THE PUBLISHING HOUSE
OF THE ROMANIAN ACADEMY

PROCEEDINGS OF THE ROMANIAN ACADEMY, Series A,
Volume 17, Number 3/2016, pp. 253–258

HIP VERTICAL MOVEMENT MECHATRONIC SYSTEM FOR GAIT REHABILITATION

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Abstract. The hip vertical movement (HVM) mechatronic system presented in this paper is a world-wide premiere and will be an important aid designed for medical recovery of the patients with neurological affections. The system simulates the patient's alternate side hip vertical movement during gait. No actual recovery mechatronic systems have the property of moving alternatively the patient's hips. The vertical movement is transmitted to the patient's hips with the help of any known body weight support system; therefore HVM system can be easily adapted to the existing recovery systems. Recovery is achieved by the patient's active or passive motion (walking). The need of the design and execution of this new system follow the conclusions subsequently to an extended state-of-the-art research in the domain. The hip vertical movement (HVM) mechatronic system is currently proposed to be patented.

Key words: gait rehabilitation, mechatronic system, overground gait.

1. INTRODUCTION

Gait is mankind natural mean of transportation. Diminishment or loss of gait capability leads to a decrease of the person's quality of life, on different degrees, due to complex disabilities generated or supported by the specific gait impairment. Gait impairments are due to neurological, musculoskeletal or trauma conditions. The number of persons with gait imparity is rapidly increasing due to the continuous extended life span (and the subsequent increasing number of older persons with chronic disabling diseases) and to the rising number of accidents that occur in modern 21st century life. More than 15% of the world population lives with a certain degree of disability [1]. The increased number of gait impaired persons leads also to an increased pressure on health and social services and finally on European budget. Assistive technology is used nowadays on larger and larger scale in order to diminish the mentioned negative trends. The assistive technology devices are designed and experimented by large, interdisciplinary teams consisting of rehabilitation medicine specialists, mechatronic engineers and control systems engineers [1].

The new Advanced Rehabilitation Technology (ART) combines the "traditional" rehabilitation technologies with Assistive technology and Rehabilitation Mechatronics and Robotics in order to obtain complex systems that provide, at the same time, therapeutically and assistive functions [2].

This domain's inception was given, in the early 80s, by the first use of treadmills for gait recovery, now considered as "classical assistive technology". This important stage was shortly followed by new systems using body weight support. At this point, two important but different approaches appeared: mechatronic systems and robotic systems. These two rehabilitation systems were developed largely, combined with new technologies (as virtual reality) each of them presenting both ups and downs.

2. MODERN GAIT REHABILITATION SYSTEMS

The most often used robotic systems for gait rehabilitation are the ones for assisting and coordinating the subject's gait.

These systems include special treadmills, body weight support (BWS) and lower limb movement assisting systems, as Lokomat [3], Robomedica [4], Litegait [5].

Mechatronic systems are mostly used for simulating human functional gait – the first system of this kind was developed by Prof. Stefan Hesse team, at the University of Berlin [6]. It allows the patient to practice human walking movements, using direct assistance from the therapist. A similar system, called SIMESIM, was developed in Romania, from 2008, by a team led by Prof. Petre Lucian Seiciu of Politehnica University of Bucharest [7]. SIMESIM uses an original concept to impose real walking like movement to the lower limbs of the patient [8, 9]. Lower limb movement is similar to the treadmill one, but with continuous support from one or two therapists. Another original concept consists in introducing a sub-system for upper limb movement, which may be driven in phase (skiing) or anti-phase (normal walk) with lower limbs [9].

Another modern approach consists in smart neuro-prosthesis such as the device produced in Professor’s Jose del R. Millan Laboratory, from Ecole Polytechnique Federale de Lausanne, Swiss [10].

Virtual reality along with wireless technology using inertial sensors and visual feedback (Kinect and Wii devices) are already used to support active rehabilitation [11, 12].

