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THE EVOLUTION OF DEVICES AND SYSTEMS SUPPORTING REHABILITATION OF LOWER LIMBS

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This paper presents the process of development, as well as examples of devices and systems supporting rehabilitation of the human lower extremities, developed independently over the years in many parts of the world. Particular emphasis was placed on indicating, which major groups of devices supporting kinesitherapy of the lower limbs can be distinguished, what are the important advantages and disadvantages of particular types of solutions, as well as what directions currently dominating in development of rehabilitation systems may be specified. A deeper analysis and comparison of several selected systems was also conducted, resulting in gathering the outcomes in two tables. They focused on a few features of mechanical design, especially the devices' kinematic structures, and devices' additional functions associated with, among others, interaction, as well as diagnosis of the limb's state and the progress of rehabilitation.

Key words: kinesitherapy, manipulator, biofeedback, interactivity, exoskeleton.

1. Introduction

Rehabilitation has been an often addressed issue of research and an important part of medicine for many years. People have always suffered from various types of accidents and illnesses that caused impairment of their motor skills. These resulted from mechanical injuries, cardiological and neurological diseases and concerned among others: the spine and other parts of the torso, but mainly the upper and lower limbs.

Many studies show that the essential type of rehabilitation, which restores mobility and motion efficiency, is movement and exercise based therapy (kinesitherapy). Most frequently it is impossible to omit it, but also other types of treatment can be of significant assistance. However, kinesitherapy requires intense involvement of highly qualified physiotherapists that will lead the whole process of treatment and perform adequate exercises with the patient. For the therapist it is not only exhausting, but also very time consuming. For this reason, many patients may not receive sufficiently intensive and long-lasting therapy (Lünenburger *et al*., 2007).

Due to the presented reasons, for many years all around the world, research and development concerning the designing of more and more effective systems supporting rehabilitation of lower limbs have been conducted, which resulted in creation of various equipment. This article focuses on presenting the development directions of systems for the rehabilitation of the lower limbs and the obtained results in the form of created devices. Moreover, an analysis of the selected devices with the focus on their mechanical design features and applications was performed. Its results were shown in tables and a comparison of particular devices' features was conducted, attempting to indicate the advantages and disadvantages of various solutions.

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2. The development of existing systems for lower limbs rehabilitation

2.1. Biomechanics of human lower limb

Device assisting rehabilitation of lower limbs must be able to realize movements such as a human leg. For this reason, the fundamental features of such a device are its degrees of freedom (DOF). Biomechanics indicate a total number of 30 DOF present in a human leg (Bober and Zawadzki, 2003). However, many of them are situated in the foot allowing, for instance, toes activity. In order to obtain a less complicated kinematic structure these DOF may be excluded, resulting in a structure including crucial 7 DOF (Fig.2), enabling performance of the shown limb's movements (Fig.1).

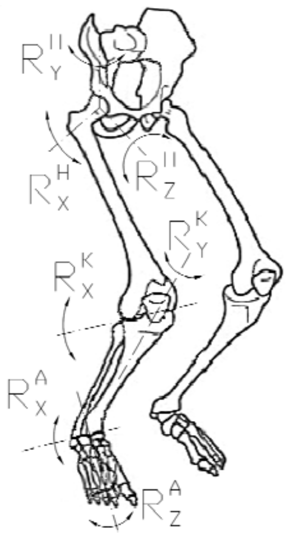


Fig.1. Basic movements of a human leg.

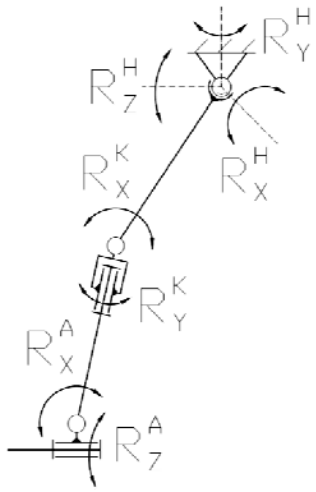
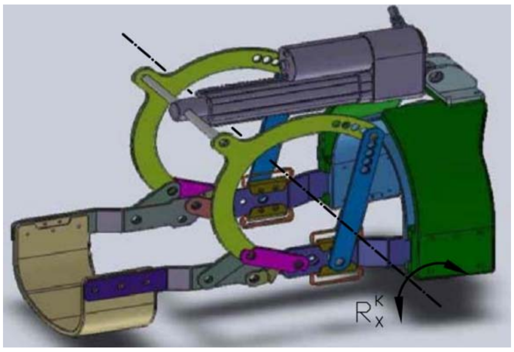


Fig.2. Kinematic structure of a human lower limb reduced to 7 DOF.

