Active Walking Mechatronic System for NeuroRehabilitation

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Abstract: - Traditional rehabilitation therapies for locomotor disabled persons use several therapists that help patient to fulfill physical exercises. The actual rehabilitation therapies use mechatronic or robotic systems. Most of them use various devices such as treadmills, suspension systems and virtual reality systems. All of these therapies use the so-called passive walking: the patient follows a predefined walking program. The concept can be called “Patient Follows the System” - PFS. These programs try to copy reality but they cannot duplicate it. The paper presents a new mechatronic system based on active walking as well as a brand new concept, defined herein as: “System Follows the Patient” - SFP.

Key-Words: mechatronic, robotic medical rehabilitation

1 Introduction

One of the most important factors that influence a person’s quality of life is walking ability. The quality of life implies the level of accomplishment of many individual daily activities and the level of participation in social and economic life and development.

Locomotor disabilities affect profoundly the normal life. These disabilities have several medical, traumatological and, most important, neurological causes: stroke, inflammatory and degenerative disorders of the central nervous system’s tissue, central, cerebral and spinal cord injuries, as well as peripheral neural injuries [1-3].

The classic medical and neurological rehabilitation use manual and assistive techniques (massage, exercises, etc.) involving the presence of several therapists but also, an intense participation from the patient.

Treadmill (TM) rehabilitation appears in the 80’s. Since than, several gait trainer models where developed for human locomotor rehabilitation. Suspending the patient over a treadmill has become a classic therapy. This therapy presents two major restrictions:

- assisted therapy;
- replacement of the physiological gait.

The first restriction implies the presence of several therapists (at least two) that have to help and sustain the patient.

The second one states that the natural body movement, on multiple directions and various planes, through its own pulse and efforts was replaced with a single direction movement on an artificial element (treadmill).

The results of these two restrictions are:
- a uniform and unidirectional motion of the lower limbs;
- the body is forced to follow the same non-physiologically movement;
- the therapy is made in a non-natural, virtual displacement.

Researchers consider that modern robotics and virtual reality technologies have great future and are important in the rehabilitation of patients with locomotor disabilities, due to the large number of patients who need a well-developed therapy, adaptable to any specific need [4,5].

Robot-based technologies present some major drawbacks: repetitiveness of movements (turning later on, from being an advantage in the early phases of the rehabilitation, into an involution factor), treatment is done in an "artificial" environment, other than the one patient’s normally operates on a daily basis.

These rehabilitation technologies focus on repetitiveness. This is good for walk re-learning, but walking in these conditions is a passive activity, the patient moving accordingly to predefined, external and non-personal programs, hence arising slower effects. The major drawback of these robotic systems is that the patient walks passively [6].

All of these therapies use the so-called passive walking: the patient follows a predefined walking program.

The concept can be called “Patient Follows the System” - PFS. These programs try to copy reality but they cannot duplicate it.
Lately, a new orientation using mechatronic systems to carry out an active walking treatment, has started to be developed.

Under these circumstances, an issue arises more and more often: Which solution is the best one? Passive or active movement therapy?

Or, from the rehabilitation system designer’s perspective: Robotics or Mechatronics?

2 State of the art: Recovery Systems

The use of assistive equipment imposed itself as an alternative to classic, assisted by human’s physical therapy.

Such equipment can consist of a treadmill with specific assistive devices - suspension systems (harnesses, bars, etc.) e.g. Gait Trainer 2 (Biodex) [7]. This led to improved walk performance, but the results aren’t superior to classic methods, therapists’ effort still being high, with low impact over the rehabilitation period and effectiveness.

During the therapy with these treadmills it is impossible to simulate real and complex situations encountered in everyday life (climbing stairs, walking over rough terrain etc.) and that is a major disadvantage.

An essential factor, with negative impact on recovery, is that **treadmills cannot even simulate a real, natural one directional gait**! This is because the treadmill is moving, and the feet must obey and move accordingly, while the general vision for the user is a static one.