All the state-of-the-art rehabilitation systems use patient’s gait on treadmill (TM) with body weight suspension (BWS) or overground ambulation (assisted walking on the ground) with BWS. All these systems are walk-in place devices where the patient “moves” only in one single direction (forward). Most of the last decade’s studies conclude that these devices are just *an incomplete substitute for reality*.

An optimal rehabilitation program should consist of [13]:

• repetitive elements of intensive mobility and gradually increased intensity;

• assistive empowering technology (e.g. electric stimulation);

• a series of different exercises (walking on TM, TM suspension system, open field walking, climbing/descending slopes and stairs etc.);

• ”traditional” methods (weight lifting for strength, aerobics, balance and coordination exercises etc.).

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

3. A NEW MECHATRONIC SYSTEM CONCEPT

An interdisciplinary team of researchers from University Politehnica of Bucharest and Elias Emergency University Hospital in Bucharest is developing a new therapeutic system [7] based on the concept of patient’s active overground walking using a new, original approach [14].

One of the new rehabilitation system’s cutting-edge solutions is the Hip Vertical Movement (HVM) Module. HVM Module facilitates both the patient Center of Mass (COM) vertical displacement and the alternate hip vertical movement.

Murray *et al*. [15] determined that the gait parameters for health persons are: gate cycle period – 1.03 sec (90÷120 single steps/min); comfortable gate speed – 4.5 km/hour; average step length – 700÷820 mm; average step width – 7÷8 mm. Elderly have shorter steps with lesser flexion-extension angles. Women have larger side hip displacement.

HVM Module solves the problems of achievement, impulsion and assisting the vertical up and down hip movements during the gate cycle in order to obtain a physiological gate with the COM trajectory within normal gate. The vertical movement is achieved through alternative lift and descent of the hip sides, similar to physiological gate. The hip vertical trip will be personalized according to one’s anthropometric parameters, the pathologic condition, the functional rest and the objectives of each rehabilitation program stage. HVM Module is endowed with a rotation mechanism around the vertical axis. This mechanism rotates the four suspension belts (laterally placed, in pairs and in front and back of the patient).

Figure 1 presents the cinematic schema of the HVM Module. In this figure, the patient supposedly stands with the back.

The patient is suspended by the rotating carriage (1) mounted on the girder (2). The girder can be fixed or can move on roller slides (3) along a fixed structure. The carriage is rotated by a cog belt transmission (4) actuated by a rotating geared motor (5). All the system is mounted on girder (1).

Patient vertical position is achieved with the vertical movement system, mounted on the rotating carriage (1) and consisting of the rotating geared motor (6) that rotates the drum (7) on which, cables (8) and (9) are coiled. The force transducers (13) and (14) have double roles: for patient weighting (before the exercise starts) and for active feedback (during the exercise).

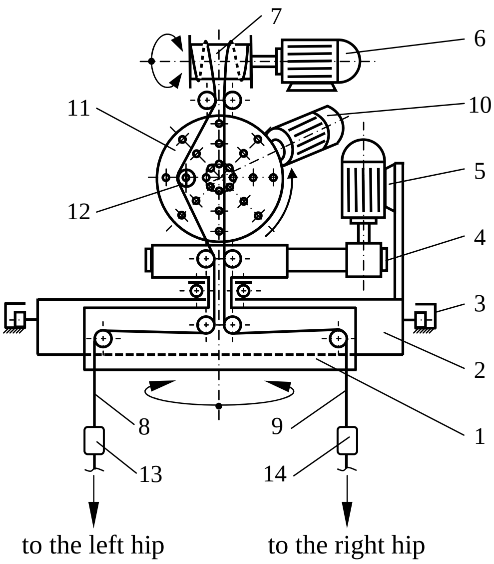

Fig. 1.

The HVM Module, consisting in the rotating geared motor (10) and the holed disc (11), is mounted on the rotating carriage (1). The roller, that pushes the cable, is mounted on the disc (11).

Functioning description. Before the treatment session starts, the suspension belts are fixed on the patient; afterwards, he/she is weighted using the force transducers (13) and (14). The patient is displayed in the treatment area and lowered to the necessary foot force, using the rotating carriage (2) and the vertical movement system (6, 7, 11 and 12). During this phase, the roller must be in vertical position, placed on the system's vertical axis (0° or 180°).