The leg's movements performed by selected 7 DOF include (Fig.2): 3 DOF in the hip joint - flexion/extension (***R_X^H***), internal/external rotation (***R_Y^H***), abduction/adduction (***R_Z^H***); 2 DOF in the knee joint - flexion/extension (***R_X^K***) and internal/external rotation (***R_Y^K***); 2 DOF in the ankle joint - dorsiflexion/plantarflexion (***R_X^A***) and inversion/eversion (***R_Z^A***) (Bober and Zawadzki, 2003).

2.2. Examples of existing and developed devices

One of the developing groups includes devices intended for rehabilitation of only one of the leg's joints. An example is a robot for knee joint rehabilitation named Kin-Com (Fig.3), developed at universities in Seoul. The robot's design was based on the fact that position of the instantaneous centre of rotation of a human knee changes during the rotation movement. Therefore, a mechanism based on the Chebyshev's linkage structure was used (Fig.4). It allowed achieving the appropriate trajectory of instantaneous centre of rotation, maintaining required patients posture and obtaining similar to the human knee joint range of motion (ROM) equal to *135*°. A linear actuator was applied to move the femur and an additional link was used to change the actuators translational motion into a rotation of the knee joint. This kind of approach can support the patient's revival of proper ROM, which is the most important in knee joint rehabilitation (Kim *et al.*, 2012). However, it cannot be concluded that such seemingly simpler mechanisms are less technically advanced than more complex and universal devices. They focus on different purpose, which is for example, the best realisation of the kinematics and dynamics of natural physiological human movements. These kinds of devices are currently developed mainly in this direction.



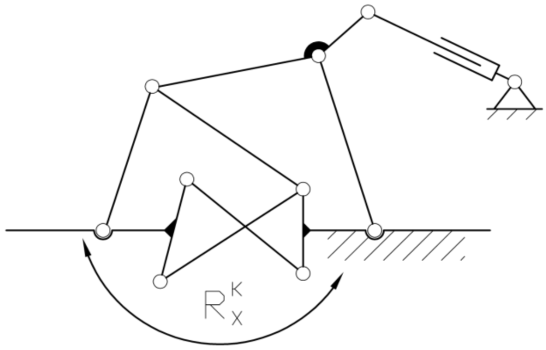


Fig.3. Design of the Kin-Com robot for the knee joint rehabilitation (Kim *et al*., 2012).

Fig.4. Structure of the Kin-Com knee rehabilitation device.

Evolutionary forms of the previous devices are stationary systems intended for the whole leg. They include manipulators fixed to various kinds of frames or seats and attached to the patient's leg. Their structure enables the simultaneous kinesitherapy of several leg's joints. Their distinctive feature is the transfer of the force from the machine to each joint, by attaching structure to the individual parts of the limb. Such a mechanism is incorporated in ITAM* device named Leg-100 (Fig.5). It is used for stationary rehabilitation of lower limbs. It has five degrees of freedom and is driven by electric motors and harmonic gears. An advanced control system of the device consists mainly of a PC and measuring-executive modules. The modules are placed in each joint and communicate with the computer transmitting various data. As a result, they enable recording reference trajectories and realising them during passive training - the movements are conducted by the device without the patient's active participation and effort. The device allows also active training, when the movement performed by the patient is only aided and corrected. In addition, it is possible to assess the progress of rehabilitation by comparing successively recorded trajectories (Michnik *et al*., 2012). There are many other similar robots like for instance: the French Multi-Iso, Turkish Physiotherabot, or a robot especially for children rehabilitation (Wu *et al*., 2011).

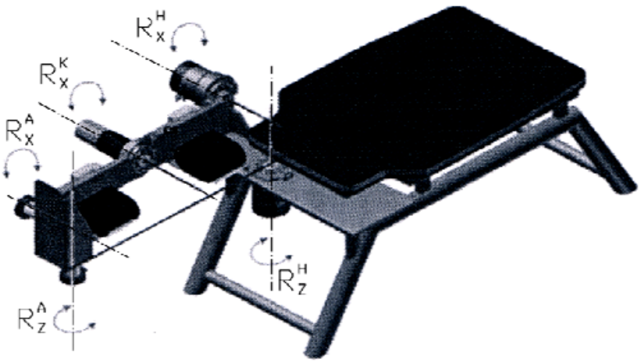


Fig.5. Leg-100 - virtual model with available movements (Michnik *et al*., 2012).

