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Prospective applications of assistive robotics for the benefit of population groups

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ABSTRACT

The development of robotics has reached various fields of application such as the assistance field, where robots support people with different abilities in different activities to provide independence, comfort and interaction, even improving their self-esteem and quality of life. The objective is to identify the main benefits of the application of assistive robotics achieved to project its future fields of action. For this purpose, the Scopus database is used to find documents related to assistive robotics, which are filtered by publication date and according to the elimination criteria determined by the authors, and then bibliometric networks are constructed using VOSviewer. Finally, the main findings are analyzed and presented according to their area of application. Five areas of application of assistive robotics are identified that benefit children, the elderly, provide hospital assistance, help people with disabilities or support therapy and rehabilitation work, developments that allow the formulation of areas for future study. It is concluded that there are many advances in assistive robotics that demonstrate robotic development and provide assistance to a particular population, but more work is still needed to increase the number of beneficiaries, reduce costs and expand research in the areas mentioned and to be developed.

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1. INTRODUCTION

The use of automation and robotics technologies for the care and assistance of people has become a research topic with important contributions in the field of applied robotics [1], [2]. Research in assistive robotics has experienced increasing attention over the last decade, given its usefulness in the search for intelligent solutions for health and social care. Also to compensate for the labor shortage projected for 2030 by the World Health Organization (WHO); however, a challenge for effective assistive robots is to deal with a wide variety of situations and to contextualize their interactions according to the living environments and habits (or preferences) of the assisted persons [3].

In recent years, there have been considerable advances in medical health care, resulting in an increase in the elderly population [4]. This increase in the elderly and even disabled population has created the need for robotic assistive devices to counteract the lack of reliable servers [5]. It is projected that with the aging population and decreasing family support, new tools will be needed to ensure the well-being of the elderly. Many of them would prefer to live at home, but will need help and assistance from someone. Innovations in robotic systems can be used to enable independence, prolong the lives of older people in their familiar environments, maintain connections by reducing social isolation, and improve overall quality of life [6].

It is found to be crucial to increase the independence of people with severe motor or cognitive disabilities who have limitations [7]. The care of these patients results in a high economic burden for their families and society [8], considering their dependence on continuous human assistance [9]. Assistive and wearable system-based robotics help people with movement impairment and mild cognitive deficits to be independent and successfully perform their activities of daily living [10]–[14], a scenario where human manipulation of the environment is crucial for patients' independence, self-esteem and quality of life. Gradually, but with increasing presence, robotic assistive systems are becoming a core technology for the service sector, as they are able to help people in need of assistance in a wide variety of tasks [15].

The benefits of assistive robotics for society have motivated the study of several approaches, developing systems ranging from rigid robots to soft robots with single-modal and multimodal sensing, heuristics and machine learning methods, and from manual to autonomous control for upper and lower limb assistance [16]. There are basically two approaches to assist elderly and disabled people: one is based on mobile assistant robots; the other is based on fixed robots such as the use of an external robotic arm or a robotic exoskeleton attached to or mounted on a wheelchair [17]. Assistive robotic manipulators (ARMs) provide a potential solution to mitigate the difficulties associated with manipulation deficits in people with upper extremity disabilities [18], [19]. So assistive robotic manipulators are becoming increasingly important for people with disabilities [20] given their benefits, *e.g.*, robotic assistive arms allow people with upper limb disabilities to perform everyday tasks on their own [21].

Diseases related to upper limb mobility are increasingly common among today's population; for this reason, physical assistive robotic systems have been proposed to support therapeutic processes and improve the functional capabilities of individuals [22]. Social assistive robots have the potential to increase and improve therapist efficiency in repetitive tasks, such as cognitive therapies [23]. Social assistive robotics is widely used in healthcare to enhance conventional treatments and increase patient engagement [24].

Social assistive robotics (SAR) aims to design robots capable of ensuring social interaction to human users in a variety of assistance scenarios ranging, for example, from medication recall to monitoring daily life activity to giving advice to promote a healthy lifestyle to psychological follow-up [25]. Social assistive robotics (SAR) is receiving a lot of attention for its potential to assist elderly users [26]. Social robots are an interesting tool that allows enriching the range of psychosocial interventions that exist to support adults in their autonomy, adapting to situations that include individuals and difficulties in verbal communication; however, the solution to the implementation of these technological devices is necessary to identify the requirements required for their implementation and develop protocols for clinic preparation and use [27].

