Technology in Rehabilitation/TechReh

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WP1

State of Art

REPORT

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1.Introduction

The publication of this report regarding the State of art is the result of the collaboration between partners of the TechReh project as part of WP1 User Need Analysis. This report is the first step in strengthening the knowledge about the use of advanced ICT solutions for rehabilitation.

This guide aims to be an instrument that will provide a possibility to contribute to the report on the state of art of leading-edge technologies for rehabilitation applications.

This guide aims to be an instrument for European partners that will provide an extensive image of the leading-edge technologies for rehabiltiation to transfer for Uzbekistan partners based on their previous experience and as resulted from national experiences in education, research and technological knowledge in rehabilitation.

WP1 activities want to focus on the newest technologies and resources to support the innovation processes in the Uzbekistan economy. The state of the art analysis about technology are essential to identify the advanced technologies that may involve more complex rehabilitation activities and then generate stronger linkage effects for the local economy.

2.Aim of the report

The aim of TechReh proposal is to define a learning and cooperation environment to deliver more opportunities to access new competences related to the use of advanced ICT solutions for rehabilitation. These new competences may go a long way towards goals and priorities in terms of optimization of the national healthcare organizations network and of ICT development, as staded in the Wallfare improvement strategy of the Republoc of Uzbekistan.

Aims to define new tchnological skills for:

- Rehabilitation profesionals using specific ICT solutions (las generation sensors and equipment) to be integrated in rehabilitation protocols.
- Figures with background in technical sciences who face the chalenge to innovate rehabilitation treatment working in tight collaboration with medical operators.

3.Organization

This report is organized as follows:

1. Data collection about new technologies in rehabilitation
2. National experience
3. VILNUNI were in charge for coordination for report of state of art of WP1; Contributed to

the definition of the state of art. Participating organization focused on upper and lower limb rehabilitation robotic devices.

4. UNISANN were contributed to the definition of the state of art. Participating organization focused on rehabilitation devices with is used for rehabilation efficiency evaluation.
5. UNIPEMC were contributed to the definition of the state of art. Participating organization focused on upper and lower limb rehabilitation robotic devices.
6. MEDUPLO were contributed to the definition of the state of art. Participating organization focused on upper and lower limb rehabilitation robotic devices.
7. EUSPRME were contributed to the definition of the state of art. Participating organization focused on ICT and telerehabilitation.
8. PLUX were contributed to the definition of the state of art. Participating organization focused on EMG biofeedback.
9. Report writing.

4. NEW TECHNOLOGIES IN REHABILITATION

The interest to integrate robotic treatment (RT) and new or assistive technologies (NT) in any field of Rehabilitation, and mainly in neurorehabilitation,_is dramatically increasing and in last decade numerous studies of robotic-assisted rehabilitation in combination with conventional techniques showed improving results in patients (1,2).

The field of these treatments was at first Neurorehabilitation (stroke, SCI, TBI, MS) but now there is increasing utilization in musculoskeletal impairments and disabilities after bone and joint traumatisms and prosthesis: as a matter of fact, in these fields too they are preeminent for the recovery in many aspects of cognitive and neuro-functional training and new technologies can support them very strongly, reducing times and enriching outcomes and patient's satisfaction.

NTs may be considered all the development of Assistive Technologies (AT), (robot-assisted therapy, non-actuator devices), telerehabilitation, virtual reality (VR) and brain stimulation techniques.

Hapticity and interaction between robots or NT and humans are still a key issue and all aspects of this relation have to be better studied in order to understand the effective value of robotics to optimize treatments and understand how to enhance the potentials of these means reducing at same time related problems.

Main factors of RT are: correct use of measurement observations, both clinical and robotic assessment outcome means; direct and indirect costs; feasibility studies of RT/NT and difficulties in research; education and health management, acceptance by patients and professionals.

Robots were first introduced into rehabilitation as mechanical care attendands or smart aids but nowadays the development is increasing; all the different fields of rehabilitation are involved from strength recovery to activities of daily living (ADL), perception, visual, speech, communication and vocational tasks improvement.

Robotic Treatment devices are stated to guarantee high compliance, repeatability, feasability and flexibility improving human activities. They should provide support to the residual strength consistent with the motor learning phenomena and they also have to adapt to progress during the treatment and they should help both caregivers and patients, in the whole process of rehabilitation (3).

Starting from **definition**, it is generally agreed that **"robots** tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behaviour, especially behaviour which mimics humans or other animals"

But there has not been yet a full consensus on robots qualification (4). Still there is a lack of perfect classification of devices with regard to the variability, characteristics, utilization, aims, etc. Robotics provides an integral solution to the treatments and objective assessments of neurological and other disorders.

The robots can perform repeated treatment protocols without the need of continuous involvement of therapists. A robot can save therapists' arduous efforts by helping with heavy, challenging and repetitious movements. Physical strain and professional injury in therapists can be minimized. It is cost-effective to strengthen some basic elements, such as muscle strength, range of motion, and sensorimotor coordination, in preparation for higher skill-level movement patterns on a mass-practice basis. Robotic therapy techniques can mimic appropriate functional kinematics or apply novel patterns of force with precision, such as isokinetic contraction, that are potentially effective for muscle strengthening. More advanced robots can provide tactile feedback that kinetically and kinematically corrects the impaired movements. Data collected during the robot training sessions can be quantified with ease to complement the subjective and qualitative observation of clinicians.

Robots are very helpful to serve various purposes of rehabilitation. For the patients with severe paresis, robots can provide the passive movement of the upper limb. Passive movements activate cerebral areas involved in active movements. For the patients with some movement capacity, robots can support the weight of the limb against gravity or due to the physical interaction between the robot and the subject. A robot and a patient can exchange forces or share position based on the type of control system. This provides a greater opportunity for movement than the patient might otherwise have. Rehabilitation robots aim to help therapists by increasing the duration of rehabilitation exercises, but especially their variety, quality, and adaptation to the patient's individual state (5).

The robots were principally used for their abilities to provide a large number of repetitions. Coupling of rehabilitation robots with fun, motivating, virtual reality interfaces is an excellent manner to increase intensity of rehabilitation. This has important implications with regard to the capacity of therapy services to deliver higher intensity therapy. If robots are as good as therapists and can provide a means to deliver more therapy, this has obvious advantages for patients (6). Unlike conventional therapy, robotic manipulanda or exoskeletons can deliver training at a much higher dosage (i.e., number of practice movements) and/or intensity (i.e., number of movements per unit time) with hundreds if not thousands of repetitions in a single session. This dosage per unit time may be a critical factor in rehabilitation as animal data show that changes in synapse density in primary motor cortex occurs after 400 reaches but not after 60.

Robots allow for more precise measurement, in terms of movement kinematics and dynamics, of both initial impairment and of impairment changes in response to treatment. Not only does this measurement capability virtually eliminate the effect of inter-rater differences on outcome assessments, but also allows a biomechanical model to be used to perform inverse dynamic analysis on movement data to compute forces at joints (7). Robots can provide both the movement controllability and the measurement reliability, which makes them ideal instruments to help neurologists and therapists address the challenges facing neurorehabilitation. Rehabilitation robots have sensors that record the movement data such as the position, velocity, and force/torque of joints.

They are often equipped by actuations to move the subject's limb, and they are designed to make the compensations of physical capabilities of patients. Rehabilitation robots include both actuated robotic limbs and the robotic suits that enclose the affected limb like an exoskeleton frame (8). Rehabilitation robots for the upper limb and for gait training are divided into exoskeleton and end-effector systems.

Robots currently available for NR typically integrate a growing number of sensors and actuators, for proprioceptive and exteroceptive perception, for the measure of the quantities characterizing the physical interaction with the human body and for monitoring the motor, cognitive and physiological parameters of the users; for this reason RT is more and more considered in clinical activities in regard to daily care. Such machines are therefore becoming mechatronic systems, with a central processing unit elaborating information recorded during motor exercises and with a system controlling and customizing rehabilitation itself depending on the subjective conditions of the single user and on the personal training strategy.

The benefits of robots for rehabilitation are therefore multiple: they can produce repetitive high quality movements, allowing increased intensity of rehabilitation; they can provide a large variety of exercises for the therapist to choose from; they provide a man-machine-interaction which allows an objective measure of progress, which itself can condition changes in the interaction by altering control parameters (5).

A comprehensive rehabilitation program requires therapy protocols and equipment that differ in the acute and chronic stages of recovery. The capacity of robots to deliver training with high intensity, dosage, reliability, repeatability, quantifiability, and flexibility makes them an ideal tool to both test, and eventually implement rehabilitation paradigms to aid motor recovery from stroke and other forms of brain injury and disease.

The clinical acceptance of RT will depend upon the capability of these devices to offer benefits that are not easily achieved by additional conventional therapy and these benefits must relate to impairments improving such as other issues as feasability, cost, acceptance and management (9).

5.Rehabilitation robots

Tejima classified the rehabilitation robots into four types: augmentative manipulation (wheelchairs, workstation, power-feeder, mobile robots, robotic orthoses, and robotic room), augmentative mobility (robotic wheelchairs, mobility aids for visually impaired people, and walking support systems for the elderly), therapy robots, and robots for help care-givers (10).

Rehabilitation robots can be distinguished by the mechanism of human-robot interaction and the number of segments which the robot can directly control. From the point of view of human-robot interaction, some robots are adapted from industrial robots with more or less degrees of freedom but only one point of physical contact between the distal end of the upper limb and the extremity of the robot. Two types of robot in this category are traditional manipulators and cable robots. MIT Manus resembled a traditional industrial manipulator. The examples of cable robots are

NERbot, Maribot, Kinehaptique, and Gentle/s (4). Cable robots impose forces or positions or provide assistance at the point of contact between the patient and the machine but only at this point. They cannot, therefore, directly control the different movement synergies used by patients in order to achieve the displacement of the end-point. A new category of recent rehabilitation device is robotic orthoses. These orthoses allow contact at several key points of the upper limb and can therefore control the different segments of the limb. This implies that they can influence coordination patterns and/or better follow the particularities of the patient's postures or movements. Examples of robots in this new category are (i) anthropomorphic robots, which are in contact practically with the whole limb such as ARMin and RUPERT, and the robots which have discontinuous contact with limb such as ARMguide and Dual Robotic System (4). All of them have a certain number of actuators to provide assistive motions to the subject, but the system topologies are so different from one to another. However, it is unnecessary to have so many variations of components, from where different rehabilitation robots can be assembled. The study on reconfigurable and modular architecture for rehabilitation robots is lacking. It has also been discussed that existing rehabilitation robots have two critical issues of the limited capability for personalization and the high ratio of price and performance.

Rehabilitation robots were studied primarily in motor relearning and recovery of the **upper limbs**. There are exoskeleton (e.g. Armeo, WREX) and end-effector systems (e.g. MIT-Manus, Bi-Manu-Track, Reha-Slide, Amadeo). A systematic comparison of the devices is difficult because of the variability of the robotics and movement's complexity of the upper limb. Nevertheless several reviews show an improvement of the upper limb motor function when robotics were used in combination with physiotherapy. Effective systems are the Bi-Manu-Track with a bilateral distal approach and the MIT-Manus InMotion2 with a proximal approach.

Clinical and biomechanical evidence available to date implies substantial improvement of the paretic arm after robot-assisted neuro-rehabilitation, with longer and dedicated training sessions being made possible at no additional work for the therapist. Clinical tests with MIT Manus report improved strength in the proximal upper limb, with reduced motor disability of the shoulder and elbow and smoother movement after training (possibly due, in part, to the robot support in the development of novel alternative motor strategies applicable to everyday life. In addition, robotic treatment helps to prevent complications such as muscular atrophy, spasticity and osteoporosis (11). A meta-analysis of 10 controlled studies confirmed efficacy in the recovery of everyday motor activities of patients with recent stroke. In several instances, robot-assisted treatment improved motor control more than conventional therapy (12).

Gait machines improve significantly the chance of regaining an independent walk in patients. For gait-machines two approaches can be distinguished: end-effector (like GaitTrainer GT1 and LokoHelp) and exoskeleton based solutions (like Lokomat and Auto- Ambulator). A recent Cochrane Report states, that robotic assisted gait training in combination with physiotherapy improves chances to regain independent walking capacity.

The Lokomat was used as a bilateral computerized gait orthosis in conjunction with partial body weight support treadmill walking. It did not provide active assistance at the ankle, and the foot drop is counteracted by a spring-loaded mechanism to support dorsiflexion during the swing phase of gait. Another two lower limb rehabilitation robots are Hesse's Gait Trainer I and Active AAFO. Ankle joint perturbators were developed to introduce ankle joint rotation to stretch ankle extensors. (13) A Stewart platform-type haptic interface called “Rutgers Ankle” was introduced to measure foot position and orientation. The system uses double-acting pneumatic cylinders, linear potentiometers, and a 6-DOF force sensor. It provides resistive forces and torques on the patient's foot, in response to virtual reality-based exercises (13).

Reconfigurable Modular Architecture for Rehabilitation Robots is the new concept. Each potential patient or client has different abilities, functional needs, and interests. This suggests that the personalization of a prescribed therapeutic program is essential to an assistive device. An emphasis on more autonomous use of robotic therapy systems makes the personalization of the human technology interface very important. Perhaps the greater research challenge relates to what and how to personalize and routinely customize and adjust the focus of therapeutic intervention especially as a client demonstrates improvement. This suggests the importance of a training protocol that is easily (and often purposefully) varied, in terms of use of both the full “ability” workspace (including force assistance to gently expand this ability space) and the types of tasks performed within the workspace.

Assistive Technology (AT) is defined as "any item, piece of equipment, or product system whether acquired commercially off the shelf, modified or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities. It is a broad range of devices, services, strategies, and practices that are conceived and applied to ameliorate the problems faced by individuals who have disabilities.” (14)

AT helps to enhance the independent functioning of people bearing disabilities; there is a wide range for the AT conception: from low-tech aids, such as built-up handles on eating utensils, to high tech devices such as computerised communication systems, alternative access systems or powered wheelchairs. The ultimate objective of AT is to contribute to the effective enhancement of the lives of people with disabilities and elderly people by helping to overcome and solve their functional problems, reducing dependence on others and contributing to integration into their families and society (15). This definition perfectly fits the actual rehabilitation coding of ICF because it consider the functional capabilities of individuals also in terms of quality of life.

Moreover, nowadays we assist to a more frequent integration of AT with NT and RT: examples may be the recent studies on the integration of neuro-modulation such as tDCS and RT in stroke rehabilitation, the uses of VR in training and Occupational therapies or the various attempts to improve measurements in NR considering both clinical and NT (16).

5.1.Upper limb rehabilitation robotic devices

A description of the specific field of application for upper limb rehabilitation devices often determines solutions for which the device itself may be applied. Two main application fields of robotic devices stand out: support to perform some activity daily living actions (ADL) (e.g. by power assistance or tremor suppression) and providing physical training (therapy). Although there is a significant need for powered devices supporting basic ADL at home**,** there are only a few of such devices proposed so far. This is mainly due to technical and economical restrictions. Portability is also often expected from devices assisting patients to perform basic activity daily living actions (17). Another group of the robotic devices used for rehabilitation purposes, much bigger than the group of devices supporting basic ADLs, constitute devices providing physical therapy**.** These may be designed for either specialized therapeutic institutes or home-based conditions. A vast majority of these devices may be used only at therapeutic institutes since they require supervised assistance from qualified personnel (18).

Devices for upper limb rehabilitation may provide different types of motion assistance: active, passive, haptic and coaching.

- **Active device** - A device able to move limbs. Device requires active actuators. It may also be apply to subjects completely unable to move their limb.

- **Passive device** - A device unable to move limbs, but may resist the movement when patiens moves to the wrong direction. These devices may only be used for rehabilitation of subjects who is able to move their limbs.
- **Haptic device** - A device that interfaces with the user through the sense of touch. Sometimes device is able to generate specific movements. Haptic devices are commonly used in rehabilitation settings with virtual environments.
- **Coaching device** - Device is able to track the movement and provide feedback related to the performance of the subject, commonly used in rehabilitation settings with virtual environments.
- **Active exercise** – An exercise in which subjects actively move their limb, although some assistance of the device may be provided.
- **Passive exercise** - An exercise in which the subject remains passive, while a device moves the limb. This type of exercise requires an active device (19,20).

When comparing the mechanical structure of robotic devices, scientist must discuss about how movements is transferred from the device to the patient's upper extremity. Devices are often divided in two categories: end-effector-based and exoskeleton-based.

- **End-effector based device** - Contacts a subject's limb only at its most distal part, however, it may complicate the control of the limb position in cases with multiple possible degrees of freedom.
- **Exoskeleton-based device** - A device with a mechanical structure that mirrors the skeletal structure of the limb, i.e. each segment of the limb associated with a joint movement is attached to the corresponding segment of the device. This design allows independent, concurrent and precise control of movements in a few limb joints (21,22).

Robotics devices for upper limb rehabilitation should be divided by system supported movements, because its easier to compare them.

Systems assisting elbow movements

Robot-assisted exercise shows promise as a means of providing exercise therapy for weakness that results from stroke or other neurological conditions. Exoskeletal or "wearable robots can provide therapeutic exercise and/or function as powered orthoses to help compensate for chronic weakness. A novel electromyography (EMG)- controlled exoskeletal robotic brace for the elbow and the results of a pilot study conducted using this brace for exercise training in individuals with chronic hemiparesis after stroke. Data shoved that EMG-controlled powered elbow orthoses can be successfully used in stroke rehabilitation (23).

Another study of myoelectrically controlled robotic system with 1 degree-of-freedom was developed to assist elbow training in a horizontal plane with intention involvement for people after stroke. The system could provide continuous assistance in extension torque, which was proportional to the amplitude of the subject's electromyographic (EMG) signal from the triceps, and could provide resistive torques during movement. This study investigated the system's effect on restoring the upper limb functions of eight subjects after chronic stroke in a twenty-session rehabilitation training program. With the assistive extension torque, subjects could reach a more extended position in the first session. After 20 sessions of training, there were statistically significant improvements in the modified Ashworth scale, Fugl-Meyer scale for shoulder and elbow, motor status scale, elbow extension range, muscle strength (24).

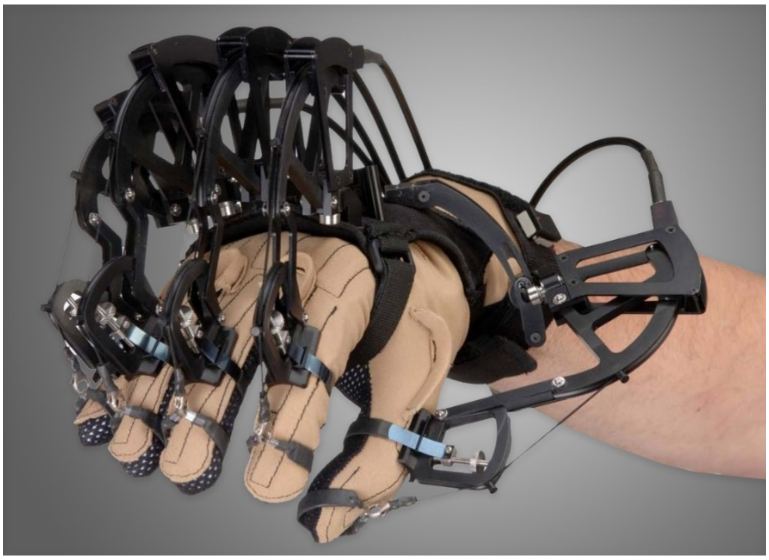
Systems assisting finger(s) movements

Hand plays a critical role in upper limb function (25), functional recovery of the affected arm can be predicted by means of clinical evaluation at the bedside; in particular, active finger extension has been demonstrated to be a strong early predictor of short-, medium- and long-term poststroke upper limb recovery (26).

The Amadeo robotic system (Tyromotion GmbH Graz, Austria) can be considered as an external manipulator with end-effector workspace suitable to cover the human hand fingers workspace. The robot performs an intensive training, with a high frequency of gripping movements combined with visual feedback. The exercises may therefore be accompanied by a goal-oriented rehabilitation games, whose difficulty is based upon the progress of rehabilitation and level of success rate in games (27). The experimental treatment was performed using the Amadeo Robotic System. The positive results obtained through the safe and reliable robotic rehabilitation treatment reinforce the recommendation to extend it to a larger clinical practice (28).

1 Example. Amadeo Robotic Sytem.

Another robotic equipment for finger movements is CyberGrasp system is an innovative force feedback system for your fingers and hand. The CyberGrasp device is a lightweight, force-reflecting exoskeleton that fits over a CyberGlove data glove (wired version) and adds resistive force feedback to each finger. With the CyberGrasp force feedback system, users are able to feel the size and shape of computer-generated 3D objects in a simulated virtual world (29).



2 Example. CyberGrasp glove.

The device exerts grasp forces that are roughly perpendicular to the fingertips throughout the range of motion, and forces can be specified individually. The CyberGrasp system allows full range-of-motion of the hand and does not obstruct the wearer's movements. The device is fully adjustable and designed to fit a wide variety of hands (30). Data showed that the establishment of motion features along with a prototype motion measurement system allows the continuous development on the CyberGlove as a hand function assessment tool (31). The system has proven to be safe and feasible for the training of hand function for persons with hemiparesis. It features a flexible design that allows for the use and further study of adjustments in point of view, bilateral and unimanual treatment modes, adaptive training algorithms and haptically rendered collisions in the context of rehabilitation of the hemiparetic hand (32,33).

Gloreha glove is a tool for upper limb rehabilitation. A comfortable and lightweight glove performs all the combinations of joint flexion-extension. If the patient has partial capabilities, he can actively complete his movements. During motor exercises the patients could see the therapy on screen 3D animation which motivates and involves the patient. Therapist can choose the most fitting modality of rehabilitation: active-assisted, active, bimanual, passive (34,35).

3 example. Gloreha simfonia work station

Data showed that using Gloreha glove during rehabilitation treatment ROM, improvement of grip, functional skills could be improved. Most of trials were performed for patients after stroke, neuro-oncologcal surgery, traumatic brain injury (36,37,38).

Hand of hope is a therapeutic device that may help patients regain hand mobility through motor relearning. It facilitates muscle re-education by both amplifying and rewarding a patient with desired motion in concert with his or her own muscle signal. The system continuously monitors and senses, but does not stimulate, the affected muscles. The patient can self-initiates movement through their often very weak voluntary EMG signals that indicate the intention to move. The system then filters and processes data to a motor on the brace to enable the desired motion. This processing occurs so quickly that it is transparent to the end user but more importantly, the EMG-driven robotics requires the patient to be actively engaged throughout the therapy session (39).

4 Example. Hand of hope.

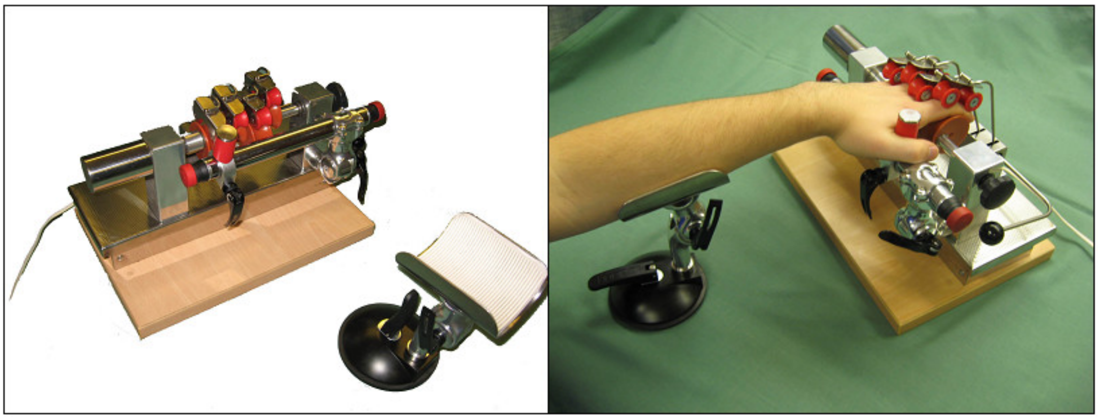
Study showed the potential efficacy of robot-assisted fingers training for hand and fingers rehabilitation and its feasibility to facilitate early rehabilitation for a wider population of stroke survivors (40).

Loss of hand function and finger dexterity are main disabilities in the upper limb after stroke. An electro- myography (EMG)-driven hand robot had been developed for post-stroke rehabilitation training. The effectiveness of the hand robot assisted whole upper limb training was investigated on persons with chronic stroke (41,42).

The Electric Powered Prehension Orthosis (EPPO) Wrist-Hand Orthosis, commonly referred toas a wrist can be utilized by those who lack hand grasp and sufficient tenodesis-enabling wrist extension strenght. The Power-Grip is indispensible for providing the ability to pick up, grasp, hold and manipulate objects. It helps to provide good function without damaging fingers that lack sensation (1). Is stil lack of scientific proof of benefits of this device.

5 Example. Power-grip orthosis.

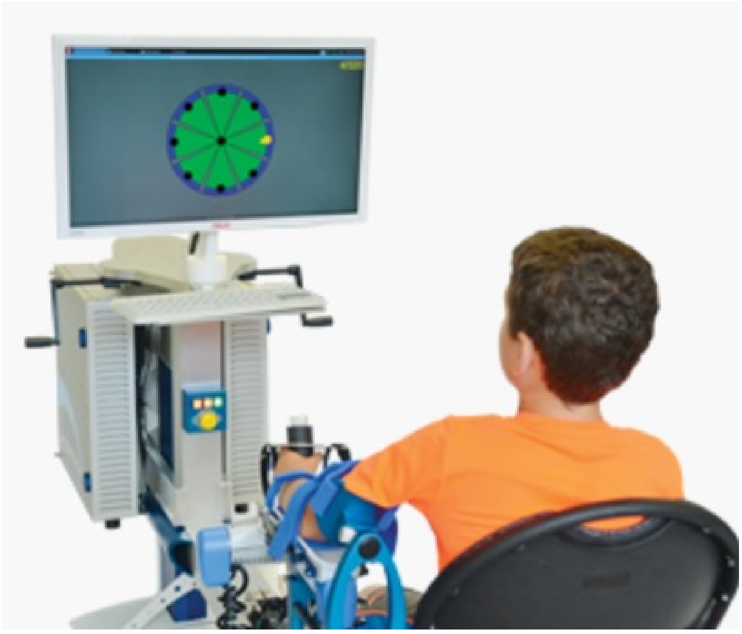
The human hand is our primary means to interact with our environment. Without this ability, we are subject to significant restrictions. To optimise the recovery of sensory and motor abilities you may use the Reha-Digit. The Reha-Digit fills a gap in the rehabilitation of the upper extremity to the treatment of plegic fingers. The Finger Trainer, Reha-Digit, consists of four, mutually independent plastic rolls, each fixed eccentrically to the powered axle of the device, forming a cam-shaft. Each finger-roll can be repositioned & secured by turning a knob on the main axle, on the other end from the motor, to fit the size & range of movement of each individual finger (43).



6 Example. Reha-Digit device.

Treatment with the Finger Trainer was well tolerated in sub-acute & chronic stroke patients, whose abnormal muscle tone improved. In sub-acute stroke patients, the Finger Trainer group showed small improvements in active movement and avoided the increase in tone seen in the control group. But still lack of scientific proof of device utility because trial was too small to demonstrate any effect on functional outcome however (43).

The InMotion WRIST exoskeletal robot is capable of lifting even a severely impaired neurologic patient's hand against gravity, overcoming most forms of hypertonicity. The InMotion WRIST exoskeletal robot accommodates the range of motion of a normal wrist in everyday tasks. Robotic arm with 3 active degrees-of-freedom is universal design for fast and easy patient setup. The authors who made a trial with InMotion WRIST identified a set of kinetic and kinematic macro-metrics that may be used for fast outcome evaluations. These metrics represent a first step toward the development of unified, automated measures of therapy outcome. Also authors came to conclusion that robot-based measures are highly repeatable, have high resolution, and could potentially reduce assessment time (44). Authors tried to deremined the additanial cost of robot-assisted therapy and test its cost-effectiveness. The added cost of delivering robot or intensive comparison therapy was recuperated by lower healthcare use costs compared with those in the usual care group. However, uncertainty remains about the cost-effectiveness of robotic-assisted rehabilitation compared with traditional rehabilitation (45).



7 example. Mit-Manus WRIST device.

The InMotion HAND robot is an add on module to be used with the InMotion ARM Robot. The InMotion HAND™ is smart, capable of continuously adapting to the needs of each patient — delivering customizable therapy. This module provides assist-as-needed grasp and release training with flexible positioning. It may be used in neutral (vertical) or pronation mode for patients with limited range due to developmental or tone impairments.

8 Example. InMotion Hand device.

Systems assisting shoulder and elbow movements

The InMotion ARM™ Robot is evidence based, intelligent, interactive technology that is capable of continuously adapting to and challenging each patient's ability. This allows the clinician to efficiently deliver personalized intensive sensorimotor therapy to neurologic patients. Trials sugest that in patients with long-term upper-limb deficits after stroke, robot-assisted therapy did not significantly improve motor function at 12 weeks, as compared with usual care or intensive therapy. In secondary analyses, robot-assisted therapy improved outcomes over 36 weeks as compared with usual care but not with intensive therapy (46).

9 Example. InMotion ARM device.

Robot-delivered quantitative and reproducible sensorimotor training enhanced the motor performance of the exercised shoulder and elbow. The robot-treated group also demonstrated improved functional outcome. When added to standard multidisciplinary rehabilitation, robotics provides novel therapeutic strategies that focus on impairment reduction and improved motor performance (47). Other trial says that activity-based therapies using an arm ergometer or robot when used over shortened training periods have the same effect as OT group therapy in decreasing impairment and improving disability in the paretic arm of severely affected stroke patients in the subacute phase (48).

Systems assisting forearm and wrist movements

The Bi-Manu-Track enables patients to perform units of underarm pro- and -supination and exercises to train wrist flexion and extension. Amplitude, speed and resistance can also be easily adjusted to the needs and abilities of the patients. The Bi-Manu-Track addresses specifically both sides of the human musculoskeletal system. Lost movements are reanimated with the help of the healthy side. Different modes of active and passive movement allow a therapeutic treatment according to the patients abilities. The use of the Bi-Manu-Track is designed to be as easy to use for therapists as for the patient. Flexible adjustment of height and handle position are easy to use, same as cushion and hand strap. The arm trainer made possible intensive bilateral elbow and wrist training of stroke patients (49).

10 example. Bi-Manu Track device.

The computerized active arm training produced a superior improvement in upper limb motor control and power compared with electromyography-initiated electrical stimulation group in severely affected stroke patients. This is probably attributable to the greater number of repetitions and the bilateral approach (50).

The Hand Mentor is an exercise device that uses video games and robotics to cognitively involve the patient in his/her rehabilitation. The Hand Mentor can be used in the clinic, or taken home and incorporated into patients' daily therapy sessions to lengthen shortened tissues, facilitate hand opening and closing, and reduce spasticity (51).

11 example. Hand-Mentor device.

Data says that intensive repetitive Hand-Mentor therapy improves function and quality of life for stroke patients. The development of a pneumatic muscle driven hand therapy device, reinforces the need for volitional activation of joint movement while concurrently offering knowledge of results about range of motion, muscle activity or resistance to movement. The device is well tolerated and has received favorable comments from stroke survivors, their caregivers, and therapists (52,53).

Systems assisting shoulder, elbow, forearm, wrist and finger movements (whole arm)

ArmeoPower is the world's most advanced arm rehabilitation device. It enables highly intensive arm rehabilitation for early-stage patients even before they develop active movement. The device provides support for the affected arm and hand and allows patienst to reacquire and improve motor control. During treatment patients are playing video games, simulate regular activities of daily living and the software gives the patient feedback through monitor screen. Assessment tools allows the care givers to monitories the patients recovery (54).

12 example. ArmeoPower device

Studies clearly indicate that intensive arm therapy with the robot ArmeoPower can significantly improve motor function of the paretic arm in some stroke patients, even those in a chronic state. The findings of the studys provide a basis for a subsequent controlled randomized clinical trial (55,56).

The ArmeoSpring is suitable for the widest range of patients from severely to moderately affected. It is specifically designed for patients who are beginning to regain active movement of the arm and hand.

13 example. Armeo- spring device.

The ArmeoSpring is the most widely used arm and hand rehabilitation exoskeleton. It enables independent arm and hand training for moderately to severely impaired patients. Ergonomic exoskeleton enables functional and self-initiated movement therapy. Extensive 3D workspace supports simultaneous arm and hand therapy During of present pilot study suggest that upper limb functionality of high-level disability multiple sclerosis patients can be positively influenced by means of a technology-enhanced physical rehabilitation program. (57)

ReoGo Robotic Therapy- an innovative device that works in 3 dimension and specifically designed to aid in the rehabilitation of upper extremities. Highly recommended for patients who are suffering from stroke or other brain-related injuries. During treatment ReoGo helps to use friendly exercises, collects data and offers challenging and functionally relevant games (58).

14 example. ReoGo device.

After trial patients were capable of completing the treatment and showed good participant satisfaction. This pilot study led to the finding of a clinical improvement and excellent patients compliance. It is possible that the learning process experienced by the patients was robot-dependent, especially in consideration of the general maintenance of the achievements observed on all activities (59).

5.2.Lower limb rehabilitation robotic devices

Gait rehabilitation of patients with central nervous system problems such as stroke , spinal cord injury (SCI) or traumatic brain injury (TBI) is one of the most important rehabilitation goals and often determines whether the patient will be able to return to daily activities or work (1) .Stroke is the third cause of mortality in the world and one of the main causes of disability in America and Europe. Neurological damage after stroke usually determines hemiparesis or partial paralysis of one side of the body (2).

The rehabilitation process in order to regain mobility can be divided into 3 stages (60):

• Patient's transfer to a wheelchair;

• Gait recovery;

• Improvement of gait parameters.

Traditional rehabilitation measures require high physical work of professionals, especially gait recovery, which can require up to 3 physical therapists who help shape the step and holds the torso during workouts. Also, in light of demographic changes in the world, such as aging, we determine that we can contend with shortages of health professionals, for people who need health care will only increase in future (60). All of these factors contribute to the development of new innovative robotic rehabilitation measures to facilitate the work of professionals and to allow the patient to do more reps.

Treadmill gait trainers

This robotic gait training group uses treadmill as basic, which helps to achievement better results in gait symmetry than walking over ground (61) and it requires less patient effort (62)

Many treadmill gait training uses body weight support system (BWSS), which in gait reconstruction after stroke is a more effective option than a workout when the patient's body weight isnt supported (63). BWSS also alows patient to perform longer physical work without fatigue (64).

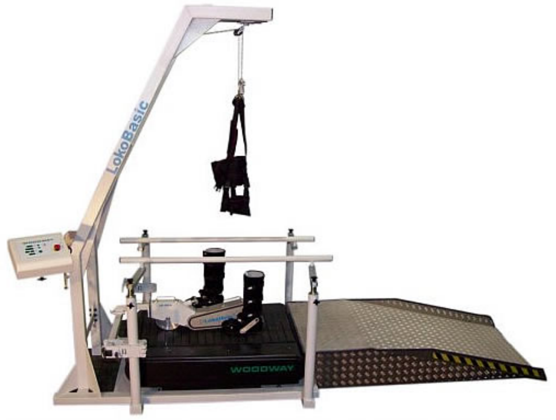
LOKOMAT gait trainer consists of adjustable BWSS, robotic gait orthoses and treadmill (65). This device has a fixed kinematic gait type that has been adapted to healthy people (66).

15 example. Lokomat device

Research conducted with SCI patients showed that Lokomat trainer with robotic gait orthoses caused activation of the same neurons in the spinal cord centers as activation when patient is walking manually. The study showed that LOKOMAT trainer not only increases the potential workout time, but also reduces the physical stress attributable to a specialist (67,68) and improve the patient's walking (69). Also LOKOMAT simulator can be used as a reliable tool for evaluating the clinical evaluation of the patient with the SCI joint situation awareness (70).

Other clinical trials suggest that LOKOMAT gait trainer is an efficient gait recovery tool for patients after stroke (70,71).

LokoHelp gait trainer consists of BWSS, active foot orthoses "Pedago", which was designed to create a similar motion asgait and treadmill (72). Unique LokoHelp systems help patients after stroke, SCI and TBI train their gait without alot active professional help (73,74). This greatly reduces the physical stress and discomfort incurred by the specialist that is using traditional gait rehabilitation measures (75).



16 example. LokoHelp device

Netherland University researchers in 2001 began developing robotic gait trainer LOPES. The first prototype was developed in 2006 and was made up of a fixed part and a lower extremity exoskeleton. Exoskeleton part has 3 joints (1 on knee 2 to the hip) which allows knee and hip joint motion (76). LOPES gait trainer improves patients' ability to walk after a stroke, and the quality of gait (77).

In 2010 Lopes trainer became part of Mindwalker, whose aim is to assess LOPES exoskeleton of autonomy using different algorithms.(78). Mindwalker project conducted studies have shown that LOPES exoskeleton through algorithms can help to carry out the steps without knowing the exact pre-step path. Further investigation is trying to control the entire step cycle, rather than separate steps (79).

17 example. Lopes device(left) and Mindwalker project (right)

Foot-plate-based gait trainers

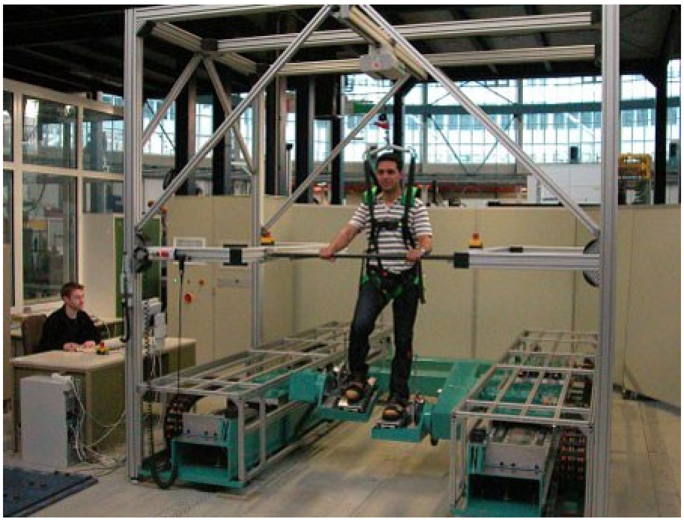
Some rehabilitation machines are based on programmable foot plates. That is, the feet of the patient are positioned on separate foot plates, whose movements are controlled by the robotic system to simulate different gait patterns.

Gangtrainer GT 1 trainer uses a BWSS and adapts to each patient's speed capabilities. The patient is wearing a corset, which supports patient's weight, and his feet are mounted on two platforms, which creates support and step phases (80).

18 example. Gangtrainer GT 1 device

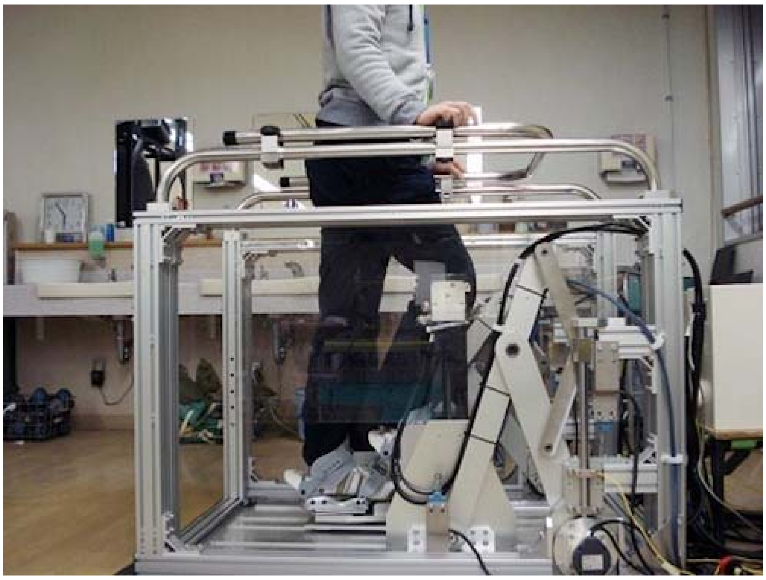
Many studies have found that the use of GT1 trainer requires much less effort of assisted specialist (81,82), and improves patients' balance and gait speed (83).

The HapticWalker is a haptic locomotion interface able to simulate not only slow and smooth trajectories (like walking on an even floor and up/down staircases), but also foot motions like walking on rough ground or even stumbling or sliding, which require high-order system dynamics (84). The trainer can also help to train daily activities. This trainer is greatmodification of previous mentioned Gangtrainer GT1.



19 example. HapticWalker device

GaitMaster 5 is a gait trainer designed by Tsukuba University, which allows to train not only walking forward but climbing the stairs up and down. The patient's feet are strapped to sensor-laden pads on motionplatforms. At the beginning, the machine controls the movement of the patients, but after several hours, the patient may have already regain some muscle memory. When the patient’s muscle memory improves, the system control will be tweaked to allow more autonomous movement. The patients knees are not fixed, in order to allow the therapists access for physical contact with the patient, which is an important factor in rehabilitation and also allows him to do minor corrections of the knee motion if needed.