The group of stationary systems may also include devices that transmit motion just on the patient's foot and through it the remaining part of the limb is moved. The robot NeXOS (Fig.6) developed in UK has such features. This system for lower limbs rehabilitation can work in various modes. It is able to act fully

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* ITAM - Institute of Medical Technology and Equipment in Zabrze

independently in a passive mode, provide support for the physiotherapist in an active assisted mode and in a resistive mode it can produce adequate opposing forces for the patient's training. The device has three degrees of freedom: active hip and knee rotation and an additional passive joint enabling rotation of the foot in a limited range (Fig.7). The motion is provided by two pneumatic linear actuators (q_1, q_2). It is equipped among others with precision linear and rotary potentiometers for checking positions of the actuators. The robot is able not only to measure and record the process of treatment, but also to evaluate its correctness and the degree of improvement. For example, the device can measure the patient's ROM and display the results. The whole system is meant to work in "telehealth environment", which means it may be used by the patient at home and via the internet have the physiotherapist's supervision. On the other hand, its largest field of usage is predicted to be the clinical environment. This means that with the aid of this system physiotherapists can work with many patients simultaneously realizing the concept of "superclinics" (Bradley *et al*., 2009).

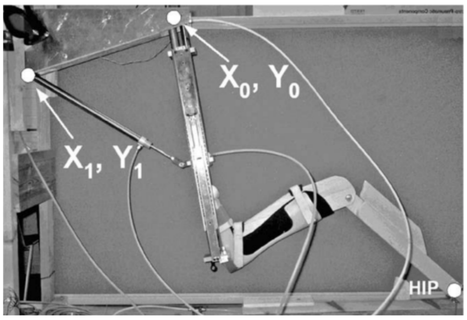

Fig.6. Robot NeXOS- the working rig (Bradley *et al*., 2009).

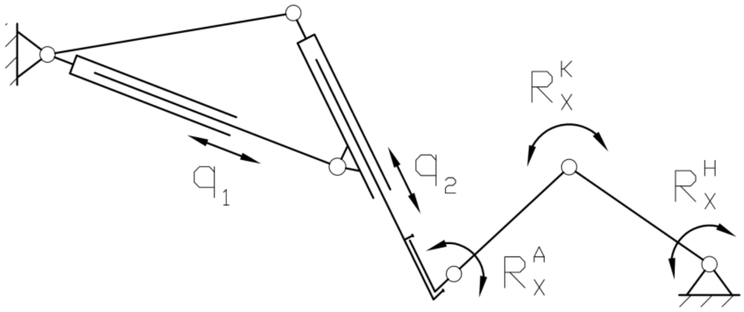

Fig.7. Kinematic structure of NeXOS with a model of human leg attached.

A similar device is Artromot®Active-K from a German company Kalmed. It is equipped with a motor and its kinematic structure provides anatomical movements and ROM for the knee joint (*-10°÷120°*), as well as for the hip joint (*0°÷115°*). During the rehabilitation process the device uses passive, active and resistive training, as well as synchronised electric stimulation of muscles. An embedded sensor measures the strength of the limb and an interactive remote controller with display provides the patient with feedback, which is also recorded. The kinematic system of the device allows its adjustment to different heights of the patients in the range of *135÷205cm*. Furthermore, the device can be used not only in a hospital, but also at home. Another example from the group is a device developed by scientists in Berlin called Haptic Walker.