For this reason, the objective of this study is to identify the main benefits of the application of assistive robotics, in order to guide future research in this area. The methodology adopted to achieve this objective is presented below, as well as the population groups of greatest interest and the conclusions reached. This exploration allows for the projection of future research relevant to each interest group studied.

2. METHOD

The exploration and analysis of the state of the art in robotics is consulted in the literature published at Scopus database. This bibliographic database was selected because it is reliable, easy to use and provides universal bibliometric indicators. Using the search equation “assistive robotics” in the title, abstract and keywords, 1,677 scientific articles were found, showing a behavior with an almost exponential growth, so the topic is considered cutting-edge, and the research was delimited to know the advances in recent years (since 2021). Of these, the following were discarded: 7 conference reviews, 4 editorials, 1 editorial letter, 26 reviews, 1 book chapter, 11 articles that are in print, leaving only open access documents, which allowed an initial selection of 202 documents based on the title and abstract. To define the reported works to be included in the analysis, the following four initial elimination criteria were determined: i) be proposals that do not demonstrate robotic development, ii) analyses that do not aid a particular population, iii) be a presentation of an event or course, and iv) be a critical analysis.

Subsequently, the application areas of the selected documents are classified and those that correspond to the topics of control or application in industry are eliminated. Then, a general characterization of the documents chosen for study is made, where their bibliographic data are analyzed using VOSviewer software, which allows the construction of bibliometric networks. Finally, the main findings of the papers are presented according to their area of application, considering developments that benefit children, the elderly, provide hospital assistance, help people with disabilities or support therapy and rehabilitation work, which allows the identification of research needs in each of these areas.

3. RESULTS AND DISCUSSION

Using established elimination criteria, 85 papers were discarded: 38 papers for being proposals that do not demonstrate robotic development, 44 for being analyses that do not help a particular population, 2 presentations of an event or course, and 1 critical analysis. Subsequently, the documents are classified by areas of application and those whose areas correspond to control or industry are eliminated because they do not fulfill a social task. The summary of the process used to select papers to be included is shown in Figure 1.

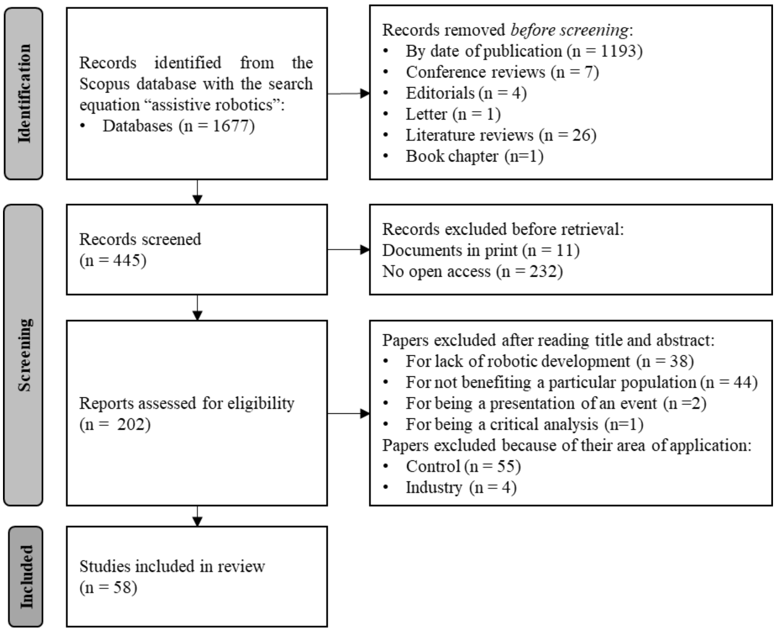
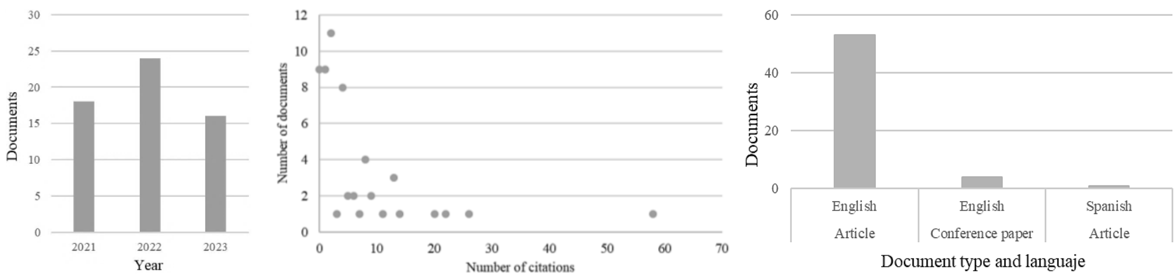