Probably the most used robotic systems used in rehabilitation are Lokomat (Hokoma) [8], Robomedica [9]. Universities from several countries (Germany, Great Britain, France, Italy, Spain, USA, Japan etc.) designed and developed similar robotic systems.

The state-of-the-art robotic systems use virtual reality, for a simulation as realistic as possible.

All these robotic systems were designed and developed to use the PFS therapeutic concept.

The last decade presented some mechatronic systems that simulate human walking, with outstanding results in practice. These systems also use the PFS therapeutic concept.

The first system of this type was developed by a team of German engineers and physicians from University of Berlin lead by Prof. Stefan Hesse [10]. The device was a first for its time, allowing patients to practice human walking movements with direct assistance from the therapist.

A similar system (SIMESIM) was produced in Romania, in 2008, by a team led by Assoc. Prof. Petre Lucian Seiciu from the University Politehnica Bucharest [11]. This mechatronic system uses an original concept [12] to simulate lower limb movement.

Figure 1 presents a photo of the system meanwhile figure 2 shows the mechanical design.
The hardware interfaces are:
- serial communication interface between PC stand and converter;
- serial communication interface between converter and controller stand;
- process interface between controller stand and stand transducers and working elements. Unified signals are brought by in the local screen.

Communication Interface between real-time database and high level batch processing database (PC);
Communication Interface between levels MODBUS Protocol components installed on the PC (OPC – for the Master Hub Server) and communication software MODBUS on the Controller (for the Slave Hub).

The system presents also several Batch Database Interfaces:
- main batch database operating screen;
- patient ID entering screen;
- patient rendering-back screen for biometric data entering;
- biometric data screen;
- patient browsing screen for file completion/checking etc.

Fig. 3 Hardware system architecture

Figure 4 presents the software system architecture. The main software interfaces are:

The system has real-time database and batch database. The system presents an end-user interface that is updated and reloaded every time it is used. Another original concept consists in introducing a sub-system for upper limb movement, which may be
trained in phase (skiing) or anti-phase (normal walk) with lower limbs [13]. Lower limb movement is similar to the treadmill one, but with continued need for one or two therapists’ support. All these systems are walk-in place devices where the patient "moves" only in one single direction (forward) using passive walking. These devices are just a modified and incomplete substitute for reality.

3 State of the art: Scientific Research

Scientific literature studying rehabilitation with the above described systems is extensive; therefore I will present just a few important research studies done in the last decade. Moseley et al. (2005) made a comprehensive analysis on 15 TM types, concluding that there are no obvious statistical differences between the treadmill exercise and other physical therapy methods [14]. Other researchers have concluded that exercising with treadmill systems lead to a faster gait improvement, especially in combination with suspension systems. Eng and Tang (2008) point out that optimal rehabilitation schedule should consist of repetitive elements and intensive mobility which need to be increased gradually as tolerated by the patient [15]. Assistive technology, such as electrical stimulation also plays an important role in rehabilitation, but in most cases it cannot be done outside hospital boundaries. Ideal rehabilitation programs must combine a variety of exercises that include treadmill walking (especially at high speed), suspension systems, overground gait, climbing/down slopes and stairs, all complemented with “traditional” methods (weight lifting, aerobics, increase in functional strength and balance exercises and so on). Gilpin (2009) studied comparatively TM with suspension (STM) gait and overground ambulation (assisted walking on the ground) [16]. Study findings were:

- advantages of STM therapy are: repetitiveness, treatment can be started in early stage, development in a safe environment;
- disadvantages of STM therapy are: high initial cost, the necessity of a second therapist involvement, treatment period shortening due to all time needed for necessary adjustments;
- both methods are safe and effective;
- in terms of walking speed and distance, therapy with suspension across the treadmill isn’t more effective than the traditional one;
- in terms of quality, both therapies complement and reinforce each other, so as, used together lead to better results than carried out separately.