The next stage of development of stationary systems are devices enabling walking on a treadmill. They support the process of rehabilitation in more serious cases where it is necessary for the patient to re-learn the correct gait. One of them is Lokomat (Fig.8) - a robotic gait-orthosis designed and built in Switzerland (Jezernik *et al*., 2003; Lünenburger *et al*., 2007). The system was developed particularly for rehabilitation of the spinal cord injuries and patients suffering from stroke. Thanks to the automation of treadmill training the length and quality of exercises could be improved. The whole system includes a treadmill, a suspension system to support the bodyweight, the robotic orthosis Lokomat (2 legs) and two PCs. Each leg is equipped with two active DOF- the hip and knee flexion/extension (Fig.9). The ankle joint is moved with a passive foot lifter. The whole kinematic structure is designed in such a way as to address the problem of lateral balance. Motion is provided by linear drives mounted to upper and lower parts of the robotic legs. The patient's limb is fixed to the robot using braces. Apart from working in a passive mode, additional working modes were introduced to allow the patient to actively take part in the training and influence the gait-pattern. This approach improves motivation, as well as muscles' activation and coordination. Training of only one impaired leg is also possible. The force is controlled for the healthy leg to allow movement without resistance, while for the other leg the position is controlled, basing on the first leg's trajectory. In order to measure the actual joint angles and forces of linear drives, respectively precision potentiometers and in-built force sensors are used. The knowledge of driving forces allows determining the torques in the knee and hip joints. Further research conducted with the usage of Lokomat resulted in enhancing the robot with advanced "biofeedback system". This aspect of therapy is also called "feedback" and involves providing patients with current data on the state of theirs organisms, measured by various sensors (Robertson and Roby-Brami, 2010). In Lokomat, apart from the simple feedback, a robot-aided assessment of gait training and rehabilitation process is included. The system's displays may show the current and previously recorded parameters of the gait to the patient and the therapist. This helps to adjust the training to individual needs, basing on the assessed patient's performance and improvement. Furthermore, the patient is able to better fit his movements to the desired pattern and increase his motivation (Lünenburger *et al*., 2007). There is also a robot called LOPES developed in the Netherlands, which is similar to Lokomat in rehabilitation function.

Fig.8. The driven gait orthosis Lokomat Pro (Lünenburger *et al*., 2007).

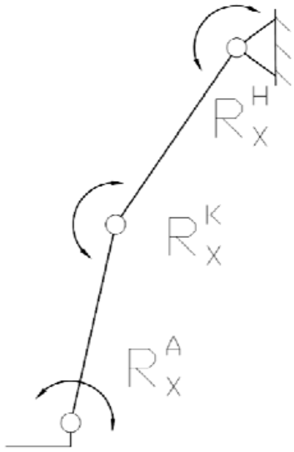

Fig.9. Kinematic structure of Lokomat's single leg orthosis.

Further developments of technology of devices for rehabilitation focus mainly on two types of systems: exoskeletons; and interactive rehabilitation systems enriched with additional mechatronic extensions supporting the recovery process.

Exoskeletons extend the capabilities of previous devices allowing walking on a treadmill. In addition to the rehabilitation of limbs, they enable autonomous bipedal motion out of the treadmill and increase strength and endurance for healthy people. For this reason, many exoskeletons have been developed for the military and their rehabilitation task has become an addition to a wide range of other applications. It was only after that, when exoskeletons were tried to be adjusted to supporting paraplegics and rehabilitation purposes. The University of, Berkeley California was one of the first to start studies on exoskeletons. Their studies resulted in the development of, among others, BLEEX, HULC and, finally, Austin in 2011 and Ekso in 2012 (Berkeley Robotics & Human Engineering Laboratory). However, design of some existing exoskeletons, from the beginning assumed the application in medicine rather than in the military. One of them is the exoskeleton robot suit HAL (Hybrid Assistive Limb) developed by Cyberdyne and University of Tsukuba (Suzuki *et al*., 2007). For the purposes of rehabilitation and resistive exercises a similar robotic exoskeleton named X1 was developed by NASA.

The Polish exoskeleton from the Poznan University of Technology is a prototype of a device for the lower limbs (Fig.10). The robot is placed on the sides of both legs at the same time. It allows not only stationary rehabilitation of the limbs, but also walking on a treadmill. Each limb has four degrees of freedom two passive and two driven by electric motors (Fig.11). The exoskeleton provides sufficient ROM in individual joints and smooth adjustment of parts' dimensions, allowing easy and quick adaptation to different people. It is equipped with limit switches to restrict the ROM, as well as with encoders in particular joints and pressure sensors in the straps fixing the device to the limb. It also has the ability to register EMG signals (Kaczmarek *et al*., 2012).