The vertical hip movement is achieved by the holed disc rotation with a speed of 1 rotation/double step. The roller pushes against the left cable (as shown in Fig. 1) so that the left hip is lifted during the upper-left quarter of the disc (as represented in Fig. 2) and according with the rotation direction.

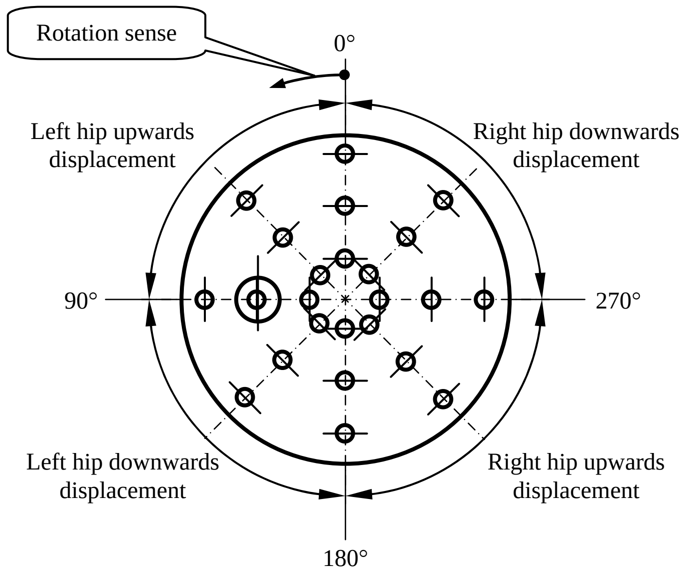

Fig. 2.

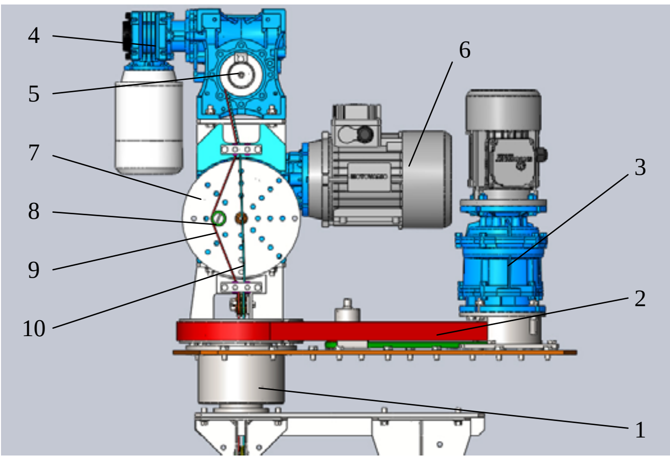

Fig. 3.

Figure 3 presents the HVM Module technical design consisting of: 1 – rotating carriage; 2 – cog belt transmission; 3 – rotating geared motor; 4 – vertical displacement geared motor; 5 – drum; 6 – hip displacement geared motor; 7 – holed disc; 8 – roller; 9 – left suspension cable; 10 – right suspension cable.

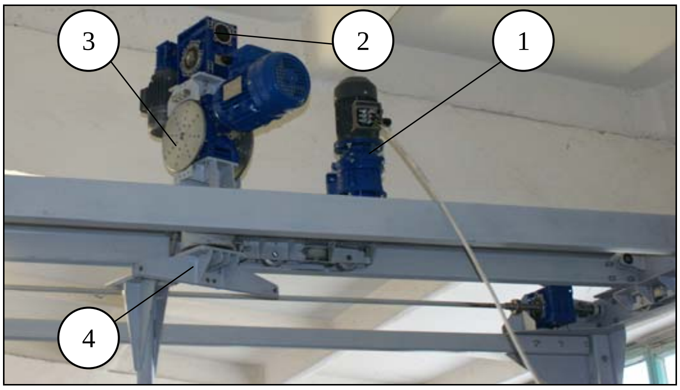

Fig. 4.

