AMBULATORY SYSTEMS FOR ENHANCED HUMAN MOTOR CONTROL

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Abstract

People with impaired human motor control may be disabled in the performance of daily activities. Their motor control performance may be supported by ambulatory artificial motor control systems that are body-worn and exchange information with the human body. Exchange of information can be achieved at the level of the neural system, muscles activation, interface forces with the environment and body movements. Such motor support systems may not only be relevant in the case of impaired motor control but can also assist healthy people in performing tasks under high loading. This paper describes the general concept of these systems and several examples of applications which are investigated.

1 Introduction

People with impaired human motor control may be disabled in the performance of daily activities. Their motor control performance can be supported by ambulatory artificial motor control systems that are body-worn and exchange information with the human body. Such motor support systems may not only be relevant in the case of impaired motor control but can also assist healthy people in performing tasks under high loading.

2 Concept

The primary issue in the design of systems for support of human motor control concerns concepts of assisting impaired human motor function (Veltink et al. 2001). The secondary, derived, issue concerns methods of interfacing with the human body (figure 1).

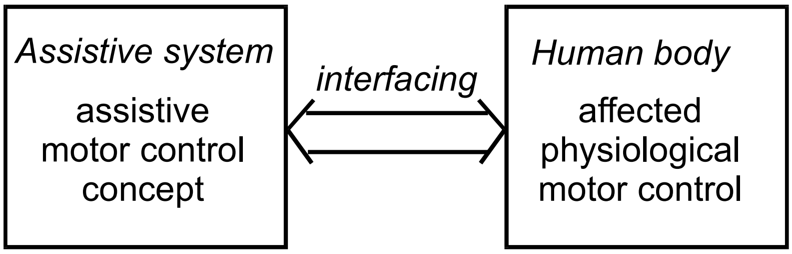

Figure 1. The two essential aspects of assistive motor system are the concept of motor support and the interfacing with the human body (Veltink et al. 2001).

The application of motor assist systems may serve several goals:

- It can take over part of the affected motor control. Examples are Functional Electrical Stimulation systems for activation of paralyzed muscles (Bajd et al. 1983; Franken et al. 1994), controlled prosthetic systems (Popovic et al. 1995; Taylor et al. 1996).
- It can tune the neural control to perform the desired function. Example are deep brain stimulation for improving motor control performance in Parkinson patients (Limousin et al. 1995), influencing sensation and reduce pain by spinal cord stimulation (Holsheimer 1997; Holsheimer 1998), or reducing hypersensitive stretch reflexes by stimulation of antagonistic muscles (Veltink et al. 2000).
- It can aid in training the impaired physiological system. Examples of are robot training systems for upper and lower extremities in stroke and incomplete paraplegics (Dietz et al. 1998; Krebs et al. 1998; Hesse et al. 1999) and training by electrical stimulation (Ladouceur et al. 2000).

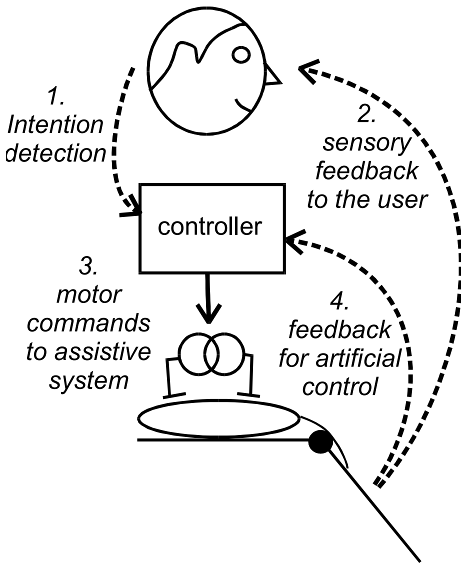

figure 2. The interface between the human body and an assistive device can provide signals from the user to derive motor intention (1), provide the user with lost sensory information (2), transfer motor commands to the assistive system (3) and provide feedback for the assistive motor control (4) (Veltink et al. 2001).

The interface can provide signals from the user to derive motor intention, provide the user with lost sensory information, transfer motor commands to the motor assist system and provide feedback for assistive motor control (figure 2)

Interfacing with the human motor system can be realised via several channel (figure 3). Sensory and control signals can be supplied to the body both mechanically and by electrical stimulation of nervous tissue, both peripherally and centrally. Sensory and control signals can be derived from the body by electrical and magnetic measurements of nervous and muscle activity or by use of artificial sensor systems (Veltink 1999).

