Recent trends for practical rehabilitation robotics, current challenges and the future
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This paper presents and studies various selected literature primarily from conference proceedings, journals and clinical tests of the robotic, mechatronics, neurology and biomedical engineering of rehabilitation robotic systems. The present paper focuses of three main categories: types of rehabilitation robots, key technologies with current issues and future challenges. Literature on fundamental research with some examples from commercialized robots and new robot development projects related to rehabilitation are introduced. Most of the commercialized robots presented in this paper are well known especially to robotics engineers and scholars in the robotic field, but are less known to humanities scholars. The field of rehabilitation robot research is expanding; in light of this, some of the current issues and future challenges in rehabilitation robot engineering are recalled, examined and clarified with future directions. This paper is concluded with some recommendations with respect to rehabilitation robots. International Journal of Rehabilitation Research 00:000–000 © 2013 Wolters Kluwer Health Lippincott Williams & Wilkins.

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Introduction

Robotics is a division of technology that comprises and involves the design, operation and applications with computer systems, electronics and software programming for their information and signal processing, control and measurement feedback. Technologies in robotics deal with automated and programmed machines that may replace a human’s functions in many situations such as hazardous manufacturing processes, healthcare, military or simply doing human tasks. Looking back at the history, this technology has been often seen to mimic human behaviours and frequently used to perform tasks in a typical manner (Fong et al., 2003). The recent trend in robotics is to design and develop an intelligent generation of robots that are competent and capable of moving, acting, helping and interacting in human-centred environments and participating in daily activities serving various practical purposes. There are many types of robotics such as industrial robots, medical robots, agricultural robot, military robots, etc. One of the ongoing highly interactive topics among researchers and industry is rehabilitation robotics, which can be divided into two main groups: therapeutic or therapy robots and assistive robots. A therapy robot is used during a rehabilitation programme for a certain period to improve certain functions through the application of robotic devices aimed at increasing and expanding an individual’s ability by enabling him or her to regain the capability of movement. These robots are part of human–robot interactions that are often considered robotic therapy aids to assist handicapped patients with a manipulative disability instead of solely as assistive devices (Harwin et al., 1995; Burgar et al., 2000; Eriksson et al., 2005). In contrast, an assistive robot is used mainly in the patient’s home for a longer time to support their everyday life. Assistive robotics is designed to improve the quality of life of individuals with severe or degenerative disabilities, motor or cognitive limitations, such as the severely disabled and elderly, or to substitute a lost function (Saito et al., 2003; Wada et al., 2003b). The important goals in the rehabilitation robots field are to develop executable and implementable technologies that can be simply used and managed by patients, engineers, therapists and clinicians, hence increasing the case of activities in the daily lives of patients with motor impairments by improving the efficacy and performance of clinician’s therapies. Figure 1 shows the classification of a rehabilitation robots system; the study of robot systems other than rehabilitation robots is beyond the scope of this paper. The inclusion of all types of rehabilitation robots in one paper is impossible; thus, only examples of various rehabilitation robots are presented. Therefore, in particular, the main objective of this paper is to present an overview of the trends of rehabilitation as a therapy and assistive robotics for human use with current issues and some future research challenges. The main contributions of this paper are (i) the current issues and key technologies most reflected and affected in rehabilitation robots and (ii) directions and future challenges for individuals using rehabilitation robots, with recommendations and related suggestions. The rest of the paper is structured as follows: the second section elaborates the literature on...
current rehabilitation robot systems towards its application to therapy and social robots. The third section is focused on key technologies and some current issues of rehabilitation robots. Finally, conclusions with some open challenges and recommendations for future research direction in the field of rehabilitation robot systems are discussed in the fourth section.

**Rehabilitation robot systems**

In 2008, there were almost two million individuals in the USA living with limb loss. Among these, there were almost 507 amputations daily and over 60% of these were preventable. It is estimated that the number of individuals living with limb loss will almost double to 3.6 million by the year 2050 (Ziegler-Graham et al., 2008). Considering these numbers, rehabilitation robotics should be used in therapeutic and rehabilitative procedures to achieve the best and better motor or cognitive functional recovery in daily life for disabled individuals with various diseases such as stroke, brain trauma and neuromotor disorders (Prange et al., 2012). Thus, improvements in rehabilitation technologies are not only necessary but are also urgent and important. As mentioned in the introduction, rehabilitation robots are mostly used in robot therapies; therefore, here, we consider rehabilitation robots as therapy robots for mental and physical aids instead of assistive devices only.