Figure 4 presents a photo of the mechatronic system taken during the implementation. The system comprises the following: 1 – the carriage rotating system; 2 – the vertical movement system; 3 – the hip vertical movement system.

Brief experimental data presentation. Figure 5 presents the hip displacement measured for several roller positions. The experiments were performed using a co-axial roller.

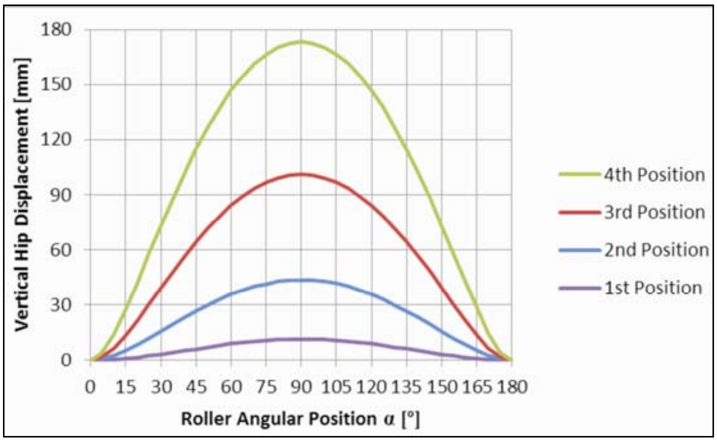

Fig. 5.

The maximum values of the vertical HVM system COM displacement are presented in Table 1.

Table 1

HVM Vertical Maximum COM Displacement

Roller position		1	2	3	4
HVM COM maximum displacement, mm	Co-axial roller	11.5	32.05	57.5	72.5
	Eccentric roller	9÷14	30÷35	55÷60	70÷75

Another set of data was obtained with a second roller having an eccentricity of 5 mm. Finally, the system will be equipped with a set of 5 rollers, with different eccentricities, so as to cover the whole domain.

Table 2

COM Displacement Values

	Lee and Farley [16]	Hesse and Ulebrock [17]	Gard and Childrens [18]	Chai [19]	Orendurff [20]	Kirtley [21]	Gard *et al* [22]
COM vertical displacement, mm	20÷40	50÷80	30÷75	40÷50	27.4÷48.3	30÷50	30÷70

Table 2 presents various COM vertical displacement values published by several researchers. It can be observed that HVM Module covers all the experimental data.

HVM Module is one of the several breakthrough new sub-systems that is part of a larger a comprehensive therapeutic system that are based on an original holistic approach in rehabilitation.

4. CONCLUSIONS

Technology evolves, concepts evolve. The patient must become an active participant to the rehabilitation program, not only by executing its tasks, but also by helping the technical team to adjust the rehabilitation devices and systems, and by deciding the goals of his/her own therapy.

HVM has several advantages presented as new features in recovery systems. In this respect, HVM:

- is the first system that simulates the natural alternate hip vertical movement;
- is highly versatile; it adapts both to the physical and physiological patients characteristics and to any recovery session request (gait speed, vertical displacement, foot load etc.);
- allows the patient's body controlled rotation along the vertical axis, with feed-back;
- can easily be adapted to any recovery system (mechatronic or robotic) with or without TM;
- has simple and robust construction.

HVM is a new threshold in the evolution of rehabilitation systems, a qualitative leap on the Advanced Rehabilitation Technology scale. The development of such complex system requires the conjugated work of an interdisciplinary team, consisting of rehabilitation medicine specialists, psychologists, mechatronic specialists and engineers.

ACKNOWLEDGMENTS

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI– UEFISCDI, project number 190/2012.

This paperwork is sustained by the Sectorial Operational Program - Human Resources Development (POS DRU), project co-financed by the European Social Fund and by the Government of Romania under the agreement no. POSDRU/159/1.5/S/137390, as well as by COST Action TD1006 European Network on Robotics for Neuro-Rehabilitation.

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Receiving May 20, 2015