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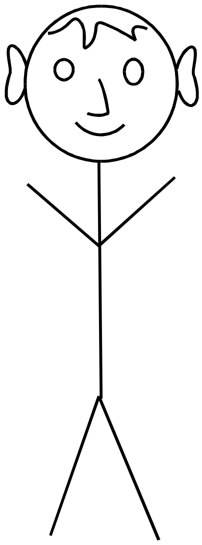
Supply control signals to the body

- stimulation of the central nervous system
- activation of muscles by stimulation of peripheral nerves
- sensory feedback by stimulation of afferent nerves

Supply information via sensors of the body

- influence vision
- influence hearing
- supplement touch
- Influence vestibular and proprioceptive perception by influencing body movements



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Derive motor control signals from the human body

- brain (EEG, MEG)
- peripheral nerves (ENG)
- muscle activity (EMG, MMG)

Derive kinetic and kinematic information from the body

- measure interaction force with environment
- measure movement of body segments

Figuur 3 Channels for ambulatory information exchange with the human motor control system

3 Results

In Twente, ambulatory systems for enhanced human motor control are developed for several applications, for example:

1. Functional Electrical Stimulation (FES) of the paralysed neuromuscular system, after spinal cord injury and stroke. Control strategies have been developed and tested for control of cyclical movements like walking (Veltink 1991; Franken et al. 1995) and to detect the motor intention of the user (Veltink et al. 1996b). Hybrid mobility systems consisting of FES and orthoses have been developed and tested (Baardman et al. 1997; IJzerman et al. 1997) and the therapeutic effects of FES on motor control have been evaluated for the upper extremities (IJzerman et al. 1996).

2. The application of electrotactile stimulation is being investigated for sensory supplementation for transfemoral prostheses users. This method may provide transfemoral prosthesis users with information about kinematic quantities, like knee angle at the end of the swing phase of gait, which are currently lacking, avoiding uncertainty and fear in current prosthetic gait (De Vries 1999; Buma et al. 2000).

3. Ambulatory systems for monitoring back loading during labor task (Luinge et al. 1999; Baten et al. 2000), and EMG-based Biofeedback systems for avoiding work related chronic pain complaints like RSI, which are often associated with inadequate physiological motor control. Both approaches have applications in ergonomics.

4. Application of inertial sensor systems for measuring running velocity in sports (Slycke 2000). This application is related to experience of ambulatory measurement of body movements using inertial sensors as developed for rehabilitation purposes (Willemsen et al. 1990a; Willemsen et al. 1990b; Veltink et al. 1996a; Lötters et al. 1998)

4 Discussion

Concepts of enhanced human motor control by application of ambulatory sensory-control systems include artificial motor control, and tuning or training of the neuromuscular system. In many cases, tuning or training of the neuromuscular system is preferable because it enables the person’s own neural control system to perform motor tasks in an improved way, providing natural user control and maximal flexibility.

As indicated in the application examples, the concept of enhanced human motor control by application of ambulatory sensory-control systems not only has applications in rehabilitation but also in ergonomics, sports and other non-medical fields where intelligent user-machine interaction is important.

References

Baardman G and IJzerman MJ (1997): design and evaluation of a hybrid orthosis for people with paraplegia. Electrical Engineering. Enschede, University of Twente: 252.

Bajd T, Kralj A, Turk R, Benko H and J.. S (1983): The use of a four-channel electrical stimulator as an ambulatory aid for paraplegic patients. Physical Therapy 63: 1116-1120.

Baten CTM, van Moerkerk H, Idsart Kingma I, Van Dieën J, Dolan T, Veltink PH and Hermens HJ (2000). Ambulatory low back load exposure estimation. XIVth tri-annual congress of the IEA / 44th annual meeting HFES, San Diego, pp.

Buma DG and Veltink PH (2000). Effects of different electrode surface areas and intermittent signals on the sensoation during prolonged electrocutaneous stimulation. PDutch Annual Conference on BioMedical Engineering, Papendal, Research school for Integrated BioMedical Engineering for Restoration of Human Function (iBME), pp. 17-20.

