To address the needs and problems faced by the target users, more application possibilities could be explored in future research, like the use of telepresence robots for social inclusion in education and working environments, shopping, family communication, and various indoor and outdoor leisure activities. This is evident in a study on the older adults [42] which showed that users wanted to apply telepresence robots to attend concerts or sporting events, and visit museums or theatres.

5.2 User conditions

User conditions were not especially addressed in the research of telepresence robots in traditional usages. However, this is an important issue in terms of telepresence robots for persons with special needs, as the user conditions could lead to barriers in using telepresence robots. The focused user conditions in the selected papers had been analyzed and presented in the previous section, but there were certain limitations. Two-way audio and video communication is considered an essential feature [21]. Visual and auditory experience is vital in telepresence experience. However, people with hearing- and speech disabilities have not yet been addressed. Except for [39,49,25], all the selected papers only focused on one type of condition. Research restricted to the focus of only one condition of special needs may lead to the problem that a group of users with multiple special needs gets ignored.

5.3 Methods and Solutions

While types of different solutions have been proposed (see Tab. 4), only one study [47] provided a comparison of the BCI-based method and eye-tracking-based method, and two studies compared their proposed method to hand control as a baseline [43,57].

An overall consideration on the outcome of the research presented in this review would be if any of them have actually pointed to solutions that has has been or may soon be implemented for people with special needs. While there has been considerable research in the use of BCI and gaze interaction with wheelchairs and other vehicles [81], we are not aware of any of this having reached a solution that are robust enough to become a product on the market for assistive technology. This points to the need for more research in this area with more user-involvement and focus on the real-life challenges outside laboratories. The comparison study by [47] identified advantages and disadvantages of two methods (e.i. BCI and eye tracking) for immersive control of a humanoid robot with an HMD. Such comparisons is vital for future design and research, especially how to make it better and more accepted by users. Therefore, more comprehensive studies comparing methods are needed in future research.

Overall, the proposed methods have, to some degree, solved the problems presented by each special need, which are at least now not a total barrier preventing them from using telepresence robots. As mentioned previously, user conditions with multiple special needs have not been addressed. More solutions need to be explored for people with multiple special needs. The novel solutions presented in the selected papers were usually based on mapping body movements, or physiological signals to corresponding control inputs to the robotic system, or converting visual signals into tactile signals. However, many people with disabilities already have their own preferred assistive devices (e.g., eye trackers or speech recognition devices) that they use for other purposes. Future research could explore how to integrate existing assistive devices with telepresence robots seamlessly and easily. Moreover, multimodal interaction [82] may be explored by combining different input methods. It can enable users to interact with the system using different physiological signals and body movements more intuitively. This has been seen in the case of the combination of head movement detection for changing the field of view and eye-tracking for other interaction [59]. Moreover, it has the potential to make the existing methods better and more accepted by the users. For example, BCIs are more often used in comparison to other techniques for people with motor disabilities, which have been successful according to the results [47]. However, for our target users, BCIs have been unable to compete with simpler assistive technologies such as eye-tracking for typing tasks [83]. A combination of BCI and eye-tracking has been proposed [84]. Combined with motor imagery selection by BCI, gaze control could be improved by solving the existing problems of both methods, namely the Midas touch problem of eye-tracking [85]. This could be further explored in the area of telepresence robots for people with motor disabilities.

5.4 Devices

The high cost of products or technology is one of the barriers for people with disabilities worldwide to have access to assistive devices [23]. As telepresence robots for people with special needs can be considered assistive devices, the cost is an important issue to focus on. The costs of typical commercial robots used in the selected studies are relatively high. This is evident in the case of using VGo ($6,000) and Double ($2,499). A study estimated that the deployment of the home-to-school mobile robot telepresence solution was at a cost of $3,100 to $3,300 [62]. A few robots featured humanoid appearance, and the price was significantly higher. An example of this is an *Engineered Art's Robothespian* ($59,000) used by [47]. It is notable that inexpensive *Raspberry Pi* ($35 to $75) was widely used in experimental telerobots [55,52,59,57]. Cost of devices should be considered in future research and it is highly relevant to develop low-cost telerobots for people with special needs who cannot afford the high-end solutions offered today.

Beam Pro, *VGo* and *Padbot* do not allow for adjustment of the face display height. Possibility to adjust height is an important feature for our target users and their social connections [86] in order to communicate at the same eye level, and may be considered a fundamental requirement when designing telepresence robots with a concern for the dignity of the user. Moreover, the impact of robot height may be explored in field studies of how remote participants relate to the user of a telerobot.

Most of the robots in the selected papers featured wheels for driving. However, this may limit their mobility range to flat surfaces. Walking humanoid robots have been presented in a few studies [47]. Drone-like telepresence robots (or telepresence drones) have been explored for general usage [87] and they may be further explored for people with special needs.