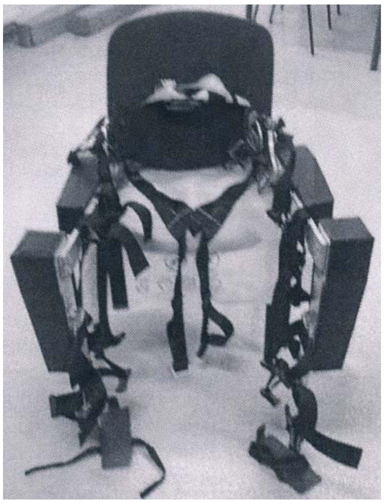

Fig.10. Prototype of lower limbs exoskeleton from the Poznan University of Technology (Kaczmarek *et al*., 2012).

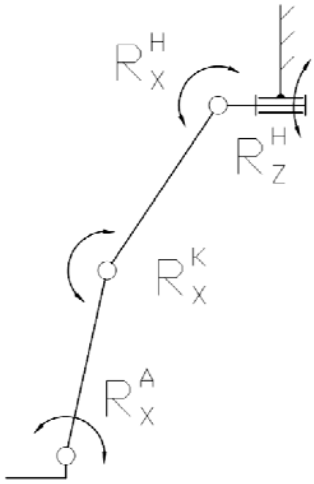

Fig.11. Kinematic structure of exoskeleton from the Poznan University of Technology.

The second group of systems being currently rapidly developed are machines constituting a continuation of studies on stationary manipulators. These are the already mentioned rehabilitation devices with mechatronic extensions, which among others increase the patient's motivation. It is extremely important in terms of the obtained results, since a common problem that therapists need to cope with is the patient's low motivation. However, there are ways to influence the patient's condition and improve their level of motivation (Pilch, 2011). By applying serious computer games or virtual reality technics, tedious repetition of movement patterns becomes much more interesting and less arduous. This can be incredibly useful, for instance, in the case of younger patients (Michmizos and Krebs, 2012). The games difficulty can be individually adjusted to the patient and his progress. Furthermore, each game can be directed towards improvement of different aspects, like dexterity or on the contrary speed and force. However, the mere repetition of movements is not enough. Each action must focus attention, have meaning and be goal oriented. Research indicate, that this type of therapy causes positive neurophysiological changes in the spinal cord and brain (Robertson and Roby-Brami, 2010). Moreover, for many patients the level of motivation is associated with independence. For this reason, if they are deeper involved in the rehabilitation process and able to work more autonomously with the rehabilitation devices, it will positively affect the treatment outcomes. A similar effect will arise from their ability to observe and evaluate the progress of therapy, with the usage of feedback. With this information, individuals learn how to change their movements to achieve the determined goals of rehabilitation and become aware that they are able to perform the given tasks. This is also a kind of praise and encouragement to further work (Pilch, 2011). Biofeedback is made possible, for example, by visualization of the results of consecutive training sessions or comparison of current and recorded data about the state of the limb, such as the angular ROM in the joints. In addition to the visual transmission of such information, other methods include acoustic transfer and vibrotactile stimuli. The possibility of obtaining data on the parameters of the limb and the progress of therapy is also very important for the rehabilitants. Due to the use of mechanical devices, they lose the ability to assess the patient's condition basing on their own physical sensations during conventional-manual therapy (Lünenburger *et al*., 2007).

A good example in this group of devices and the trend of development is Anklebot designed by researchers at MIT (Fig.12) (Michmizos and Krebs, 2012; UM Rehabilitation and Orthopaedic Institute). Presented in 2011, Anklebot is a device that aids improving walking and balance functions, as well as return of ROM, passive stiffness, strength and motor control, including poor coordination, speed or accuracy. Most of the time the device delivers only a gentle push on the limb to help the movement. A larger force is used when the trajectory deviates strongly from the assumed. The device serves only ankle treatment, but allows movement in 3 DOF (Fig.13) (Michmizos and Krebs, 2012; Advance Electronic and Medical Industries Co. LTD). However, only two of them (ankle dorsi/plantarflexion and inversion/eversion) are active and the third (internal/external rotation in the knee joint) is passive. The actuators are 2 brushless DC motors with linear traction drives used to magnify their torques. Actuators are mounted parallelly and provide torque for dorsi/plantarflexion when working together in the same direction. The inversion/eversion movement is achieved by an opposite work of both motors. Rotary encoders, as well as incremental linear encoders, are mounted on the actuators to measure their position and torque. This data is then used to estimate the angles of ankle position. The state of sensors and actuators is monitored by an additional electronic system. The robot is attached to the thigh and shank by an orthopaedic knee brace, straps, quick-release mechanisms and an orthopaedic shoe. An additional connection is a shoulder strap that provides support of the robots weight (Khanna *et al*., 2010). People of both sexes with different leg dimensions may use the device, as a result of the availability of various sizes of knee braces and orthopaedic shoes (Advance Electronic and Medical Industries Co. LTD).

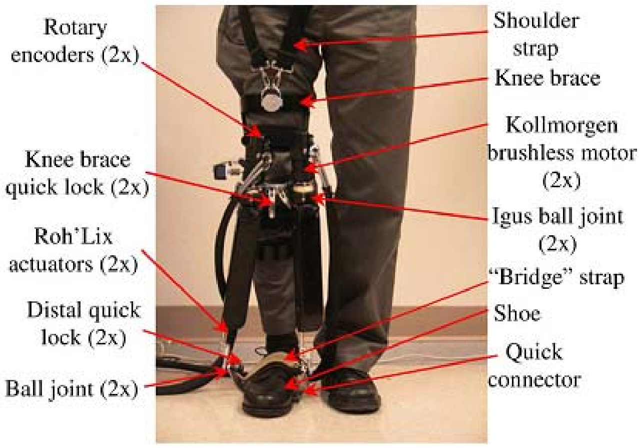

Fig.12. View of a mechanical device for rehabilitation - Anklebot (Advance Electronic and Medical Industries Co. LTD).

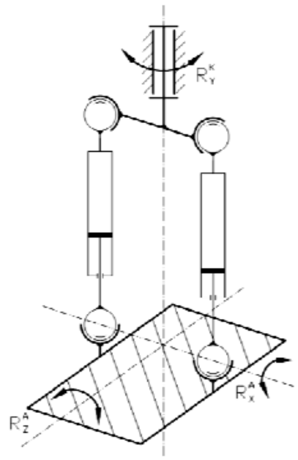

Fig.13. Kinematic structure of Anklebot.

The whole system comes with equipment and games creating an interactive environment enabling treatment in a seated position, as well as task oriented training on a treadmill. Furthermore, the system is capable of assessing patient's current progress and performance. Additional serious games were developed for this device. The most challenging of them is the Shipwreck, because patients are moving their ankle in both active DOF to control 4 barriers preventing a ship from crashing. What is more, the gameplay environment is the most changeable of the 3 available games. They were designed in such a way to enable training of various features like dexterity or velocity. The difficulty level may also be adjusted to individual needs and improvements by changing the ROM, level of assistive force, targets size or the game's speed. There are also works concerning using this device along with electroencephalography (EEG) to assess the influence of the training on brain "plasticity" (Michmizos and Krebs, 2012; Advance Electronic and Medical Industries Co. LTD; UM Rehabilitation & Orthopaedic Institute).

Intensive development of devices supporting kinesitherapy takes place also in Poland. Since as early as the sixties of the twentieth century, research has been carried out among others in Warsaw at the Technical University and PIAP†. The result was the creation of the first Polish rehabilitation robots Renus-1 and Renus-2 intended respectively for support of the arm and leg. The research was conducted as well at

† PIAP- Industrial Research Institute for Automation and Measurements

ITAM, where manipulator Arm-100 for rehabilitation of the upper limb was constructed. Afterwards, basing on these experiences, the already described device Leg-100 designed for the lower limbs was created. Furthermore, for many years, studies on the construction of an artificial arm has been carried out at the Wroclaw University of Technology (Nawrat, 2012).

The mentioned device Renus-2 is a mechatronic system supporting the rehabilitation of the patient's lower limbs, through realisation of a complex spatial movement. It can save the defined trajectory, realise it during a passive training, as well as operate in a resistive mode when the manipulator provides a slight programmed resistance force opposing the movement performed by the patient. It is also possible to collect, display and record data about the movements of the limbs and the progress of rehabilitation (PIAP).

The new rehabilitation systems recently built in Poland are: the prototype of the exoskeleton of the lower limbs from the Poznan University of Technology described earlier (Kaczmarek *et al*., 2012) and the manipulator for the rehabilitation of legs of patients with cerebral palsy constructed at AGH University of Technology. The works are also in progress at the Silesian University of Technology. Following the recent construction of an exoskeleton for the upper limbs controlled by myoelectric signals, a mechanism intended for the lower limbs has been developed (Egzo.polsl.pl). Moreover, an ongoing research is currently conducted at PIAP under the project "Exoskeleton" started in 2013. Its aim is to develop a demonstrator of technology for lower limbs and spine exoskeleton.

3. Comparison and analysis of devices for rehabilitation of the lower limbs

A more detailed analysis of selected rehabilitation systems and their comparison in terms of several important features, divided into two groups, reveals the advantages and disadvantages of different solutions. The first group includes features related to the mechanical design like: the amount, type and position of the DOF; the ROM in particular joints; the ability to adjust the device's dimensions to various patients and the type of drive (Tab.1). The second group contains features connected with additional assistance of the rehabilitation process like: sensors, interactivity, the ability to diagnose the state of the limb and progress of rehabilitation (Tab.2). Although the price of the system does not affect the healing process, it constitutes an important factor indicating the availability of the device. The details of the exact prices of the devices are hardly available, but the vast majority of them is very expensive, which limits their field of application to clinics and hospitals, not allowing common home use (Ceccarelli *et al*., 2014). The selection of various systems included in each of the tables was caused by an attempt to show and compare best the interesting features. In some devices detailed data of these features were not available, or did not exist at all. Furthermore, in Tab.2 the exoskeleton of the Poznan University of Technology and the first device from Tab.1 were omitted, since they are only slightly mechatronized.

It should be noted that even after simplifying the human leg's movements, there still remain 7 DOF (Bober and Zawadzki, 2003). None of the compared devices had the number of DOF even close to that, not to mention the number of active DOF, ensuring full control. For this reason, the presented devices do not reflect the actual mobility of the human leg and most of them allow the limb's rehabilitation only in the sagittal plane. Furthermore, one cannot forget about the occurrence of "compensatory strategies" during the rehabilitation process. The patient's organism replaces the lost mobility, by compensating it using other joints and muscles. In such cases, no correct rehabilitation of a damaged place occurs, but merely teaching the patient the erroneous replacement movements. Therefore a very important aspect of rehabilitation is the control of the whole leg's movements, including particular joints and muscles used by the patient. Such control and obtainment of appropriate treatment can be supported by the already mentioned biofeedback (Robertson and Roby-Brami, 2010).

Devices that besides the rehabilitation of limbs, allow also the "retraining" of gait are very useful and popular (Lünenburger *et al*., 2007). Conventional treatment requires the simultaneous involvement of two or even three physiotherapists. Thus, it is easy to notice that devices such as the Lokomat, aid the therapy and save time as well as work. Thanks to them the treatment can be carried out under supervision of only a single specialist. Researchers also indicate that treadmill training allows achieving greater symmetry than training overground and as a result causes better improvement of gait pattern. What is more, it is suggested that combining treadmill training with electromechanical-assisted gait training may show even better results (Khanna *et al*., 2010).

The lack of powered DOF at the dorsi/plantarflexion of the ankle joint in most of the assistive devices for the whole leg, as well as gait training is surprising; especially, in view of the frequent post stroke complication called “drop foot”, caused by the dorsiflexor muscle weakness. Its features are “foot slap”- hitting the ground with foot after the heel contact and dragging the toes over the ground during the “toe swing” phase (Advance Electronic and Medical Industries Co. LTD).

Table 1. Comparison of 6 presented devices concentrating on features from the first group (mechanical design features).

Feature / **Name of System**	**Particular DOF of one limb and overall sum of DOF**								**Adjustment of the dimensions to the patient**	**Type of drive**
	R_X^H	R_Y^H	R_Z^H	R_X^K	R_Y^K	R_X^A	R_Z^A	**Sum**		
Kin-Com	-	-	-	A ROM 135°	-	-	-	1	ND	Electric linear actuator
Leg-100	A	-	A	A	-	A	A	5	Smooth adjustment of the limb parts' dimensions using extending actuators	Rotary electric motors
NeXOS	A	-	-	A	-	P	-	3	Accommodates different leg sizes	Pneumatic linear actuators
Lokomat	A	-	-	A	-	P	-	3	ND	Electric linear actuators
Lower limbs exoskeleton (Poznan University of Technology)	A ROM -12° ÷ +38°	-	P	A ROM 0° ÷ +59°	-	P	-	4	Smooth adjustment: Hip width *300÷535mm* Thigh's length *350÷532mm* Tibia's length *335÷554mm* Ankle joint's height of axis *72.5÷112.5mm* Hip joint's axis *63÷163.5mm*	Rotary electric motors
Anklebot	-	-	-	-	P ROM 15°	A ROM -25° ÷ +45°	A ROM -25° ÷ +20°	3	Different sizes of knee braces and orthopaedic shoes	Rotary electric motors with linear traction drives
Legend: The appropriate degree of freedom of the device is: A - active, P - passive, “-“ does not exist ND - no data available										