**Therapy robots**

Rehabilitation robotics is closely related to physical and developmental therapy focusing on three main areas: neurological, which aims to help those born with little or nonexistent neurological control by fostering or restoring muscle control; cardiopulmonary, for the treatment of breathing problems and rehabilitation of individuals who have undergone cardiac trauma; and the musculoskeletal field, which enables individuals to restore functionality in the muscle group and skeleton by improving coordination and strength (Buerger et al., 2004).

**Emotional and developmental therapy**

Robot therapy has been shown to be beneficial to children and elderly individuals with a wide range of social, emotional and developmental disorders by creating a social engagement, promoting emotional response and motivating positive behaviour change, especially in children with autism spectrum disorders (ASD) (Grynszpan et al., 2005). Children with autism typically respond better and are drawn to computers and robots because of the predictable behaviour and reduced amount of external stimuli. It has been noted that identification of children with ASD in their early stages and treating them with social behaviour and emotional building experiences may improve their lives by reducing the severity of their illness (Duquette et al., 2006; Lathan et al., 2007; Feil-Seifer and Maja, 2008). These robots mostly simulate a pet or a toy, and their main function is to increase user interaction, in a more or less intelligent manner, to enhance health and psychological well-being by providing companionship. Some examples of the most interesting companion robot therapies and pictures of the robots are given.

(1) **Paro** (Fig. 2) is a soft seal robot, an advanced interactive robot that has been developed by AIST, which is in use in Japan and throughout Europe since 2003 (Wada et al., 2003a). The Paro robot allows animal assistive therapy to be administered to patients. It is essentially targeted at the elderly in different
environments and situations where live animals might pose treatment difficulties. *Paro* is not mobile, but it can be taught to act in a way that the user desires and stimulates interaction between patients and caregivers by responding to it. From interaction with humans, *Paro* responds by producing sounds, moving its head and legs and shows patient-favoured behaviour, thus giving the impression of a live animal. *Paro* has been proven to reduce stress or mental fatigue for patients, nurses and caregivers, improves the socialization of patients with each other, increases their relaxation and motivation and enhances health and psychological well-being of the patients (Wada and Shibata, 2007; Shibata et al., 2009).

(2) *Keepon* (Fig. 3) is a small yellow robot designed to study social development. It has two cameras in each eye, a microphone in its nose and four motors at the base with a rubber skin. This robot is not just a toy; *Keepon* is being used to help therapists engage and interact with children as a tool to express attentive, intentional and emotional behaviours (Kozima et al., 2004). Kozima and Nakagawa (2006) and Kozima and Nakagawa (2007) reported, by working with *Keepon* during the therapy sessions, that children who are overwhelmed with the complexity of human social expression such as those with ASD show better improvements in desired behaviours and interactions.

(3) *Popchilla* (Fig. 4) is a small robot stuffed animal able to express emotions through ear, eye and face movements and colour. Equipped with a movable mouth and paws, *Popchilla* has been used as an intermediary to facilitate and increase communication and understanding of the child’s internal feelings and communication skills, thus reducing behavioural frustrations (Smith, 2010). Currently, this fluffy robot is being used in research along with an iPad application to allow the child to identify *Popchilla*’s emotions themselves, to improve responses to social cues in children and aid in emotional identification that reduces long-term negative behavioural ramifications (Yakov and David, 2012).
(4) **Nao** (Fig. 5) robot is an interactive humanoid robot capable of interacting and understanding when used by children with Asperger syndrome and ASD associated with learning problems and also those who have difficulty in expressing and reflecting emotions. Use of the Nao robot led to an improvement in brain functions, stimulated emotional responses and improved interactions with other individuals (Toczauer, 2010). As is known, the most important part of social interaction is the need to understand what is being said and to be understood. Shamsuddin et al. (2012), using cameras that are capable of sensing human face and body gestures for gestures and behavior-based communication that are normally difficult for children, show that Nao robots can support and assist therapists and help children to understand the interaction. For more information on the experimental case study for senior citizens, see Elena et al. (2012).

The advantages of these robots are not only the interaction and company they provide to the children and elderly but also the fact that they promote rehabilitation, therapy and development of physical well-being. These robots can react in a more or less complex manner in terms of sound and movements such as touching, caressing and talking; indeed, the user may feel that the robots can understand what the user says or does.

**Physical therapy**

Rehabilitation robots have been used in physical therapy for upper and lower extremities including semiautonomous prostheses for quiet some time. As opposed to emotional therapy robots, physical therapy robots are not designed to be perceived as a social entity, although they usually have the shape of an end effector, arm, leg or autonomous wheelchair. The first rehabilitation robots were developed for upper limbs during the 1990s, followed by supporting devices for lower limbs and the entire body (Tápus et al., 2008; Wei et al., 2011). In general, they provide some form of physical support and mobility in case the affected limb is no longer functional or it has been amputated, and also in rehabilitation exercises when the limb is still functional but with limitation such as in a stroke patient. Here, we divided physical therapy into three main categories: upper body extremities, lower body extremities and full body extremities, with some examples of robots therapy for each category.

*Assistive devices for upper extremities:* Rehabilitation robots for upper limbs usually consist of arms with various degrees of freedom, where the position of the end effector is often
represented graphically on a computer screen, whose endpoint is held by the patient’s arm or hand (Bogue, 2009; Péter et al., 2011). The target users are individuals who have had brain stroke and other neurological events, but not limited to the elderly, who usually suffer from lack of mobility because of age. Detailed information on current hand exoskeleton technologies for rehabilitation robots can be found in Pilwon et al. (2012). A few examples and their pictures are given below.

(1) MIT’s most recent robotic therapy called MIT-Manus (Fig. 6) provides high-intensity interactive physical therapy especially for stroke and spinal cord patients by improving movement of the shoulder, wrist and elbow on the affected side. The MIT-Manus robot can detect even the slightest amounts of patient

![Fig. 7](image1.png)

**Fig. 7**

ARMit/Armin II.

![Fig. 8](image2.png)

**Fig. 8**

HWARD/HOWARD.

![Fig. 9](image3.png)

**Fig. 9**

Disgust Neutral Sadness Face.
movement as much as they can on their own, and it seems to help stroke patients regain some use of their arms even if the stroke had occurred years earlier (Krebs et al., 2004; Charles et al., 2005). For clinical test and results, see Albert et al. (2010).

(2) ARMin/Armin II (Fig. 7) is a highly responsive robot with a semi-exoskeleton or a full-exoskeleton structure with two passive and four active degrees of freedom, equipped with force and position sensors that allow naturalistic arm movement and shoulder translations to prevent joint degeneration and preserve joint mobility. The robot is equipped with an audio–visual display that detects movement and motivates the patient with simple games. It has been shown that with intensive and repetitive training combined with patient-compliant therapy, motor functions of the paretic arm in chronic patients can improve significantly even years after stroke, thus increasing the patient’s motivation and activity (Nef et al., 2006; Patricia et al., 2009). For clinical studies, see Robertson et al. (2010).

(3) HWARD/HOWARD (Fig. 8), a Hand-Wrist Assisting Robotic Device, is a robotic therapy device that may help individuals regain normal strength, brain relearn and use of affected hands long after a stroke. With the use of HWARD in therapy sessions, stroke patients’ brains with impaired hand use were reported to be rewired; also, an improved ability to grasp and release objects has been observed, enabling weak limbs to move better (Takahashi et al., 2008). The HWARD prosthesis that has an inbuilt algorithm, patients with minimal strength and reduced hand function were able to initiate hand movement because of support from the prosthesis. The HWARD prosthesis can also support patients with a paralyzed hand, with excellent, significant, or moderate results (Damme, 2010).

(4) Face robot (Fig. 9), developed by the University of Pisa, is designed to display and express life-like human emotions to help autistic or nonautistic children improve their communication skills. It has more than 30 motors and a sensorized skin to acquire tactile information and cameras to identify the different emotional expressions ranging from happiness to sadness of the user. The Face robot can reproduce emotions and can be used for other neurological disorders (Pioggia et al., 2008).
There is evidence that with task-oriented exercises, in patients with paralysis of the upper extremities because of lesions in the central nervous system, arm movements can be enhanced and improved by intensive and repetitive training (Robertson et al., 2010). Currently, they are mostly used in hospitals because of their high cost and required infrastructure, but recently, they have been made portable so that they can be used at home (Ricks and Colton, 2010).

**Assistive devices for lower extremities:** Rehabilitation therapies are crucial and decisive to regain functioning; in the case of stroke, one of three patients surviving do not recover independent walking ability and those who can move have an asymmetric gait (Lloyd-Jones et al., 2010; Shuai et al., 2012). There are many ongoing studies in this field and this section discusses selected examples of commercial studies and ongoing research on lower-limb rehabilitation. For more detailed information on a literature review for lower limb rehabilitation robotics, see Inaki et al. (2011).

(1) **LOPES,** Lower-extremity Powered ExoSkeleton (Fig. 10), is a treadmill-based lower limb therapeutic robot for gait training and assessment of motor function; it can perform and support walking in humans by robotic legs, aiming to improve the motion and activity of stroke patients and those with impaired motor control (Veneman et al., 2007). **LOPES** aims to train and enable the patient’s body and mind to recover naturally. For a preferred leg and element, **LOPES** is smart enough to offer directed support, at the same time identifying the suitable and correct realignment if the patient is doing it wrongly. Moreover, **LOPES** is still being tested on spinal cord injury patients who have regained some movement and activity in their legs (Veneman et al., 2007). For experimental results of clinical tests, see Ronsse et al. (2011).
Lokomat (Fig. 11) is a robot-assisted walking therapy that has a body weight support system with a treadmill machine and robotic legs that helps a patient improve his/her ability to gain a natural walking pattern after disability caused by stroke, brain and spinal cord injuries. The Lokomat with repetitive walking may help improve circulation and strengthen bones and muscles and aid natural movement patterns (Wellner et al., 2007). The patient is suspended in a harness over the treadmill and the outside of the robotic legs are attached to the patient’s own legs with straps controlled by a computer and can be monitored by the physical therapists. For experimental results of about 80 patients in clinical trials on the use of Lokomat, see Alcobendas-Maestro et al. (2012).

ReWalk (Fig. 12) from Argo Medical Technologies is a robot based on a patient’s walking movements on the ground for gait training with a wearable brace support suit and backpack rechargeable batteries that integrate actuation motors at the joints, an array of motion sensors and an electronic and computer system with safety control and algorithms. ReWalk allows and helps a patient move as the centre of gravity shifts by their own control; this enables individuals with lower limb disabilities to perform routine ambulatory functions such as standing, walking and even climbing stairs (Neuhaus et al., 2011).

GM5 (Fig. 13), the GaitMaster5 developed recently by University of Tsukuba, is a gait rehabilitation system based on programmable foot plates. It can essentially help address the major shortage of physical therapists as the Japanese population ages. The patient straps his/her feet into pads that are connected to motion platforms lined with sensors that allow simulation of stair ascent and descent. GM5 has the advantage of never tiring, which means that it can put a patient through paces repeatedly (Yano et al., 2010).

Assistive devices for full body extremities: To the author’s knowledge, currently, only the HAL (Hybrid Assistive Leg) robot has been developed and used for full body exoskeletons.

HAL (Fig. 14), a hybrid system, has a power assistive suit that has been developed by the team at the University of Tsukuba for a wide range of applications since 2002 (Kawamoto and Sanka, 2002). This exoskeleton suit provides a self-walking aid for individuals with gait disorders or elderly individuals, and can be used for movement augmentation and rehabilitative purposes. DC motors have a harmonic drive at the joints that is used to supplement joint torques necessary for flexion and extension at the hip, knee and ankle. The current version
5 uses skin-surface electromyography electrodes attached under the hip and over the knee on both the front and the back sides of the wearer’s body, and been tested for clinical purposes (Suzuki et al., 2005). The latest version could be used by workers at nuclear plant disaster sites, which are still dangerous to humans; the latest prototype developed is brain controlled but has also evolved to a full body robot suit that protects against heavy radiation without feeling the weight of the suit (Yoo et al., 2010).

Socially assistive robotics
Socially assistive robotics (SARs) in rehabilitation fields, focusing on rehabilitation by social interaction rather than through physical interaction among the human and the robot, have become a prominent and substantial focus of robotics research nowadays. SARs have the capability and potential to improve the quality of life for large user populations, individuals with cognitive disabilities, social and developmental disorders such as Alzheimer’s disease and children with autism disorders, individuals with physical impairments such as stroke and limb loss and individuals receiving rehabilitation therapy including the elderly. A paper on the human-like socially assistive robot for elderly individuals can be found (Derek and Goldie, 2013). Therefore, with human-oriented interaction skills, one of the main goals of SARs is to create close, effective and engaging interactions for the purpose of providing assistance and achieving measurable progress in convalescence, rehabilitation and therapy (Feil-Seifer and Maja, 2005; Heerink et al., 2006; Dollar and Herr, 2008; Heerink et al., 2010).

Key technologies and current issues
A rehabilitation robot is based on several key technologies. The main characteristic of these robots is that they are usually navigated in places where there is human presence. Here, some key technologies and current issues related to rehabilitation robots are discussed.

Safety
Robots are essentially dangerous and rehabilitation robots are mainly a mechanical structure-based device especially for physical rehabilitation that is designed to share a common space and proximity to people; thus, proximity accidents can occur. At present, a rehabilitation robot usually navigates across a cluttered room, with movement of various limbs; hence, rehabilitation robots need to be designed with utmost safety considerations. Therefore, to avoid and reduce the chance of injury and impairment to the human user, recent rehabilitation robots have been designed to perform at very low power, to be lightweight and be safely manipulated to mainly move at a very slow pace and light goods; thus, the performances of the robots have become very slow and are limited to the task at hand (Kikuuwe et al., 2008). Rehabilitation robots are equipped with several sensors, real-time processing and advanced user interfaces that can develop capacities of self-learning, react to undefined environments or users, and unexpected input signals; thus, their behaviour can change over time and they may perform differently depending on the circumstances and how they have learnt to overcome past situations. To avoid system failure, as a built-in system, backup systems and error recovery functionalities are added. Unfortunately, this does not represent a 100% guarantee for human user safety (Bemelmans et al., 2012). Therefore, fundamental technology to minimize the risks should be clearly understood and clarified.

User interfaces
As rehabilitation robots are used by individuals lacking specialist skill with disabilities, they should be very simple to interact with. Current trends focus on the capacity of the robot to learn, detect and recognize a new object and, among the latest developments, is the recognition of not only human faces and voices but also emotions expressed, body postures, movements of individuals, visual interaction and interfaces using sensors that measure tactile responses and force (Tsui et al., 2008). For acceptance of rehabilitation robots, a good user-friendly interface is highly preferred and desirable, commonly for multipurpose robots. Hence, appropriate attention must be paid to the particular needs of physical disability. However, in the rehabilitation field, results have shown that many of the robots were still in the human-centred or human-friendly interface (Roberta et al., 2006). Age-related disabilities and illnesses such as brain stroke and arthritis may affect user interaction with robots, for instance, response speed, colour vision, hearing auditory sensitivity, hands or fingers movement control, changes in posture and balance. Other aspects that should be taken into account when designing rehabilitation robots are that the robots should have a working memory and long-term storage, attention, word finding and repetitions language. Currently, an interface complies with the various needs of the each user through a random trial and error process (Iida et al., 2009). Therefore, a systematic and efficient adaptation using an artificial intelligence technique, design and usability should be developed, utilized and improved in the future.

Cost and maintenance
The value of the robots will depend considerably on its cost because this has an effect on how widespread an audience these robots can potentially reach. This category will help identify whether the robots can only be used by large rehabilitation centres or by ordinary people. Cost can be the deciding factor for many individuals depending on the service provider because how much the primary care provider makes in a year will determine how much aid the patient will receive from their healthcare service (Hakkaart-Van et al., 2010). The most important category is the results, which include how the robot helps improve the patients’ quality of life. This
category will investigate the level of training necessary for the proper use of a robot. The use of some robots requires trained personnel that not only add to the cost but also limit the accessibility of the robot, whereas the use of some robots requires none or very little training that the user can learn on their own. This category examines these issues as initial/ownership cost can affect several other categories such as accessibility, repair costs, power issues, usable outdoors, calibration, etc. Users will not want to use anything prone to malfunctioning all the time and may require constant maintenance, thus increasing the initial cost. Some patients expect to be able to use their robot during normal daily life activities; thus, weather and power issues also come into play (Schoone et al., 2011).

Ethical aspects
As discussed in the Rehabilitation Robot System section, rehabilitation robots as a therapy modality are intimately involved with a patient's day-to-day life, although the designed robot may not perform as humans do. Generally, initially, robots operatively may behave and interact with the user on the basis of the environment, situation and user characteristics that are not really familiar (Arkin, 2008). This unfamiliarity experienced by the patient may lead to an ethical and social issue of focus, review and analysis of the human and robot interaction and relationship, not only become influenced by commonly accustomed human ethics, but also including the robot action and their interaction, integrated in its artificial way of behaviour, and well-established ethical principles. In the case of rehabilitation robots used for support of the elderly, additional ethical aspects should be determined and analysed because of the particular physical and mental levels of this age group of individuals (Ingram et al., 2010). As a robot is a composite of advanced techniques, especially in the case of rehabilitation robots, there is a need to clarify the ethical or legal issues that become relevant to the implementation of these technologies in robotics (Sharkey and Sharkey, 2012).

Conclusion
Future challenges
There are many substantial challenges for future rehabilitation robots and, among these, the most crucial lies in controller design, which should allow easy and natural movement with physical incidence and minimal ethical implications. On the basis of the studies by Rohrer et al. (2002) and Timmermans et al. (2009), in the case of stroke patients, kinematics of the actuator robot appear to be saturated and it cannot perform a movement in the full range because of the presence of submovements of the robots. In the field of neuroprosthetics, over the next few years, mapping from electromyography patterns to muscle forces as an early step for the foreseeable future should be a main research focus (Pino et al., 2012). Interesting topics of research in the future include further studies on the mechanism of cortical control, as well as those on signal processing of peripheral or spinal nerves, especially low-level neural signal tapping into peripheral or spinal nerves (Lawrence et al., 2004).

There are several future challenges that should be considered:

(1) The needs of elderly and disabled individuals should be considered, focusing on techniques to maximize patient motivation with the fact that they evolve with time. Thus, improvements of user interface for more natural human interactions are needed such as by voice, body gestures, natural language and dialogues (Casas et al., 2008).

(2) Better context for awareness in terms of capacity of learning, reasoning, interpretation, decision making, classification of scenarios, locations and ability to recognize and differentiate individuals (Casas et al., 2008).

(3) Affective computing involves robots interpreting the emotional and cognitive aspects of human users, adapting their behaviour to the specific state of the user and the environment, and desirable sensory feedback mechanism that should be supported (Fakhreddine et al., 2008).

(4) Increasing capacities of future robots in terms of more flexibility, mobility, transportability, handling capacity, mental capacity of robots and empowerment to perform certain tasks on behalf of the user (Bock et al., 2012). Integration of a wide scope of diverse technologies and cooperating in such a way that they may result in better behaviour of the robot.

(5) New forms of rehabilitation robots such as biorobotics, telerehabilitation robotics (Craig and Hermano, 2006) and nanorobotics, with challenges, should focus on intelligent implants, neural interfaces and online adaptation. New technologies of an autonomous robot should be considered for simple and easy use by a user who may have cognitive disability.

(6) In terms of ethical aspects, it is imperative that patients have full control of the level of intrusion by the robots and their privacy is protected. It is also important that on using a rehabilitation robot, due respect and assurance are given to the patient in terms of control of autonomy, cognitive ability, as well as the final responsibility (Datteri and Tamburrini, 2009). However, there is a trade-off between the user for the dignity of freedom and autonomy and for supporting and initiative by autonomous robots. For a clinical test, the patient’s personal identity must be assured and the health and other information collected must be kept confidential and protected (Datteri, 2013).

The field of rehabilitation robotics is ever expanding. New research is leading to the creation of new devices and technologies each year. As the technology develops,
the area of discussion in this field increases, which makes it necessary to provide a definition and information on some terms before we continue on to the main devices.

**Recommendation**

There are many factors and issues that influence and determine the design and development of rehabilitation robots such as ease of use of the robots and low maintenance, user reparable, affordability, compatibility and convenience of use of the devices at home, system equality and accuracy level of predictability, adjustability to familiarize with the user’s preferences, efficiency and potential to lead to improvements in the user’s life, simple learning and operating of the system, mental and physical safety and comfort of the user. Some recommendations and corresponding proposed actions are as follows:

1. For ongoing and current research projects, results or outcomes related to rehabilitation robots used should be considered and subsequently, new projects should be initiated and launched to determine the particular conditions and requirement of individuals with disabilities, the elderly and individuals with impairments because of developmental disorders.

2. In terms of clinical testing, a large diversity of patient groups in terms of their educational levels, age, social status, cultural context, injury and disabilities must be considered with specific characteristics of the associated diseases.

3. More studies on robot therapy in terms of physical and psychological implications and significance such as place dependency, level of affection, sense of belonging and space distribution should be carried out.

4. Advancements should be made in signal processing, artificial intelligence, cognitive computing and cloud computing with improvement in sensors, actuators and control algorithms with the ability to perform and allow motion or activity in a smooth, easy, safe and robust manner for artificial arms, fingers, hands, legs and limbs.

5. A set of guidelines and best practices should be established for rehabilitation robots that cover several issues on regulation for the functioning and manufacture, physical or mechanical constraints of motion safety, emergency and restart procedures, and portability and flexibility for ease of use.

Definitions of several levels of autonomy that a robot may offer should be set; for each of these, a certain set of functions and expected behaviour could be described. A similar procedure could be established for other features of the robot such as capacity to learn, reasoning and emotional response.

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