Current solutions should be explored with state-of-the-art control devices in future research. For instance, the most widely used method BCIs utilized wet electrodes in their exploration [69, 46, 47], but these devices needed to be set in a laboratory and cannot be used in real-life situations. Existing real-time brain-sensing wearable devices could open doors for BCIs to move outside the lab. For instance, *NextMind*, which is available for the developers' community, has dry electrodes and a remote, Bluetooth connection. It has the potential to be used for the BCIs in telepresence robots.

5.5 Universal Access

Universal access [24] needs to be addressed in future research and the design of telepresence robots. It is important to explore how to combine telepresence robots easily with other assistive technologies, for instance gaze- or head- input. From a system development perspective, application programming interfaces (APIs) would be needed to provide this. One of the selected papers [37] presents a platform with an API manager included. Future work on APIs for telerobots may pave the way for an easy adaptation to different user needs. From a hardware perspective, possibilities of connecting the robots with existing assistive devices need to be considered in the design process. It should be possible for the target users to use their own input device when piloting telepresence robots.

5.6 Safety

Safety is crucial in human-robot interaction [88], and research of telepresence robots [2]. As stated in the introduction, generally, independent use of existing telepresence robots can be problematic for those with cognitive impairments [25]. Novel control methods addressing special needs have been proposed in 28 selected papers. For those of our target users with special needs who are also novices, it is particularly vital to consider safety issues. When a telepresence robot is being teleoperated, the safety of the local operator and the remote users needs to be considered, for instance, damages caused by control or display devices. How to safely operate the device without doing damage to other people or to the environment is important [31]. The most common accident cause is a collision in the remote environment [53, 69, 57]. Some of the telerobots weigh around 10kg (e.g., [37]), which can be dangerous in case of a collision with humans. It is still an open issue how a telepresence robot should balance between user's movement commands and safety in an environment crowded with people [42]. Also, damaging interiors in the remote environment can be costly.

A heuristic evaluation by [31] suggested that the base of the system should be stable, sturdy, and have some free distance from the floor. An unstable or lightweight base was difficult to drive over normal thresholds like a doorstep and when driving on slightly uneven surfaces, the lightweight robot wobbled and toppled over in some cases.

Obstacle detection and avoidance are important for safety reasons, and have been equipped in commercial telepresence robots for general usages (e.g., [9, 89]). These features may be essential for people with special needs, for instance people with cognitive disabilities. However, only a few studies mentioned this [25, 67, 37, 31, 45].

When navigating a telepresence robot, the definitions of an obstacle or a target are not absolute [68]. An object in the remote environment could be considered an obstacle to avoid, or it could be the target the user wants to get close to. How to provide the user the information from collision avoidance sensors efficiently needs to be studied as well. Too much information from the sensors can overwhelm the operator and be counterproductive [21].

Besides some automatic safety mechanisms used in telepresence robots for normal users [2], new safety mechanisms may be considered for people with special needs in the future, for instance, adaptable speed [53] and auto-stop in the case of loss of network coverage. In a home-setting, functionalities like stair detection should also considered in future research [31]. As safety has shown its importance in other applications of assistive technology for people with special needs, typical safety mechanisms like Dead-man's Switch [90] has become an essential feature to enhance the safety of wheelchairs for people with special needs [91]. It has been enhanced and become more intelligent [90]. Such a safety mechanism has been applied to the field of robots, and teleoperation [92, 93], and could be considered in future research of telepresence robots for people with special needs.

5.7 Simulated environments

The previous section has shown the importance of the safety issue, especially for people with special needs.

Traditional hand control methods in general telepresence robots do not require much training. In many cases, only a simple tutorial is needed, even for novice of telepresence robots. However, novel control methods for people with special needs usually require sufficient training, sometimes even long-term. Simulated environments can be applied in future research for economic and safety reasons. The potential of using such simulation environments for teleoperation training was demonstrated by [94, 95]. Simulated environment has been used in helping children with disabilities to learn how to use a powered wheelchair [96]. Moreover, these simulation environments can be used for user studies in assistive technologies [97].

There are particular challenges when conducting evaluation studies in VR wearing HMDs. Requiring participants to leave and re-enter the virtual environment displayed by the HMDs costs time and can cause disorientation [98]. Moreover, "break in presence" (BIP) problems [99] happen when users have to remove the HMDs and complete questionnaires. New solutions have been proposed addressing this problem. An example of this is the study carried out by [98], in which they enabled measurement of presence when users were wearing HMDs. The presence questionnaires (e.g., [100]) were presented in the virtual environment and the users could complete the questionnaires directly in the virtual environment. Another possibility is to measure situation awareness when users are driving with the VR headset on [101]. Measurement of important metrics (e.g., situation awareness, presence) with specific devices like HMDs need to be considered in future studies with the target users. These challenges should be considered, especially when the operators are people with special needs.