Figure 1. Selection process of the papers to be included in the systematic review of the literature
Source: Adapted from [28]

Once the documents have been defined, a general characterization of them is made. Figure 2(a) shows the distribution of documents with respect to the year of publication, highlighting 2022 as the year with the highest number of documents considered. The behavior of the number of citations per document is shown in Figure 2(b), which shows that 86% of the documents have less than 10 citations, and the document with the highest number of citations (58) corresponds to the development of a humanoid robot for children with autism [29], which is considered a reference in the subject. As shown in Figure 2(c), the documents included in this study may be articles or conference proceedings and their language of publication may be English or Spanish; most of them correspond to articles written in English.



(a) (b) (c)

Figure 2. General characterization of documents included: (a) distribution of documents with respect to the year of publication, (b) behavior of the number of citations per document, and (c) document type and language

The analysis of the bibliographic data of the selected documents using the VOSviewer software shows that there are no co-authorship connections between the selected documents. In contrast, with respect to the indexed keywords, it is observed that the five most used keywords are, in order: robotics, assistive robotics, human, social robot, human-robot interaction, co-occurrence network was elaborated using full count with the 20 words that appear at least 5 times, results are shared in Figure 3, where two clusters are identified, one in red around the concept of robotics and the other in green around the concept of assistive robotics.

Figure 4 shows that the largest number of applications corresponds to those specially designed to serve the disabled population, followed by those that benefit the elderly, then in equal proportion those that support children and provide therapies in rehabilitation processes, and to a lesser extent those that help at the hospital level. Figure 4 shows a detailed description of the topics covered by the application areas identified in the selected documents, followed by an extension of these results.