As for the drives, it is believed that the application of light pneumatic actuators causes little additional strain on the treated limb. However, some research conducted with the usage of other devices like Anklebot indicates no substantial alteration in the gait pattern caused by the additional mass of the machine even with an unpowered device. Moreover, the results and conclusions signify that exoskeletons may possibly be worn by patients safely and with negligible impact on their gait pattern (Khanna *et al*., 2010).

Table 2. Comparison of 4 devices concentrating on features from the 2nd group (Additional support for rehabilitation).

Feature / System's Name	Sensors and measurements	Interactivity	The ability to diagnose the state of the limb and progress of rehabilitation
Leg-100	Force and pressure measurement	Recording the limb's reference trajectories	Comparison of recorded trajectories
	Angles and velocities measurement for particular joints		
NeXOS	Angles and displacements measurement	Possible physiotherapist's supervision by internet while used at home	Measurement, recording and evaluation of the degree of improvement
Lokomat	Angles and forces measurement	Advanced biofeedback system	Evaluation of the efficiency and progress of training and rehabilitation
		Displays current and recorded parameters of gait	Measurement of the patient's force shortage
Anklebot	Angular and linear displacements measurement	Serious games	Quantifiable feedback on progress and performance

Based on the comparison in Tab.2 it can be concluded that mechatronization and interactivity of rehabilitation assistive devices are widely developed and implemented. It can be stated that robotic rehabilitation and gait training should be supplemented by biofeedback allowing introduction and improvement of robot-aided training, as well as robot-aided assessment. Biofeedback may not only be the source of knowledge about the patient's performance, but also a way to assess the rehabilitation progress and improvements. In addition, it can provide further motivation to the patient and be a good way to introduce individual training suited for each person (Lünenburger *et al*., 2007).

4. Conclusions

The examples of rehabilitation devices and systems presented herein are only a part of the whole range of similar equipment, which has been developed independently over the years in many parts of the world. This review, however, shows well which major groups of devices supporting kinesitherapy of the lower limbs can be distinguished. It also indicates what are the important advantages of particular types of mechanisms. What is more, it describes directions currently dominating in the development of rehabilitation systems.

In addition, a deeper analysis and comparison of several selected systems supporting rehabilitation were conducted. Focus was placed on a few features of mechanical design and their additional functions associated with sensors, movement programming, interaction, as well as diagnosis of the limb's state and the progress of rehabilitation. It was concluded that the features mentioned in the second group, currently have the highest potential for development for this type of systems. Moreover, this area is a subject of interest not only to the researchers, but also to rehabilitants, who in the development of equipment rehabilitation see a chance to receive even greater support in their work. Applications of such devices are very likely to cause an improvement in results of the patient's rehabilitation by increasing their independence and motivation.

Medical robots have already been adapted as great tools to assist in the diagnosis and rehabilitation. In the near future, a significant growth in the number of required systems around the world is predicted. As a result, many new devices, having improved effectiveness and lowered cost, will be developed. Moreover, this approach may be the only sensible way to respond to the increasing social demands in the medical field (Nawrat, 2012).

Nomenclature

A	– active degree of freedom of a device in Tab.1
DOF	– degrees of freedom
ND	– no data available in Tab.1
P	– passive degree of freedom of a device in Tab.1
ROM	– range of motion in the joint
R_X^H	– flexion/extension in the hip joint
R_Y^H	– internal/external rotation in the hip joint
R_Z^H	– abduction/adduction in the hip joint
R_X^K	– flexion/extension in the knee joint
R_Y^K	– internal/external rotation in the knee joint
R_X^A	– dorsiflexion/plantarflexion in the ankle joint
R_Z^A	– inversion/eversion in the ankle joint
Sum	– total number of degrees of freedom for a particular device in Tab.1
"-"	– particular degree of freedom does not exist in the case shown in Tab.1

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