5.8 Privacy and Security

Privacy and security are essential issues in the deployment of telepresence robots in realistic scenarios [102, 7]. The privacy and security of both local users and remote users need to be taken into consideration. These issues become more complicated when people with special needs use telepresence robots. Some problems regarding these issues have been reported in the selected papers. Our target users typically have caregivers or families to assist with the robots, which can raise more privacy concerns from the remote side. They also need to fulfill all the requirements related to the remote site they are visiting, for instance, to follow the school guidelines for a parent volunteer in the classroom [7]. For example, the system provided the pilot user with a screenshot feature of the remote environments or participants, but no notification was given to the remote participants, nor possibility for them to turn-off this functionality [31]. In addition, some users with special needs are unable to deal with issues related to privacy and security setting independently. Privacy for homebound students was also mentioned by [7], where they recommended to place the operator's computer at a location that would not violate the household's privacy. In a similar case of hospitalized children using telepresence robots, it was suggested in [62] that the issue of privacy for personnel (both hospital and school) can be addressed through detailed disclosures, agreements, and autonomy of either participant to terminate an encounter.

Most of the commercial products ensure privacy and security by log-in passwords, encrypted links, and by preventing video or audio recording. However, the privacy of the local environment and remote environment can be potentially violated [7]. The commercial telepresence robots are usually off-the-shelf robots with connecting service provided by the company. Hence, privacy can never be totally guaranteed, and the systems may be hacked. These issues should be considered in future research, as the use cases of telpresence robots by people with special needs include private daily life and public places.

5.9 Independence and autonomy

Features of autonomy can assist a person with special needs in operating telepresence robots, as it can free the users from the details of robot navigation, and the user can then focus on activities in the remote environment (e.g., social interaction) and on the remote environment itself [25]. For example, *Double 3* supports semi-autonomous driving to a waypoint that the user just needs to select once.

Autonomous telepresence robots [103] have been explored for other users, and might be a viable solution for our target users. However, some people with disabilities prefer to keep as much control as possible [69]. Moreover, fully-autonomous systems may increase mental workload if users lack trust in the automated system, especially when the underlying mechanism of automation is not clear to them [104]. Some previous studies [68, 75] with our target users suggested that they do prefer to retain control authority. Therefore, a balance between independence and levels of autonomy should be further explored in future research.

At an operational level, some of the solutions that current research is focusing on do not support independent use at its present stage. BCI control, for instance, require users to put on an electrode cap, and ensure contact between the head and the electrodes. Hence, use of BCI devices are not yet possible outside the laboratory. Similarly, people with motor disabilities might not be able to put on a head-mounted display themselves, even though it provides an attractive complete field of view and built-in gaze tracking [43,57].

5.10 Evaluation

In future research, we suggest the following issues to be considered when conducting a thorough system evaluation:

5.10.1 Target users as participants

Our review found that only a limited number of the papers included target users in their evaluation. The challenges of recruiting people with special needs were the main reasons. Compared to studies with general users, more considerations for their participation are needed, such as their health conditions, opinions from caregivers in hospitals or care homes, and opinions from their guardians. This is evident in the case of a study [62], which can be considered as the best practice in terms of these issues. Moreover, another notable reason is that devices used are sometimes limited to the experimental environment, which requires the target users to be present in the laboratory. This is evident in the studies [69,46,47], where electrode caps were needed for BCIs. Compared with general users, users with special needs have more potential problems due to mobility problems. Despite these challenges, the importance of target users as participants need to be considered in future research. Even some case studies with target users can make the study result more persuasive. For instance, this is evident in a case study on BCIs for telepresence robots with one ALS patient [27]. The result was encouraging, as the feasibility of the technology helping the target users can be found. Such a system was slow and tiring to the regular users. However, the case study shows that the patient was engaged and motivated by the task. Moreover, good performance of a newly proposed solution for healthy participants does not necessarily mean good performance for people with disabilities, which is evident in the case of using BCI, for instance [105].

Besides supporting independent use for more independent life, another common goal of the selected paper was to improve the quality of life of the target users. Due to a lack of evaluation focusing on this part, it is still unclear how the research would reach these goals.

Researchers should be aware of some potential difficulties when recruiting target users for their studies. A notable example of these difficulties can be seen in a recruitment process [62], where 65 patients had been approached, but due to their status, considerations by their guardians, and technical problems in the hospital, only 1 patient was able to participate in the system evaluation.