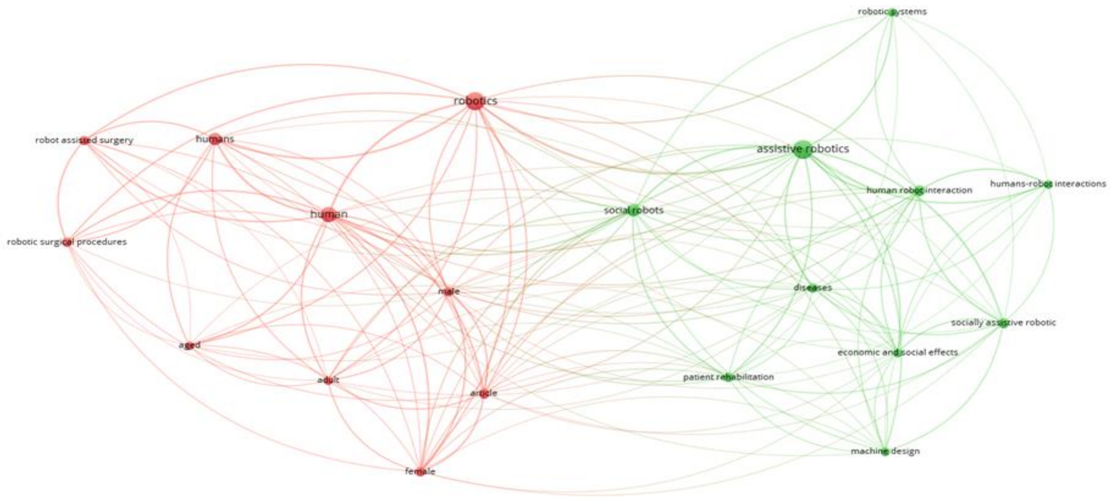


Figure 3. Cooccurrence network of indexed keywords

Figure 4. Distribution of topics in each established area of application

3.1. Disability

Developments that benefit people with some types of disability were classified into four categories, multiple disability, upper limb, lower limb and intellectual disability. For multiple disabilities, some of main developments are those presented in [30], where ROBINA, a semi-autonomous robotic system for increasing autonomy in the performance of various activities of daily living of patients with amyotrophic lateral sclerosis, is developed. In study [12], a robotic system controlled through the user's eye movements is presented that allows to actuate an arm and its fingers to reach, grasp and manipulate objects. In study [9], a robotic system for drinking beverages based on visual sensor fusion is presented, which allows a robotic arm to autonomously locate the user's mouth, bring a cup with a handle up to mouth and establish contact with lips, with option of cancellation and tracking. Study [31] using a semi-autonomous mobile robotic arm with brain-computer interface, there is a design that adapts to environment and receives cues from brain wave signals from user using an electroencephalogram (EEG) cap to pick up or drop an object selected by user. An interaction system to support disabled or bedridden patients is presented in [32] that allows the control of robots and assistive devices in a limited space in different ways: touch control, eye control, gesture control, voice control, and augmented reality control. There is also a modular mobile platform consisting of an upper limb robotic exoskeleton connected to a robotic wheelchair with customization option that allows mobilization and grasping of objects [18].

For people with upper extremity disability, a portable supernumerary robotic arm is developed in [33] to lift the arm that assists shoulder movement, the mechanism is powered by a pneumatic energy harvesting system that is taken from a user's foot strike while walking. In study [34], a portable soft robotic hand is presented that facilitates the opening and closing of the user's hand to grasp objects. A portable system called SoftPro exhibited in [7] combines different assistive technologies (sensors, haptics, orthotics, and robotics) to lift the forearm using a passive exoskeleton and to grasp objects with the affected hand using a portable robotic supernumerary finger. Another object manipulation assistance system is presented in [35] using a teleoperated robotic arm with joint torque requirements, work area constraints, and control tuning parameters. Thinking about people with lower extremity disabilities, several intelligent wheelchairs have been designed, some with complementary capabilities [36], another with a visual system for people with minor or significant visual impairments in one of the eyes that physically cannot control a traditional wheelchair, where intelligent vision is used to analyze the direction of the patient's gaze and head movements and works outdoors and indoors [37]. Also to facilitate mobility and grasping objects, a system including a robotic arm and a scooter for outdoor use is designed in [5], which uses a laser pointer to select an object and provides feedback to the user through an interface, which is better in execution time and success rate compared to what is reported in the literature and, in addition, with accuracy in selecting and locating objects on a table [38].

In the scenario of intellectual disability, a study was found of a program that seeks to replace caregivers over 55 years of age with assistive robots, which shows no increase in well-being, but allows a break for caregivers and boosts independence, safety and interaction of children with intellectual disability [39]. To help people with neurodevelopmental disorders, LOLA2, a robotic platform based on artificial intelligence to reinforce the learning of activities of daily living with a user interface for patients and health professionals with a joystick and a graphic display that allows therapists to monitor users, is validated from the technical point of view [40]. Progress is needed in constant and precise monitoring of robots with movements to ensure safe interaction between humans and robots, as well as technology with a lower level of complexity that can be installed quickly and with intuitive and user-friendly operation, giving preference to non-invasive systems and allowing recovery of capacity and autonomy of disabled patients or those with reduced motor functions.

3.2. Older adults

The developments that benefit older adults are grouped into five themes: mobility, activities of daily living, home care, social interaction, and older adults with Parkinson's disease. In mobility issues, there is outstanding research such as that presented in [41], oriented to exercise for the hip with a portable assistance robot (EX1), which improved physical function and walking efficiency in older adults, its application is effective in supporting the decline in age-related mobility, physical function and cardiopulmonary metabolic efficiency. In [42], robotic surface balance training without body weight support is worked out, which improves balance and confidence in older adults, these parameters were assessed using the balance error scoring system (BESS) and activity-specific balance confidence scale (ABC). Additionally, an intelligent robotic walker (i-Walk), which provides cognitive and mobility assistance to elderly people or people with mild to moderate mobility disabilities, was found and its utility, usability, safety and technical performance were measured [13].

In [6], a low-cost mobile robot system is proposed to support elderly caregivers in the execution of daily activities. In [43], heterogeneous multi-robot system, for use in automated home environments, is designed to propose emotional coaching activities in order to help elderly people in their daily life. By the same way, also the RobWell system presented in [44], interacts with the user and focuses on mood prediction and coaching, using artificial intelligence specifically machine learning. For home care, Cantone *et al.* [45] suggests a system composed of a stationary humanoid robot, elderly people, medical staff and caregivers, oriented to the permanent monitoring of the physical and emotional well-being of the elderly in their homes, where a machine learning model is used to predict the state of health. In [46], Marvin is presented, it is a robotic assistance platform that allows monitoring elderly people or people with reduced mobility, with remote connectivity and assistance at night, which uses a lightweight deep learning solution for visual perception and voice control that runs on the robot hardware. In [26], a social robotic system for performing home care assistance tasks for patients with mild cognitive impairment in a personalized and adaptive manner using a service-oriented approach, taking into account both user characteristics and dynamic environmental conditions, is presented.

To stimulate robot-mediated social interaction among older adults by automatically measuring social and activity participation from various sensory modalities, Ro-Tri [47] and SAR-Connect [48] are designed. Thinking about people with Parkinson's disease, a robotic social assistance platform is created with two custom-made mobile desktop robots that engage users in cognitive and motor tasks simultaneously [49]. It is possible to generate innovative robotic assistants that allow elderly people to be autonomous, at least inside their homes. The use of these assistants can improve the quality of life and give peace of mind to the relatives of each elderly person, thanks to the permanent monitoring for the collective welfare, seeking to improve semantic navigation with artificial intelligence and computer vision.

3.3. Children

Developments that benefit child population are grouped around four themes: children with autism, hearing impairment, cerebral palsy and speech difficulties. Since the late 1990s, use of robotic technology to help children with autism spectrum disorder (ASD) has been studied [29]. For children with ASD in [50] combined humanoid robots with a mobile application to enhance their educational experiences. Also in [51] they developed a software platform and mobile application to support introduction of robots in autism-specific classrooms. In [52], impacts of appearance of a social assistive robot are evaluated finding that humanoids achieve higher attention span of children with ASD and recognize simple emotions, such as happiness and sadness. Robotic tutors for long-term (multi-session) therapeutic interactions were designed in [53]. An autonomous mobile social assistance robot for autism spectrum disorder with facial expression and emotion recognition algorithms is created in [54]. It has been evidenced that the use of a small humanoid robot to support therapy for children with ASD and intellectual disability, where child imitates the robot, achieves an increase in gross motor imitation skills [55]. In this setting a humanoid robot is a multidisciplinary challenge [29], however, there are findings that suggest that children with ASD may benefit from this robot-assisted therapy approach.

Thinking about children with speech difficulties, the effectiveness of a cyber-physical robotic system to help speech therapists (speech therapists and/or speech therapists) was reported and measured in [56], finding a therapeutic effectiveness with speech improvements of up to 11.3%, when the technology is used without time constraints. Also in [57], by means of a social robotic system for rehabilitation of pediatric patients with cerebral palsy, it is proposed to reinforce patient motivation and dynamism of therapies, and in turn automate feedback to the patient. The study in [58] presents an assistive robotic system with emotion recognition capabilities for hearing impaired children. It is developed for audiometry testing and rehabilitation of children in a clinical setting, using machine learning techniques and deep learning models for classification of test configurations and for classification of emotions (pleasant, neutral, unpleasant) of children, using physiological signals recorded using a wristband.

It is concluded that progress has been made in the potential of robots and AI in general to support children, where social assistive robotics (SAR) in particular has made inroads into the emerging fields of robotic application. SAR systems are geared to address the needs of children with atypical cognitive-affective and socioemotional needs, supporting learning, therapy, social interaction, and early diagnosis. The need for future research is identified in the development of personalized autonomous SAR systems with emotion recognition tailored to those who prefer object-based interactions over human interaction.

3.4. Therapy and rehabilitation

For therapy and rehabilitation purposes, the developments identified in the literature clustered around six options: lower extremities, stroke, cognitive therapy, cardiac therapy, upper extremities, and obesity. With lower extremity rehabilitation in mind, study [59] presents a soft robotic ankle-foot orthosis designed to support the ankle when the user is standing or walking, offering multiple degrees of freedom, by means of two pneumatically actuated soft actuators. A rehabilitation robot with the required degrees of freedom whose axes of motion were determined from the kinematics of the knees, ankles, and feet can be used as a rehabilitation robot [60]. Seeking that patients with significant difficulties in their trunk and lower extremities achieve the rehabilitation of their balance while standing in [61], a vertical robotic trainer was designed that generates movements in the trunk and provides assistance in the pelvis. For the neural rehabilitation of gait, social interaction between humans and robots that monitor the evolution at the physiological level and promote social interaction with distance during therapy sessions has been proposed [62].