20 example. GaitMaster 5 simulator created Tsukuba University researchers in Japan

Overground gait trainers

This chapter consist of robots that servo-follow the patient’s walking motions overground. They allow patients move under their own control rather than moving them through predetermined movement patterns

ReWalk gait trainer is motorized robotic suit that can be used not only for exercising the gait, but also for other therapeutic purposes. The patient's upper body movements are recorded on the sensor and is used for initiating and maintaining the walking process (85).

The costume consists of:

• Two exoskeleton, which is attached to the lower extremities and has a built-in motors at the joints;

• Rechargeable batteries;

• Sensors;

• Computer control system.

21 example. ReWalk device

Research has shown that ReWalk gait trainer is suitable for patients after SCI. Ambulatory patiens undergoing treatment after 14 workouts with ReWalk was able to walk 100 meters without any assistance (85,86).

WalkTrainer simulator is a mobile robotic device is designed to train the gait overground. The legs and pelvis orthoses provides accurate lower limb mobilization and power monitoring. The patient is fixed to BWSS unique corset and BWSS allows you to control the desired weight unloading during training. Also there is 7 pairs of electrodes applied to patientslegs that are controlled by a central computer. This allows to keep the patient's muscles active during the whole walking (87).

22 example. WalkTrainer device

Studies have shown WalkTrainer trainer is an effective choicefor gait exercising for patients after stroke and SCI (88).

KineAssist a robotic simulator designed for gait and balance training. The simulator consists of a special corset which is attached to the mobile robotic part. The corset has a sensor that captures the patient's pelvic movements and adapts BWSS accordingly. KineAssist trainer leaves the patient's feet available, so the practitioner can adjust the patient's gait without the fear that the patient might fall (89).

23 example. KineAssist device

Study trials shows that after stroke patiens using KineAssist gait trainer was able to go at a higher speed, and their steps were bigger. It is also noted that the 10 %. body weight unloading was the best option (90,91).

HAL is a robotic exoskeleton designed not only to patient rehabilitation needs of elderly patients with gait alleviation, but also severe physical works to facilitate (92) HAL exoskeleton can be one of the lower limbs of both lower extremities and a full exoskeleton suit type. One of the lower extremity exoskeleton commonly used in patients with hemiplegia (93).

24 example. Hal3 device (left), Hal5 device (right)

HAL exoskeleton integrated into the rehabilitation after stroke and SCI shoved better improvement in walking speed, the number of steps and the rhythm (94). The latest version of this exoskeleton HAL 5 , which allows patients to safely complete paraplegia to stand up and sit down without additional support (95). Recent research reveals that the newly developed algorithm allows HAL 5 exoskeleton help patients with paraplegia to walk safely without additional support (96).

Stationary gait trainers

Stationary gait trainer systems are focused on guided movements of limbs in order to have an optimal effect from a therapeutic and functional perspective. The objective of these systems is to obtain efficient strengthening of the muscles and the development of endurance, as well as joint mobility and movement coordination.

The MotionMaker (Swortec SA) is a stationary training systemwhich allows to carry out fitness exercises with active participation of the paralyzed limbs (97). The limbs are only attached to the orthoses at the foot level to simulate natural ground reaction forces . The advantage of the MotionMaker is its real-time sensor-controlled exercises, combined with the controlled electrostimulation, adapted to the patients efforts. First clinical trials have been carried out with the system (98), showing an improvement of the patient's ability to develop a higher voluntary force during a leg-press movement

25 example. Stationary MotionMaker device

Ankle rehabilitation systems

The human ankle joint is a complex structure of bone, which is very important in maintaining body balance. Ankle joint pathologies can lead to stroke, SCI and TBI. The most common violations of the ankle leads to long-term disability or a limited operating life, and ankle rehabilitation is very important for the rehabilitation process robotic ankle trainers are divided into fixed and active ankle orthotics (99).

Active ankle orthoses are exoskeleton, which the patient wears on his feet, so they can be train both walking on the ground and on the treadmill. Their purpose is to compensate for weak muscles or adjust lower limb deformities. These orthoses was result of passive lower limb orthotics modifications (78,99).

The first active ankle orthoses were PGO and PAGO. Both PGO and PAGO orthoses were tested with patients, but studies did not reveal their performance and they are not to commercialize [100,101).

Anklebot ankle simulator was initially designed to assess patients' ankle stiffness and only later began to be used in rehabilitation of ankle (102,103). Research reveals that Anklebot simulator improves walking distance in patients after stroke (104).

26 example. Anklebot ankle device

6. ICT AND TELEREHABILITATION

The increasing availability of low cost internet and communication technologies (ICT) (e.g. ADSL, HDSL, fiber connection) has boosted the opportunity to apply technology- based solutions to provide health services during hospitalization and after discharge from hospital. This approach, broadly referred to as telemedicine, may guarantee better continuity of care from hospital to patients' home, as well as patients' monitoring and counseling. ICTs has become a valuable option also for rehabilitation supporting the birth of a new branch of telemedicine, called telerehabilitation (105,106).

Benefits of telerehabilitation include the delivery of prolonged therapies tailored on patients' needs while at the same time making significant savings on costs. A number of trials have been published to test the feasibility of telerehabilitation approaches and to compare their effectiveness with standard rehabilitation practice.

Functional magnetic resonance imaging (fMRI) showed that rehabilitative treatments provided via telerehabilitation activate the same cortical regions as conventional treatment. Previous studies of telerehabilitation for the treatment of upper limb motor function after stroke confirmed these data (107). Several authors observed that the use of telerehabilitation leads to high levels of satisfaction as reported by patients reinforcing the hypothesis that the delivery of rehabilitative services at a distance is a feasible alternative to routine care.

Telerehabilitation is the provision of rehabilitation services to patients at a remote location using information and communication technologies (108). Communication between the patient and the rehabilitation professional may occur through a variety of technologies such as the telephone, Internet-based videoconferencing and sensors (such as pedometers). Virtual reality programs may also be used as a medium for therapy; the patient completes therapy tasks within a computer-generated virtual environment, and data are transmitted to the therapist (109). Telerehabilitation consultations may include assessment, diagnosis, goal setting, therapy, education and monitoring (110). Stemming from the broader approach of tele-health, telerehabilitation has been described as an alternative method of delivering conventional rehabilitation services rather than a subspecialty. The approach is relatively new, with the first related literature published in the late 1990s. Increasing interest in the use of telerehabilitation has prompted professional bodies to draft position statements regarding its use (111,112). These statements have emphasized the need to ensure that quality, ethical and legal standards are met when treatment is provided remotely rather than in person. Many examples in the current literature demonstrate the scope of telerehabilitation. For example, home assessments to determine the need for modifications have been completed remotely by occupational therapists using a combination of still photography, telephone calls and videoconferencing technology (113). Physiotherapists have provided a safe and effective therapy program for people after total knee replacement using videoconferencing (114), and speech pathologists have demonstrated the feasibility of assessing motor speech disorders via the Internet (115).

One of the key advantages of telerehabilitation is that it provides the opportunity for people who are isolated to access rehabilitation services. People in rural and remote areas are unlikely to have access to rehabilitation teams with expertise in stroke, and they may not have access to rehabilitation clinicians at all. Eliminating the need for travel to rehabilitation centers may also benefit people with severely restricted mobility who have difficulty travelling or are unable to travel. Telerehabilitation services may also be used to complement and enhance the quality of current rehabilitation services. Stroke survivors have expressed concern regarding the lack of available long term support and ongoing unmet rehabilitation needs (McKevitt C., 2011). It is possible that the use of telerehabilitation may help to address these gaps by supporting patients as they resume life roles on discharge from inpatient facilities. Furthermore, the use of telerehabilitation may result in cost savings in various ways

Despite its apparent advantages, the challenges associated with telerehabilitation are well documented (116). One of the key issues facing clinicians is how to conduct assessments or provide interventions that are typically “hands on”, for example, assessment of muscle strength. The inability to conduct hands on assessment or treatment means that therapists need to modify current techniques, for example, by utilizing family members or teaching the patient ways to perform the intervention independently (110).

Increasing interest in telerehabilitation suggests that this area will continue to grow (117) Furthermore, clinical guidelines for stroke now recommend telerehabilitation for people without access to center-based rehabilitation services. However, establishment of telerehabilitation services may be expensive because of the costs of equipment, training and ongoing technical support.

Current Evidences. Despite satisfactory scientific results and recommendations from national health plans to reduce costs by shortening hospital stays, telerehabilitation is still not widely disseminated. Despite conclusions point to “inconclusive findings toward telerehabilitation”, especially with regards to neurological rehabilitation, it has to be pointed out that such conclusions were drawn by comparing telerehabilitation with standard rehabilitation. A non superiority of telerehabilitation does not involve an inferiority. (118,119,120).

The picture depicted by the systematic analysis indicates that the most extensive application for telerehabilitation was developed and tested with survivors from traumatic, degenerative and vascular diseases of the central nervous system (CNS), like: spinal cord injury, traumatic brain injury, multiple sclerosis and stroke. An interesting finding from the meta-analysis is the significant positive effect of telerehabilitation in the post TKA surgery population (121).

Sensor systems and Telerehabilitation.

One of prerequisites to develop telerehabilition and to facilitate the implementation of home-based rehabilitation interventions is the introduction of remote monitoring systems based on wearable technology, especially wearable sensor systems (122**).** Systems that aim to facilitate the implementation of rehabilitation exercise programs often leverage the combination of sensing technology and interactive gaming or virtual reality (VR) environments.

Wearable sensors have diagnostic, as well as monitoring applications. Their current capabilities include physiological and biochemical sensing, as well as motion sensing (123). It is hard to overstate the magnitude of the problems that these technologies might help solve. Physiological monitoring could help in both diagnosis and ongoing treatment of a vast number of individuals with neurological, cardiovascular and pulmonary diseases such as seizures, hypertension, dysrthymias, and asthma. Home based motion sensing might assist in falls prevention and help maximize an individual's independence and community participation.

Remote monitoring systems have the potential to mitigate problematic patient access issues. Wearable sensors and remote monitoring systems have the potential to extend the reach of specialists in urban areas to rural areas and decrease these disparities. Wearable sensors are used to gather physiological and movement data thus enabling patient's status monitoring. Sensors are deployed according to the clinical application of interest. Sensors to monitor vital signs (e.g. heart rate and respiratory rate) would be deployed, for instance, when monitoring patients with congestive heart failure or patients with chronic obstructive pulmonary disease undergoing clinical intervention. Sensors for movement data capturing would be deployed, for instance, in applications such as monitoring the effectiveness of home-based rehabilitation interventions in stroke survivors or the use of mobility assistive devices in older adults. Wireless communication is relied upon to transmit patient's data to a mobile phone or an access point and relay the information to a remote centre via the Internet. Emergency situations (e.g. falls) are detected via data processing (122).

Sensing technologies, can be seen as enabling technologies of more complete applications that will guide rehabilitation training. A great deal work has been done toward integrating sensing technologies in complete wearable rehabilitation solutions. In comparing these systems, it is important to consider the feedback part and the interface for the user. Normally the systems consist of at least two main parts: 1) wearable sensing and central controller subsystem, 2) data communication and feedback subsystem (122).

Home-based systems need to be affordable and easy to deploy and maintain, while still providing the interactional fidelity required to produce the meaningful motor activity required to foster rehabilitative aims and promote transfer to real world activities.

Virtual reality

Virtual reality (VR)based interventions are among the most-used ICT-based methodologies included and adopted in the Telerehabilitation

For example, The Rehabilitation Engineering Research Center at the University of Southern California is building on VR gaming to address compliance and motivation challenges VR simulation technology using specialized interface devices has been applied to improve motor skills in subjects undergoing rehabilitation to address functional deficits including reaching, hand function and walking. It has been proposed that such VR-based activities could be delivered in the home via a telerehabilitation approach to support patients' increased access to rehabilitation and preventive exercise programming. When this is put in an interactive game-based context, the potential exists to enhance the engagement and motivation needed to drive neuroplastic changes that underlie motor process maintenance and improvement.

An example of such systems is the Valedo system by Hocoma AG, which is a medical back training device, which improves patient's compliance and allows one to achieve increased motivation by real time Augmented Feedback based on trunk movements. It transfers trunk movements from two wireless sensors into a motivating game environment and guides the patient through exercises specifically designed for low back pain therapy. To facilitate challenging the patient and achieving efficient training, the exercises can be adjusted according to the patient's specific needs.

Several other systems are currently under development. For instance, GE Healthcare is developing a wireless medical monitoring system that is expected to allow one to gather physiological and movement data thus facilitating rehabilitation interventions in the home setting. Another example of home-based rehabilitation technology is the Stroke Rehabilitation Exerciser developed by Philips Research (124). The Stroke Rehab Exerciser coaches the patient through a sequence of exercises for motor retraining, which are prescribed by the physiotherapist and uploaded to a patient unit. A wireless inertial sensor system records the patient's movements, analyzes the data for deviations from a personal movement target and provides feedback to the patient and the therapist.

Major efforts have been made by European groups to develop systems suitable for home-based interventions that rely on wearable technology. A project that was part of the myHeart initiative led to the development of a sensorized garment-based system to facilitate rehabilitation interventions in the home setting (125). The system allows patients to increase the amount of motor exercise they can perform independently, providing them with a real-time feedback based on wearable sensors embedded in the garment across the upper limb and trunk. After the feedback phase, data is stored in a central location for review and statistics. Workstations can be installed either at home or at the hospital to support patients, regardless of their location.

Two other major initiatives in the field include the research programs set in place by TRIL and CLARITY Centers in Dublin, Ireland. Other projects carried out by European groups that are worth mentioning are the TeleKat project and the "Auxilium Vitae Volterra" at Rehabilitation Center-Scuola Superiore Sant'Anna. The TeleKat project (Aalborg University, Aalborg, Denmark) is applying User Driven Innovation to develop wireless tele-homecare technology enabling patients with chronic obstructive pulmonary disease to perform self-monitoring of their status, and to maintain rehabilitation activities in their homes.

The Tele-rehabilitation project "Auxilium Vitae Volterra" at Rehabilitation Center-Scuola Superiore Sant'Anna is a cardiac rehabilitation program that leverages the use of a sensor-based system to remotely monitor patients in their home. The system includes a computerize cycle ergometer, a wireless diagnostic 12-lead ECG,a sensor for blood oxygen saturation, a non-invasive blood pressure measurement system, and a high-performance videoconferencing system (122).

Systems for VR-based Telerehabilitation

an ICT –based system for telerehabilitation should provide the following features:

- the possibility to provide exercises and activities for the patient at home, both in offline and "on-line" with a remote therapist;
- the possibility to provide videoconferencing services with a remote therapist;
- the possibility for the therapist to remotely provide and define proper sets of activities to be conducted by the patient;
- the possibility to consistently track and record all the results and metrics arising from the patient's activities, and, in parallel, the adherence to the prescribed sets of activities;
- the consistency of the structure of data and results across the several types of activities, in order to have the possibility to represent them in a consistent reporting system allowing for longitudinal investigations and extraction of population statistics.

Obviously, the telerehabilitation system should implement rehabilitation methodologies of proven efficacy. With this regard, a VR-based telerehabilitation system should be:

- developed together with clinicians and therapists, and properly tested and validated in clinical contexts, both at clinical facilities and at home.
- Properly certified as a Medical Device (216).

There are few commercial systems available. Most of the identified systems are, de facto, series-games applications not really developed for telerehabilitation. Very few of them (just two, MediTutor and VRRS) integrate both a videoconferencing system and a desktop sharing feature; most of the identified systems just integrate 3D camera technologies to track the patient kinematic. Among them, most use the Microsoft Kinect. While surely benefiting from the low-cost aspect of such technologies, they share their limits at the same time: it is well known that the Microsoft Kinect, while permitting an acceptable skeletal tracking of the user and being optimal for gaming experience, does not allow for precise tracking of end effectors and the range of motion of skeletal joints, which is strongly recommended in the field of neurological rehabilitation, especially with neurological patients presenting limited mobility. An example of a system presenting a technological state-of-the-art for non-optimal kinematic tracking is the VRRS by Khymeia. It is up to date the most tested and clinically validated system for rehabilitation and telerehabilitation in the world: more than 70% patients in the Cochrane review on VR (127) had been rehabilitated with the VRRS System.

7.Muscular rehabilitation using EMG biofeedback

Every year a vast number of people undergo physical rehabilitation due to work related injuries, disability and other conditions (128). Technological solutions are part of physiotherapy routine, they increase accuracy of assessments and training, allowing faster recovery and increase patients satisfaction. Within the portfolio of tools that therapists currently have at their disposal, biofeedback has become particularly popular, with clinical evidence showing that it is an engaging technique with multiple benefits for the patient. A major advantage is the possibility to measure physiological signal in real time, monitoring progress and guiding rehabilitation exercises to maximize the potential outcomes. Another relevant aspect is the positive and negative reinforcement cues (usually visual and acoustic), provided to the patient in real time when a given exercise is being executed. Biofeedback is described by the AAPB (129) as the process of gaining greater awareness of many physiological functions primarily using instruments that provide information on the activity of those same systems, with a goal of being able to manipulate them at will.

One area of Biofeedback is Electromyographic (EMG) Biofeedback. EMG Biofeedback is very useful to increase strength, to correct movement patterns and muscle activation timings by giving awareness of the contraction, improve coordination and in the end of the day, play a crucial role in the motor relearning process, contributing to functionality. It can be adapted to several areas of intervention, as neurology, orthopedics or sports, even for rehabilitation of prevention of injuries. EMG signals correspond to the electrical potential generated by nerve cells that control muscle cells (from skeletal muscles) when they are electrically or neurologically activated (130).

Types of feedback

Gamecho et al. (128) described several systems of Audiovisual Biofeedback, based in their authors:

Audiovisual feedback is the most widespread approach ever since biofeedback started to being used, focuses on the use of either visual or acoustic cues (or a mixture of both) for positive and/or negative reinforcement. The authors mention Liu and Quian for their system for stroke rehabilitation that uses cameras to monitor the user’s motion and delivers visual feedback; Also based on motion tracking, the work by Lange et al. proposes a gamification approach to physical rehabilitation, in which a low cost depth sensing camera is used together with a game of balance training for adults suffering from neurological injury; Daponte, de Vito, and Sementa proposed a system based on wearable Inertial Measurements Units for range of limb motion measurement in home rehabilitation; Aung and Al-Jumaily present a shoulder rehabilitation system that aims to increase the motivation and autonomous effort of users while doing physical rehabilitation exercises; Farjadian, Sivak and Mavroidis, proposed a t-shirt that acquires multiple EMG channels and heart rate data. A smartphone interface provides audiovisual feedback, enabling the user to observe and adjust the exercises in real time.

Examples of Products in the market

Over the years a number of commercial EMG Biofeedback devices available for rehabilitation have also been made available. Thought Technology, MindMedia, and PLUX all provide a range of devices for real time audiovisual feedback, which users can follow while doing physical rehabilitation exercises.

1. Physioplux® developed by PLUX, is a versatile Biofeedback EMG system, which provides real-time muscular feedback, guides the patient to perform exercises correctly, helps physiotherapist to define goals, report and track progress and have specific and generic applications and graphics, to adapt to different clinical conditions. It's a system designed for physiotherapists, which provides an interactive experience to assess and guide the patient, facilitating learning of correct movement patters, body awareness and body control. A study performed by Santos, Matias & Carnide (131) using Physioplux in a group of patients with shoulder impingement, showed a 50% reduction in treatment time (7 weeks on average) and a recurrence rate inferior to 10% in a 2 years follow-up.

Physioplux® is a modern light-weighted portable device, intuitive and comfortable to use.

As a way of improving the effectiveness of treatments, one of the latest trends has been the extension of the rehabilitation process to people's homes with biofeedback exercises designated by the therapist to be performed autonomously by the patient at home, in-between sessions at the clinic. Physioplux also has in the market an adaptation for home usage, called Physioplux TRAINER.

2. Amadeo® is an instrument provided by GMBH, for supporting a patient in neurological rehabilitation. Depending on the degree of the neurological damage, the patient can be treated passively or actively. One of the options of treatment is interactive therapy, an active training in a virtual environment based on the goal-oriented tasks (visual feedback). The patented mechanism of Amadeo® mimics the natural grasping movement and imprints it on the patient's hand (132). As a result of the therapy program that is tailored to their individual needs, patients quickly regain more quality of life. This device also enables the measurement of the isometric force and of the scope of movement for the upper extremities having an integrated real-time biofeedback (132).

The system combines some of the best features of the equipment presented above such as being light-weighted, portable and easy to use.

8. Rehabilitation science

Rehabilitation science aims to enhance and restore functional ability and quality of life to those with physical impairments or disabilities. Common causes of disability treated by rehabilitation therapists include pathologies causing movement dysfunctions. Examples are amputation, spinal cord injury, sports injury, stroke, musculoskeletal pain syndromes and traumatic brain injury.

The re-establishment of the lost abilities is obtained through a series of activities to reduce the patient's disability: the rehabilitation process. The main aims of the rehabilitation process are:

(i) the recovery of the impairment;

(ii) the enhancement of residual abilities;

(iii) the improvement of patient's participation to the treatment, by means of actions aimed at recovering the best physical, cognitive, psychological and functional levels of the patient.

The ideal rehabilitation process can be modelled as shown in the scheme of Fig.1 (131).

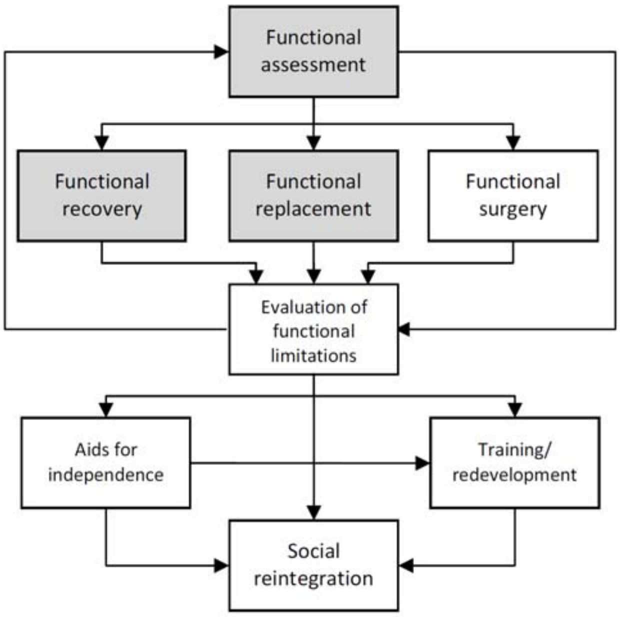


Fig.1 Scheme of the rehabilitation process. The phases in which the measurement science is fundamental are shown in grey colour.

A first phase is dedicated to the assessment of the patient capabilities. Then, a strategy for the recovery of the lost function is designed. If the lost capabilities can be recovered by means of a rehabilitation treatment, a functional recovery phase begins. Otherwise, if the capability cannot be recovered, a functional replacement is applied by means of specific equipment, which allows the patient to partially perform the lost function at least. In some cases, a surgical intervention is needed to allow the function recovery. Finally, after a new phase in which the functional limitations of the patient are evaluated, he/she is trained to perform again the lost functions, using technological aids when necessary.

The contribution of measurement science is fundamental for the following phases of the rehabilitation process: (i) functional assessment, (ii) functional recovery, and (iii) functional replacement. In the follow the contribute of measurement science in these three phases is reported.

Functional assessment

Functional assessment is a phase of the rehabilitation process aimed at understanding the motor behaviour of the patient undergoing physiotherapy treatment. In this phase, the rehabilitation team is in charge of identifying the movement disorder, the residual potentialities and the possible compensatory mechanisms used to perform a given functional task. During the functional assessment phase the physiotherapist makes a preliminary global observation of the patient with the subsequent evaluation of his/her articular range, in order to analyze the involved articulation and record, the angular amplitude of the articular movement in a given district; he/she will thereafter make a muscle assessment, a test that allows to understand which muscle groups are hypovalid and to figure out the possible causes of selective deficits. The next steps include the analysis of surface and deep sensitivity, the analysis of equilibrium capacity, using functional tests assessing gait, mobility, and gestures in general.

In the functional assessment phase, several works deal with the evaluation of the patient motion capabilities (134). They face the problem by focusing on a specific body part, such as upper limb, lower limb, trunk, or to a specific function, such as grip and gait. In the next a brief overview is given focusing on position and motion measurement. In (135) a review of the different measurement systems, for human motion and gait analysis, by taking into account several performance parameters, such as update rate, latency, resolution, motion degrees of freedom, size and weight, is given. Most of the human motion measurement systems are based on MEMS (Micro-Electro Mechanical Systems) sensors. In particular, three-axis accelerometers, gyroscopes and magnetometer are often combined to realize measurement systems with up to 6 or 9 degrees of freedom. In the last years, thanks to the diffusion and the low cost motion sensors, the research is aiming to advance methods for the analysis of the sensor data. In (136), a study about the evaluation of the functional impairments in human locomotion is presented. Measurements for this study have been obtained by a combination of (i) an instrumented treadmill, measuring the ground reaction forces during walking, (ii) a wireless EMG (ElectroMioGraphy) system, measuring the dynamic activities of the muscles on both sides of the lower extremity, and (iii) a set of triaxial accelerometers, measuring the acceleration of the body segments while walking (Fig.2).

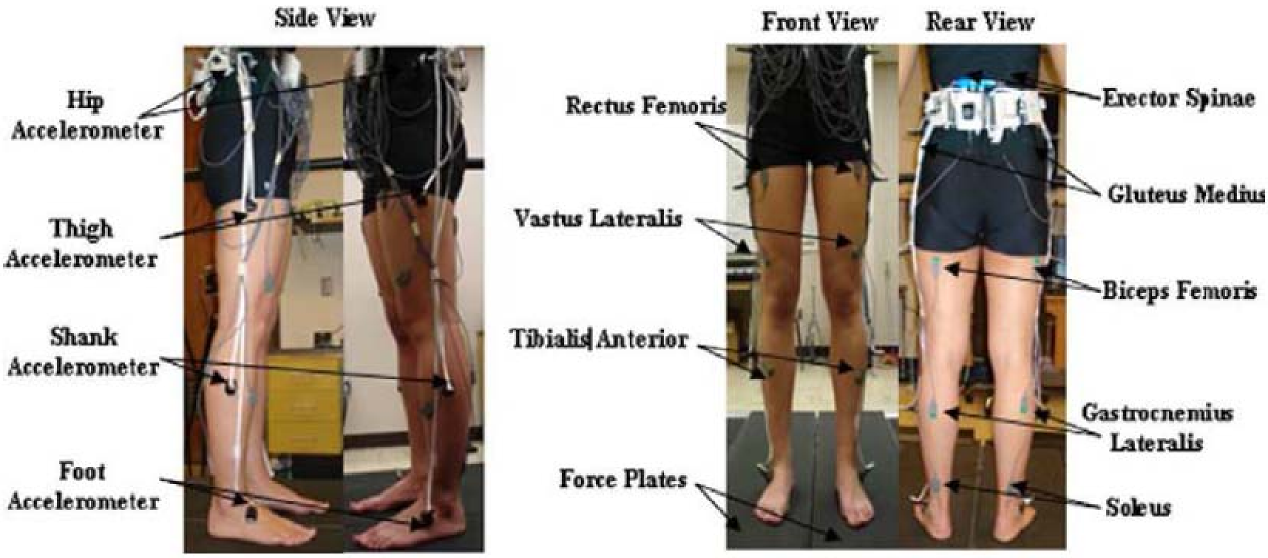


Fig.2. Sensor placement for locomotion function assessment in [5].

Then, a feature extraction technique, based on the fuzzy logic, is used to extract information about the motion impairments. Signal processing techniques often allow to quantitatively evaluate aspects that in the past were only analyzed qualitatively, by visual inspection of the therapist. An example is the inter-joint coordination. In (137), a measurement method for the quantitative evaluation of the inter-joint coordination during gait has been introduced. Measurements are obtained by means of five sensor modules, each consisting of two accelerometers and one gyroscope. An approach based on electromagnetism has been used in (138) to measure topographical features of the trunks of patients with scoliosis. The system consists of a three orthogonal-coil transmitter and a set of three-orthogonal-coil receivers. The position of a receiver relative to the transmitter is determined from the strength of the received signal. In (139) a hybrid solution (hardware and software) is proposed integrating a computer and the Kinect sensor. It permits to evaluate the range of motion for elbow flexion, elbow extension, shoulder abduction, shoulder flexion, radial deviation and ulnar deviation. In (140) it is evaluated the reliability and validity of upper extremity joint angle measurements with the Kinect for shoulder rehabilitation. Results indicate that while the Kinect is reliable for measuring shoulder joint angles in the frontal view, it is only valid for non-occlusive poses compared to the gold (magnetic tracker) and clinical (goniometer) standards for the shoulder.

In (141) a wearable system using four ultra-small, low power sensors (inertial and magnetic) to monitor seven degrees-of-freedom of the upper limb (shoulder, elbow, wrist) during motions, is presented. The accuracy of the system was characterized in measuring 3-D orientation with and without magnetometer-based heading compensation relative to a research grade optical motion capture system. Similarly, in (1420 it is proposed a measurement system to capture and analyze biomechanical signal from the upper limb. The system is composed by two inertial and magnetic sensors fixed to the arm and the forearm body segments and the signal fusion is used to perform joint amplitude measurements, elbow flexion/extension and pronation/supination.

An improved IMU-based gait analysis processing method that uses gyroscope angular rate reversal to identify the start of each gait cycle during walking. In validation tests with six subjects with Parkinson disease (PD), including those with severe shuffling gait patterns, and seven controls, the probability of True-Positive event detection and False-Positive event detection was 100% and 0%, respectively. In (143) the nature of fatigue and its impact on gait and posture is studied using inertial sensors. In this approach, the flexion/extension of knees of a subject during stair climbing test (SCTs) before and after performing a specific set of fatigue-inducing exercises is measured. The knee motion data obtained during SCT before after the exercise are compared using dynamic time warping (DTW). The amount of difference is an indication of the degree of fatigue. In (144) it is proposed the use of microwave Doppler radars embedded in four wheels walkers for gait capture. The signals acquired from the sensors are processed using time-frequency transform such as STFT. A set of gait characteristics, such as gait velocity and stride rate, are evaluated by using wavelet signal processing, STFT spectrogram and moving average filtering. A set of spectrogram features is evaluated to discriminate between normal and abnormal gait.

A simple test used to assess a person's mobility is the Timed Up and Go test (TUG). It uses the time that a person takes to rise from a chair, walk three metres, turn around, walk back to the chair, and sit down. During the test, the person is expected to wear their regular footwear and use any mobility aids that they would normally require. TUG test is one such assessment recently instrumented with technology in several studies, yielding promising results toward the future of automating clinical assessments. In (145) the Authors deeply describe benefits and limitations of different measurement methods based on: video (146), Kinetic (147,148) wearable inertial sensors (149,150) smartphone (151,152), and ambient sensors (153,154).

Functional recovery

This phase involves the treatment of the patient, in order to recover some part of the lost functionalities. Papers regarding this phase deal with the design, test and the dissemination of new technologies and rehabilitative procedures for the functional recovery of patients with sensory-motor disorders. The treatment design focuses on the movement as an integrated whole, involving all anatomical-physiological spheres: nervous, central, peripheral systems, skeletal system, metabolic system, respiratory and cardiovascular systems. In nature there is not a movement that involves just one of these systems and organs, so when referring to a physiological or to a pathological movement, it should be considered a variety of adjustments and changes, stimuli and responses. Functional recovery is achieved not only when changes in the musculoskeletal components are observed, damaging the common characteristics of movement. However, the neurological components and the related support systems, such as the cardiopulmonary and the metabolic ones have to be taken into account, too (Fig.3) (155).

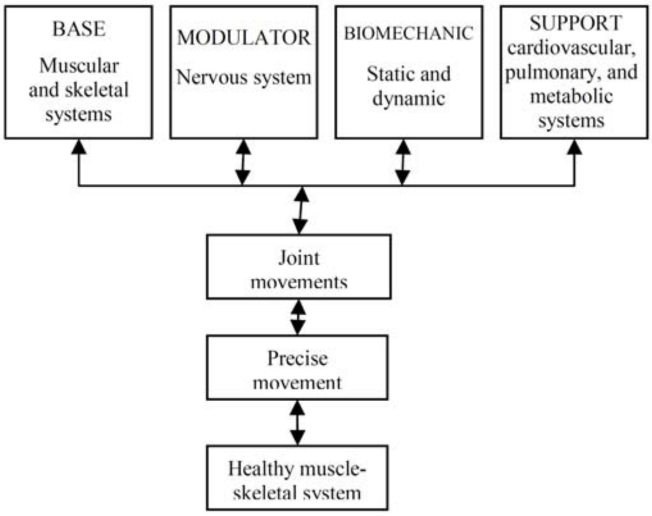


Fig.3. Kinesiologic model of the movement.

In the functional recovery phase, the contribution of the measurement science is fundamental in the evaluation of the progresses of the patient during the treatment. In particular, virtual instruments exploiting both the sensing capabilities of. A relevant example is the work conducted at the University of Ottawa, where in (156-158) environments to guide and trace the rehabilitation exercise, by means of virtual reality and augmented reality have been developed. From the execution of specific exercises on haptic interfaces (Fig.4) under the guidance of a graphic user interface, the proposed systems are able to evaluate different parameters, such as the time spent by the patient to complete the task and the amount of oscillations of the patient arm position.

Fig.4. Rehabilitation device used in [27]-[29].

Systems based on virtual and augmented reality play an important role in motivating the patient to do exercises and to improve his/her capabilities. The same goal is pursued by biofeedback systems. Biofeedback is a technique which makes use of electronic equipment to make the patient aware of some internal biological events, in the form of visual or acoustic signals, with the aim of teach the patient to change them, acting on the phenomena that such events cause]. In biofeedback systems, the contribution of the measurement discipline becomes relevant in translating in a readable form the physiological function. In (159), wireless modules are integrated on forearm crutches to measure the weight that the patients apply on the crutch, the crutch tilt and the hand position. The patient receives biofeedback by means of an audible signal when they put too much or too little weight through the crutch. Similar approach was proposed in (160) where the wireless instrumented crutches where proposed for gait monitoring in order to provide clinicians quantitative parameters of upper limbs' contributions during walking by monitoring axial forces and shear forces, tilt angles, and time of impact on the ground in real time. Always about the evaluation of the gait for post-stroke patients, in (161) it is proposed a novel low-cost system, which relies on a single wearable IMU attached to the lower trunk, to estimate spatio-temporal gait parameters of both hemiparetic and healthy subjects. The accuracy of the measurements is improved by dynamic calibration, related to the "power" of an individual gait pattern, to deal with the typical asymmetry and inter-subject variability of hemiparetic gait. The IMU is also proposed in (162) to improve detecting motion intention from EMG data. The prediction of motion intention is used in motor learning and functional recovery after the occurrence of a brain lesion. In particular, controlled functional electrical stimulation (CCFES) is a new therapy designed to improve the recovery of paretic limbs after stroke, by controlling the upper and lower limbs movements in response to user's intentionality. Electromyography (EMG) signals reflect directly the human motion intention, so it can be used as input information to control a CCFES system. The kinematic measurements from IMU are used in EMG-based pattern recognition process to improve classification. In (163) a system is proposed for the measurement of the knee hyperextension, providing a vibrotactile feedback to the patient. The system uses an inclinometer to measure the patient's knee angle. In (164) the evaluation of the patient progresses is conducted during robot-assisted therapy. In this case, four performance indicators have been defined: (i) the average movement speed; (ii) the number of sub-movements composing the main action, (iii) the remaining error after the first sub-movement, and (iv) the relative time of the first submovement with respect to the total action time.

The fast data throughput available on wide area networks gave a significant impulse to the research about rehabilitation at home (165,166). Several systems have been proposed in the last years, mainly based on body area sensor networks, capable of tracking patient movements during the rehabilitation exercises or his/her normal daily activity. Systems based on wireless sensor networks present several advantages if compared with monitoring systems designed for an ambulatory usage. In particular, wiring is reduced, thanks to the wireless connection of the sensor modules, thus not imposing constraints to the body movement (167). Moreover, since wireless modules are based on a very low-power consuming architecture, such systems are suitable for long-term monitoring. In order to improve the tracking accuracy,it is proposed a low complexity data fusion for the estimation of orientation of MARG (Magnetic, Angular Rate and Gravity) units, capable of compensating the influence of short-duration magnetic disturbances on the magnetometer. Always about home rehabilitation, in (168) it is proposed a low cost measurement device (based on the joint use of Kinetic and Wii balance) to evaluate the position of the center of mass (CoM). CoM has been used to determine stability and visual feedback could be given to patients during the execution of rehabilitation exercises to correct the posture. A personalized CoM estimate is obtained using the statically equivalent serial chain once the model parameters are identified by using the Kinect and Wii balance board.

Functional replacement

This phase is dedicated to the replacement of the permanently lost capabilities, after the treatment, by means of the instrumentation. Therefore, a primary role in this phase is played by the research of the most suitable devices to make functional a lost or not gained motor skill, or modifying the existing equipment to suit every single patient's needs. In this phase, it has to be noted the strong link with occupational therapy, including the design of tools to control the environment around the patient to allow him/her to perform his/her daily activities.

Scientific papers dedicated to the functional replacement mainly deal with the design, the configuration or the optimization of equipment, enabling the patient to perform specific functions, like walking, or moving an object. Patients which lost, also partially, the use of the upper limbs, often use head-trackers to control a computer or other electronic devices. In (169) a head-tracker device is proposed based on a light source, placed on the patient head, and a Charge-Coupled Device (CCD) camera which captures the movement of the patient's head. Then the captured frames are processed to measure the angle of the patient's head. Spinal Cord Injured (SCI) patients are forced to use a wheelchair as they definitively lost the use of the lower limbs. In (170) an auto calibrated head orientation controller for wheelchairs is proposed. The system uses two Orientation Detection (OD) units, each unit includes three MEMS sensors: accelerometer, gyroscope and magnetometer which are combined together. The first OD unit reads the wheelchair orientation, which is used as a reference orientation to calibrate the system performance, when the system is faced nonstraight road. The reference orientation is used to compensate for the changes in orientation in case of non-straight roads and also to compensate the speed in case of ascent or descent a ramp. The second OD unit is fixed on the user's head and is used to control the speed and direction of the system. The head orientation is measured using Euler angles (Roll, Pitch and Yaw). The system movement and speed control depend on the position of the user's head related to X, Y and Z axis. Moreover, for patients that have lost the use of the lower limbs, the pressure applied to the sitting tissue is a relevant factor in the development of pressure sores. A measurement system for the buttock pressure distribution has been presented in (171) to select the best cushion and to adjust the cushion pressure to the sitting position of the patient. The same authors proposed a method that, starting from 6 parameters, including the maximum pressure, the contact area, the sitting balance of the pressure distribution, can aid medical personnel in selecting and adjusting wheelchair cushions. In (172) is proposed a clinical-oriented measurement method, based on calibrated-biplanar radiographs, to generate a subject-specific finite element model of the buttocks in a non-weighted sitting position. The finite element model, by predicting realistic stress distributions, allows for the patient specific selection of a convenient wheelchair seat cushion. The proposed measurement method permits to extend the use of finite element models to study internal stresses in human structures that induce severe pressure sores also for wheelchair users.

In rehabilitation medicine, the physiotherapists train SCI patients to move themselves from their wheelchair to a bed or toilet seat after a push-up motion training. The measurement system proposed in (173) helps the physiotherapist to choose a suitable transfer method for each patient and to train the patient accordingly. The proposed system consists of four force plates and two CCD cameras, and measures the 3-D floor reaction force of the left hand, both legs, and buttock during the side-transfer motion (Fig.5).

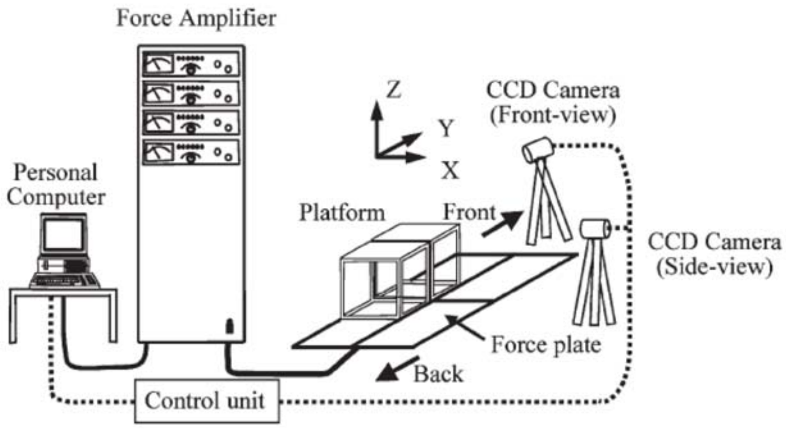


Fig.5. Transfer motion measurement system proposed in [52].

The cameras are used to obtain side and front view images during the transfer motion. An important rehabilitation assistor is the walker. It allows to increase the mobility of the patient, prevents falls and fractures, and encourages independence. In patients using the walker, shoulder joint moments are necessary to detect the onset of tremor associated with fatigue, quantify patient's stability, and identify risk periods within the gait cycle. In order to clarify the side-transfer ability of spinal cord injury (SCI) patients, in (174) the same Authors propose a measurement method to detect the body position during the transfer motion and evaluate the force of right hand. The body position is estimated by the simple human body model that consists of five cuboids, nine columns, and two elliptical cylinders. The vertical force of the right hand is indirectly evaluated from leg forces, left hand force, and left wheels' forces. These last are directly measured by using the same measurement system presented in (173).

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