5.10.2 Training

In contrast with traditional control methods of telepresence robots, novel control methods for people with special needs usually require sufficient training, as mentioned above. In future research, the learning effects from training when using newly introduced control methods need to be studied. It is notable that some of the evaluations showed that it was rather challenging for novices to use the new methods (e.g., [43,57]). However, among these studies, no training or tutorial sessions were included. The role of such training on the performance is still unclear, and the learning effects need to be explored. For instance, studies showed that adequate training of using gaze could improve operation skills of using gaze control [95]. A pre-trial session to provide adequate training for novices needs to be considered in future evaluation. This is also important for safety reasons as stated above, since the most common cause of accident is collision.

5.10.3 Adapting general metrics for HRI

General metrics (e.i. deviation from optimal path, collisions, situational awareness) for human-robot interaction (HRI) [106] have been proposed and adopted in evaluation within certain domains including telepresence robots in general usage [2]. However, these common metrics have not been applied in most of the selected studies with target users. The main advantage of using general metrics is that this allows for comparisons of findings across studies, and should therefore also be recommended in future research with our target users.

Existing studies lacked evaluation of communication quality. [2] has proposed some standard metrics that can also be adopted for evaluations of the quality of communication [2].

5.11 Ethics and study guidelines

Ethics and study guidelines for research with people with special has to be considered [107]. Participants with special needs should be informed about the details of the study. This was done in a study [63], which was carried out with written informed consent from all subjects in accordance with the *Declaration of Helsinki* [108]. When conducting a study with general users, only the participants should be informed. By contrast, contact with parents or guardians of people with special needs should also be considered. This is evident in the study [62] where one patient could not consent to participation because the parents or guardians were not available during the hospitalization. The process of recruiting the hospitalised children in this study [62] might be regarded as the best practice we have found in the selected papers. Their parents or guardians, teachers, and the school all had the right to be informed and to decide. The hospitalised children could not be recruited if one of them did not agree for any reason. Their reasons for rejection could be considerations of the conditions of the hospitalised children or any other technical/privacy issues, for instance of the school classrooms. Some children were not eligible to participate, for instance, those who had an Individualized Education Program (IEP)[62].

So when recruiting people with special needs, researchers should be aware of potential difficulties. In the case of [62], though the hospitalised patients agree to be participants, they were discharged soon, which led to inadequate time for implementation of telepresence robots in the classroom for the study. In total, 69 patients had been approached. However, after considerations by their guardians, due to their status, and technical problems at the hospital, only 1 patient was able to participate in the system evaluation.

5.12 Limitation

Overall, limitations of the reviewed papers have similarities with general accessibility research in the area of HCI. In general, accessibility research [74] found that only a few papers studied people with multiple disabilities (less than 1.0%). In addition,according to [74] a high percentage of user studies are conducted in laboratories and the number of target user participants is usually lower than within the broader field of HCI, where the median sample size are 15–16 participants [74].

Limitations of these selected papers commonly existed in the use cases, user conditions, methods, solutions, evaluation. In addition, issues such as safety, privacy, and security had not received sufficient attention in the selected papers. Thus, the recommendation for future research is to explore more that were not yet studied (e.g., new use cases) and consider more issues during the study (e.g., safety).

Moreover, the reviewed paper inevitably used numerous terms related to different types of people with special needs. It was found that certain words or phrases were not used appropriately, which might intentionally or unintentionally reflect bias or a negative, disparaging, or patronizing attitude toward people with disabilities, and in fact, any identifiable group of people [109]. We recommended that appropriate terminology should be used in the future writing about research on telepresence robots for people with special needs. For instance, *people/persons with disabilities* [109] and *older adults* [110] could be more empowering terms.

6 Conclusion

This systematic literature review intended to evaluate, synthesize, and present studies regarding different telepresence robots operated by people with special needs. The main contributions of the review are: (1) an overview of existing research on telepresence robots for people with special needs; (2) a summary of common research directions based on existing research; (3) a summary of issues which need to be considered in future research on telepresence robots for people with special needs.

From 2009 to 2019, there were 42 papers published on telepresence robots for people with special needs as operators. The special needs in the literature were disability-related (motor, visual, and cognitive) and aging-related (children and older adults). Alternative solutions have been proposed for people with disabilities (motor, visual, and cognitive). Use-cases in healthcare and education settings have been explored.

The currently developed telepresence robots are not accessible for all. There are still barriers for people with auditory or verbal disabilities, and for most people with multiple special needs. Almost half of the systems have been evaluated in lab experiments. Only a few had more than 5 target users. Most of the studies only focused on the local user, ignoring the remote persons.

Most of the papers pointed to the potential impact on the quality of life. However, due to the shortcomings of their evaluation methods, the actual impact is still unclear.

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