In post-stroke rehabilitation it is possible to use robotic rehabilitation systems for individual training, such as the one designed by [63] that allows giving important real-time information about and to patients. Also by means of wearable assistive technology it is possible to use an external headset together with a robotic arm for rehabilitation tasks, in [64], it is applied for neurologically disabled patients. In [23], a robot is implemented using the therapist's experience adding to the data it collects to achieve rapid autonomous learning in situ, of the policies of each patient requiring cognitive therapy. In [65], a TIAGo robot was programmed with back-channeling behavior generated by interpreting both verbal and nonverbal cues from people with dementia when they perform cognitive training exercises. Using the social robot presented in [66], the aim is to motivate the patient requiring cardiac rehabilitation to follow the medical indications that will allow a prompt and full recovery. For rehabilitation of elbow tendinopathies, a robotic assistance system with 7 degrees of freedom is presented, which adapts to the measurements of each user and can be used in both arms [22]. Similarly, use of educational social robots can be used in the therapeutic setting to help patients improve their lifestyle and acquire skills for the management of obesity by assisting the therapist [67].

In addition to the above, there is a clear possibility of using rehabilitation robots that autonomously collect and analyze the information obtained during the rehabilitation of each patient for a continuous evaluation that can be used both at home and in hospitals; the use of algorithms such as Bayesian classifiers would allow the robot to condition itself according to the experiences with each patient to generate therapy recommendations. At the same time, the design of robots, focused on rehabilitation stakeholders, facilitates work focused on artificial intelligence-based development to streamline machine learning processes using human experience and human-robot interaction, which could eliminate the requirement to design complex reward functions and avoid unwanted or planned outputs.

3.5. Hospital care

In the review conducted, it was found that developments focused on supporting hospital tasks are in turn categorized into three categories according to assistance beneficiary, which can be nurses, doctors or visitors. To support nurses, study [2] designs a mobile robotic assistant that includes a customized omnidirectional platform, a robotic arm, vital sign sensors, and a tablet to interact with each patient. In [68], an app with an autonomous service robot is used to reduce distances traveled and service activities performed by nurses. In [69] a multitasking intelligent robotic assistant consisting of a manipulator arm on an omnidirectional mobile base assists nurses with routine tasks of searching and retrieving objects. Finally, it is possible to implement basic nursing tasks (taking objects, measuring temperature, and providing patient support) for hospitalized people by means of an assistive robot connected with a tablet containing the interface, as shown in [70].

For medical support in surgeries, hinotori™ surgical robotic system was found to perform minimally invasive surgeries [71]; also a robotic surgical instrumentation based on real-time 3D gaze tracking that allows hands-free human-robot interaction [72]. On the other hand, when a physician must care for several patients, a robotic system, with integration of AI-based functions, is used to assess and manage patients and adapt robot behaviors to the specific needs and interaction capabilities of patients [3]. To reduce the risk of visitor infection in high-risk environments, a social robot that performs logistics, surveillance, entertainment, and remote visiting activities was tested in [73] to alleviate the feeling of isolation and a voice-controlled self-disinfecting robot that enables the delivery of items from a visitor to a resident in a care facility is presented in [74].

Assistive robotics in hospital care has potential to improve the safety and well-being of people in healthcare settings, both doctors, nurses and patients and their families. It has the potential to reduce the physical/mental burden on doctors and nurses, ensuring constant and continuous care. For long-term use in both hospital and home environments, new technologies with high comfort, biocompatibility and operability at different levels of both software and hardware are still needed [75].

4. CONCLUSION

Assistive robotics can improve the quality of life of both healthy people and people with disabilities, as well as under any type of health condition that requires therapy, rehabilitation or isolation stages. It is concluded that there are many advances in assistive robotics that demonstrate progressive robotic development and still in development, which and provide assistance to different population groups in different measures, but even more work is required to achieve that the number of beneficiaries is greater, so it remains as a line of future research. Assistive robotics is an emerging technology with great potential for future development to fill the existing gaps, complementing the advances studied and development based on the integration of artificial intelligence that gives a greater degree of autonomy and interaction to the robot with its users in the different stages of the assistance process. The projections of aging of the population added to the reduction of trained personnel in health sector, constitute a favorable scenario for the strengthening of assistive robotics in the areas referred to and to be entered.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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