Field-Fote et al. (2011) compared changes in walking speed and distance using four different locomotor therapeutic approaches: TM with manual assistance (TMM), TM with stimulation (TMS), overground gait with stimulation (OGS) and TM with robotic assistance (TMR) [18,19]. The conclusions were:

- for patients with chronic motor incomplete, walking speed improved with both OGS and TM therapies;
- walking distance improved a lot more in exercises with OGS;
- overground walking therapy offers patients an experience that is closest to normal walking;
- overground gait therapy teaches patients how to generate and control the forces necessary to initiate stepping and body movement as well as how opportune is to exercise and improve their performances;
- fundamental principles of walking learning, like intensive and repetitive exercises, specific exercises and problem solving opportunities, are best applied on overground therapy.

Today’s most locomotor recovery systems are based on treadmills. Walking on a TM is like stepping on a flat, soft, covered with carpet surface. In fact, the patient should walk both on the ground and on more complex surfaces such as climbing stairs, slippery, uneven or even muddy surfaces. Therefore we can affirm that TM is unsuitable for practicing locomotor function because they lack the flexibility patient’s need to adapt to complex surfaces.

4 A New Mechatronics System Concept

An optimal rehabilitation program should consist of [13]:

- repetitive elements of intensive mobility and gradual intensity;
- assistive technology (e.g. electric stimulation);
• a variety of exercises (walking on TM, TM suspension system, open field walking, climbing/descending slopes and stairs etc.);
• "traditional" methods (weight lifting, aerobics, strength and balance exercises etc.).

Currently there is no system that includes, in its construction, two or more of these conditions!

A team of researchers from University Politehnica of Bucharest and Elias Emergency University Hospital in Bucharest is developing a new therapeutic system named RELIVE, based on the concept of patient’s active overground walking. RELIVE combines several of the above requirements, constituting itself into a pioneer at international level. The system can be characterized by the unique combination: Reality through Repetition - Intensity - Variability (RIV).

RELIVE therapy is based on active walking as well as a brand new concept, defined herein as: “System Follows the Patient” - SFP.

The project will develop a controlled habitat (CH) for the rehabilitation of patients with locomotion disabilities. CH consists in a mechatronic complex system (MCS) functioning within a treatment area endowed with several simulation systems.

MCS integrates several independent sub-systems facilitating patients movement, motion analysis and environmental effect: electro-mechanic movement system; controlled patient’s suspension system; patient’s position, orientation and movement measuring system (PMS); integrated reality system (IRS).

RELIVE allows making complex therapy programmes based on patient’s active motion, in free choose or pre-established task schedules. The mechanical and electronic devices for control and monitoring within the mechatronic system will perform various complex neuromotor rehabilitation procedures for locomotor disabled patients, by combining 12 typical walking independent programs with proper nervous stimulation.

5 Conclusions

Rehabilitation treatment for people with locomotor disabilities had an exponential growth in the last 50 years, passing from classical therapy, assisted by several therapists, to mechanized therapy (with treadmill), robotic or mechatronic systems. All of these therapies have been important forward steps in improving patients’ live. However, after in-depth studies, it was found that these therapies cannot be universally used in all the disabling medical and neurological conditions; moreover, they are effective only in certain stages of the disease.

The main drawback consists in that they rely on patients’ passive walking. These systems use a concept that defined herein as "Patient Follows the System" - PFS. RELIVE therapy mechatronic system uses overground walking, being a step forward in the field since it can work both, in active and passive walking mode.

The system uses a new concept that herein we define as: "System Follows the Patient" - SFP. RELIVE can use 12 independent walking programs, tailored for different pathologies, different stages, different goals of the therapy programmes, unlike all other systems that use a single walking program. The system’s parameters may be customized and individually setted.

RELIVE may prove a reliable rehabilitation tool and a rehabilitation research tool, also. As it was stated before, an optimal rehabilitation program should consist of a combination of several (more or less successful) treatments such as repetitive elements of intensive mobility and gradual intensity, assistive technology, "traditional" methods such as weight lifting, aerobics, strength and balance exercises, robot and/or mechatronic based exercises (walking on TM, TM suspension system, open field walking, climbing/descending slopes and stairs etc.). The ideal therapy should bet based on as closed as possible to real life situations and the final goal is total locomotor rehabilitation.

References:


