# ROBOTICS APPLICATION IN PEOPLE WITH WEAK MUSCLES – STANDING AND WALKING

## APLIKACIJA ROBOTSKIH NAPRAV ZA PODPORO GIBANJA LJUDEM Z OSLABELIMI MIŠICAMI – STOJA IN HOJA

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**Key words:** *robotics; biomechatronics; standing; walking; muscular distrophy*

**Abstract** – *In this review paper we provide brief information on three commercially available biomechatronic devices that were primarily developed for neurological rehabilitation after stroke and spinal cord injury. First, we present Balance Trainer, a biomechatronic device that enables safe standing and balancing environment where the level of balancing support can be varied according to a particular subject's needs. Gait Trainer and Locomat are biomechatronic/robotic devices that enable repetitive practice of gait-like movement in non-ambulatory subjects. We briefly discuss potential application of the presented devices for therapeutical purposes in people with muscular distrophy.*

**Ključne besede:** *robotika; biomehatronika; stoja; hoja; mišična distrofija*

**Izvleček –** *V pričujočem preglednem članku na kratko opisujemo tri komercialno dosegljive biomehatronske naprave, ki so bile primarno razvite za podporo programom nevrološke rehabilitacije oseb po možganski kapi ter poškodbi hrbtenjače. Najprej predstavljamo napravo Balance Trainer, ki omogoča varno stojo in urjenje ravnotežja med stojo v razmerah, kjer velikost podpornih sil nastavljamo glede na trenutne potrebe posameznika. Gait Trainer in Locomat sta biomehatronski napravi, ki omogočata in podpirata hoji podobno aktivnost spodnjih ekstremitet pri osebah, ki ne zmorejo samostojne hoje. Na koncu razpravljamo o potencialni uporabi predstavljenih naprav pri terapevtski stoji in hoji oseb z mišično distrofijo.*

## Introduction

People suffering from various neuro-muscular diseases are impaired in their functional abilities such as reaching, grasping and manipulating objects as well as standing and walking. As neuromuscular diseases are generally progressive, at some point people become completely unable to stand and walk and are confined to a wheelchair. Prolonged use of a wheelchair, however, has well known consequences such as development of contractures, no adequate bone loading of lower extremities and of cardiovascular system, which compromising general health status.

In the recent decade new findings related to neurological rehabilitation of people impaired due to a stroke or spinal cord injury have shown that practising a functional task, i. e. reaching, grasping and manipulating objects in conditions that are highly repetitive, can bring about much better rehabilitation outcome as compared to traditional treatment techniques (1, 2). These findings boosted research and development of biomechatronic/robotic devices that could assist in delivering functional movement in a repeatable and repetitive fashion. The common denominator of these devices is that they assist a person that practises functional movement, such as balancing while standing (3) or walking on a treadmill (4, 5), with a degree of mechanical support that enables movement which otherwise would have not been possible without assistance of a couple of physiotherapists working in ergonomically unfavourable conditions. When training functional movement with the assistance of biomechatronic devices also the ever-present fear of falling, which impedes the outcome of traditional neurological rehabilitation is diminished, as biomechatronic devices are constructed in such a way that safety of a person practising is not compromised. It is not difficult to see that such biomechatronic devices, which were primarily developed for the purposes of neurological rehabilitation after stroke and spinal cord injury, could also be utilised purely for therapeutical purposes in people with various neuromuscular disorders and weak muscles.

In this review we give short information on three biomechatronic devices that were developed, clinically tested and transferred into commercial products, therefore being available to clinical environments. The first device, called Balance Trainer, offers safe balancing while standing to a wide range of disabled individuals. The other two devices, called Gait Trainer and Locomat, are intended for practising walking-like movement.

## Balance Trainer

BalanceTrainer is a mechanical apparatus that provides an impaired individual with a fall-safe balancing environment, where the balancing efforts of a standing individual are augmented by stabilizing forces acting at the level of pelvis in the sagittal and frontal planes of motion, assisting the balancing activity of ankle muscles in the sagittal plane and ankle and hip muscles in the frontal plane (6). In this way the apparatus enables full physiological range of swaying while standing in two principal postural degrees of freedom (sagittal and frontal planes). Figure 1 shows an able-bodied person standing on

Figure 1. *Balance Trainer (photograph courtesy of medica Medizintechnik GmbH, Hochdorf, Germany).*

Figure 2. *Gait Trainer (photograph courtesy of Reha-Stim GmbH, Berlin, Germany).*

Balance Trainer. The subject stands on the base plate, having knees supported by the knee upholstery and pelvis braced by means of a table and a pelvis belt system.
The apparatus has two mechanical degrees of freedom (DOF) enabling inclinations of the lower body in the ankles in the sagittal plane and inclinations in the ankles and hips in the frontal plane. The range of motion of the apparatus is limited to ± 15 degrees in both DOFs. The supporting forces are generated entirely by passive, compliant materials that comprises variable spring system joint complex (at the bottom of both vertical bars), which serves two purposes. Firstly, it enables movement in sagittal and frontal planes and secondly, it opposes this movement by means of helical spring. This spring is centered within two cylinders, arranged in such a way that allows displacement of the inner cylinder relatively to the base plate mounted outer cylinder. In this way the active length of the spring, which determines the level of opposing force and determines stiffness of the whole complex is adjusted. The level of supporting forces can be varied from zero up to the level where no balancing activity is needed from the standing subject. By means of a handle placed in front of the table a standing subject can lock/release movement of Balance Trainer, which allows either a caregiver to re-adjust the level of mechanical support or a standing subject to relax from active balancing on Balance Trainer. Several case studies were conducted in paraparetic (3) and hemiparetic (6) subjects, showing improvement in overall balancing abilities of the subjects following a period of training on the device.

## Gait Trainer

Gait Trainer allows wheelchair-bound subjects a repetitive practice of gait-like movement with a minimal support of a caregiver or therapist (4). Mechanical construction of Gait Trainer, which is shown in Figure 2, is based on a double crank and rocker gear system (housed within the chassis). Two footplates are positioned on two bars (couplers) that are connected with the two rockers and two cranks. An induction drive is used for propulsion of the rocker systems which transfers into elliptic and out of phase movement of the footplates. The low backward movement of the footplates simulates the stance phase while the forward movement simulates the swing phase. Planetary gear system provides a ratio of app. 60% to 40% between stance and swing phases. This ratio can be varied by therapist. A subject is standing on the two footplates, while being suspended on the weight-relief support system, providing up to 40% relief of body weight as needed. The center of mass (COM) of the walking subject oscillates sinusoidally in the vertical and horizontal directions by means of wires being connected through the crank system to the planetary gear system.
The kinematic patterns of lower limbs and muscle activation for the major leg muscles assessed in neurologically intact subjects that walked on Gait Trainer were similar to those assessed during their overground walking. Several case studies in non-ambulatory hemiparetic subjects training for certain period on Gait Trainer showed marked improvement in their walking abilities (7).

## Locomat

Locomat is a mechanical device developed to enable automated practice of highly repetitive gait-like movement on the moving treadmill to completely paralysed individuals (5). The device, shown in Figure 3, is an exoskeleton robotic, actively powered orthoses that are fitted onto the both lower extremities. The two robotic legs are merged via a pelvis frame and connected to a parallelogram mechanical construction that allows displacement in the vertical axis that normally occurs in human gait. The legs of a walking subject are strapped onto both robotic legs, which have actuated hip and knee joints, while movement in the ankles is facilitated by a moving treadmill. Dorsiflexion of the foot, needed at the beginning of the swing phase, is achieved by elastic straps attached to the robotic legs. The hip and knee trajectories of the robotic orthoses are pre-programmed and resemble those of normal walking. The movement of robotic orthoses are synchronised with the speed of the treadmill by means of a comprehensive control software running on two personal computers. The weight of a walking subject can be suspended via a weight-relief system as in Gait Trainer. Similarly to a Gait Trainer, physiological gait patterns as measured from the lower limb kinematics were

Figure 3. *Locomat (photograph courtesy of Hocoma AG, Zurich, Switzerland).*

achieved in the sagittal plane as well as COM oscillations in the vertical axis. Locomat, however does not permit movement in the frontal plane.
Several case studies were conducted with complete and incomplete paraplegic subjects walking on Locomat. In the incomplete paraplegic subjects similar improvements as presented for Gait Trainer were observed (8).

## Discussion

The main purpose of this review is to provide a short information on recent development in the field of biomechatronic devices assisting neurological rehabilitation and therapeutical movement. While there exists many more devices serving similar purposes, only the three selected devices presented in this paper were, to the best of author's knowledge, developed beyond the research prototype phase. As such they could be of interest to a broader professional and users environments.
Balance Trainer was designed in such a way that can serve as a regural standing frame or minibar that are presently used in rehabilitation environments to provide non-ambulatory individuals with benefits of therapeutucial standing. In addition, when unlocked, Balance Trainer becomes a tool for practising balancing skills, depending on each particular subject's current abilities, by means of stiffness-like support adjustment of the stabilizing pelvis forces acting in the horizontal plane. The stiffness-like support approach while balancing during standing follows recent findings on postural control in intact humans (9, 10). Balance Trainer can be effectively utilized for therapeutical standing of non-ambulatory people with weak muscles, where the level of support should be set to the level where no balancing activity, originating from the standing subject, would be necessary for upright posture maintenance. However, unlike rigid standing frames, Balance Trainer would still allow limited swaying of both upper and lower body in the sagittal and frontal planes.
Unlike Balance Trainer, which is entirely passive device, both devices for walking are powered, active devices that impose movement on a user. Gait Trainer was primarily designed for neurological rehabilitation in hemiparesis as stroke survivors are in general in reasonable control of one leg and to some extent also of the impaired leg. Therefore, the main focus is on imposing gait-like, repetitive practice of lower extremities, which is done by exercising fixed trajectories of feet by means of both footplates. A manual assistance of one physiotherapist is needed to assist in proper movement of the knee. Therefore, Gait Trainer might not be suitable for non-ambulatory people with weak muscles but only for those that have some degree of control of the knee joints. Since Gait Trainer does not manipulate directly joints and segments of the lower extremity, it is very safe and easy to get in and out of the device. Locomat, on the other hand, was originally developed for non-ambulatory people with no control over their lower extremities, therefore it could be used for therapeutical walking exercise in any population of people with weak muscles. With the Locomat the movement of knees and hips are completely determined in advance, which assures high degree of repetitiveness of practice. This approach, however, has a drawback that the geometry of robotic orthoses needs to be carefully adjusted for each individual subject to avoid potential harmful action of rather powerful motors actuating the orthoses, which is time consuming.
While the benefits of biomechatronic, automated neurological rehabilitation approach needs to be confirmed in controlled clinical studies, it can be stated that the presented devices are excellent mobility-practice tools. If the sole objective of training is to workout and to enable daily periods of physiological loading of musculo-skeletal and cardio-vascular system, which is the case in people with weak muscles, then the presented devices are very well suited for this purpose.

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