De Vries J (1999). The 'Smart' transfemoral prosthesis. International Biomechatronics Workshop, Enschede, University of Twente, pp. 5-9.

Dietz V, Wirz M, Colombo G and Curt A (1998): Locomotor capacity and recovery of spinal cord function in paraplegic patients: a clinical and electrophysiological evaluation. Electroencephalogr Clin Neurophysiol 109: 140-53.

Franken HM, Veltink PH, Baardman G, Redmeyer RA and Boom HB (1995): Cycle-to-cycle control of swing phase of paraplegic gait induced by surface electrical stimulation. Med Biol Eng Comput 33: 440-51.

Franken HM, Veltink PH and Boom HBK (1994): Restoring gait in paraplegics by functional electrical stimulation. IEEE Engineering in Medicine and Biology August/September: 564-567.

Hesse S, Uhlenbrock D and Sarkodie-Gyan T (1999): Gait pattern of severely disabled hemiparetic subjects on a new controlled gait trainer as compared to assisted treadmill walking with partial body weight support. Clin Rehabil 13: 401-10.

Holsheimer J (1997): Effectiveness of spinal cord stimulation in the management of chronic pain: analysis of technical drawbacks and solutions. Neurosurgery 40: 990-999.

Holsheimer J (1998): Concepts and methods in neuromodulation and functional electrical stimulation: an introduction. Neuromodulation 1: 57-61.

IJzerman MJ, Baardman G, Hermens HJ, Veltink PH, Boom HB and Zilvold G (1997): The influence of the reciprocal cable linkage in the advanced reciprocating gait orthosis on paraplegic gait performance. Prosthet Orthot Int 21: 52-61.

IJzerman MJ, Stoffers TS, In 't Groen FACG, Klatte MAP, Snoek GJ, Vorsteveld JHC, Nathan RH and Hermens HJ (1996): The NESS Handmaster orthosis: restoration of hand function in C5 and stroke patients by means of electrical stimulation. Journal of rehabilitation sciences 9: 86-89.

Krebs HI, Hogan N, Aisen ML and Volpe BT (1998): Robot-aided neurorehabilitation. IEEE Trans Rehabil Eng 6: 75-87.

Ladouceur M and Barbeau H (2000): Functional Electrical Stimulation-assisted walking for persons with incomplete spinal injuries. Changes in the kinematics and physiological cost of overground walking. Scan. J. Rehab. Med. 32: 28-36.

Limousin P, Pollak P, Benazzouz A, Hoffmann D, Le Bas J-F, Broussolle E, Perret JE and Benabid A-L (1995): Effect on parkinsonian signs and symptoms of bilateral subthalamic nucleus stimulation. Lancet 345: 91-95.

Lötters JC, Schipper J, Veltink PH, Olthuis w and Bergveld P (1998): Procedure for in-use calibaration of triaxial accelerometers in medical applications. sensors and Actuators, A 68: 221-228.

Luinge HJ, Veltink PH and Baten CT (1999): Estimating orientation with gyroscopes and accelerometers. Technol Health Care 7: 455-9.

Popovic D, Oguztoreli MN and Stein RB (1995): Optimal control for an above-knee prosthesis with two degrees of freedom. J Biomech 28: 89-98.

Slycke PJ (2000). Applications of inertial sensors in sports: the RunnersWatch. PATO course on Biomedical Measurement and Control Technology, Utrecht, pp.

Taylor MB, Clark E, Offord EA and Baxter C (1996): A comparison of energy expenditure by a high level trans-femoral amputee using the Intelligent prosthesis and conventionally damped prosthetic limbs. Prosthetics and Orthotics International 20: 116-121.

Veltink PH (1991): Control of FES-induced cyclical movements of the lower leg. Med Biol Eng Comput 29: NS8-12.

Veltink PH (1999): Sensory feedback in artificial control of human mobility. Technology and Health Care 7: 383-391.

Veltink PH, Bussmann HB, de Vries W, Martens WL and Van Lummel RC (1996a): Detection of static and dynamic activities using uniaxial accelerometers. IEEE Trans Rehabil Eng 4: 375-85.

Veltink PH, De Vries W, Hermens HJ, Baardman G, IJzerman M, Heinze S, Nene AV, Zilvold G and Boom HBK (1996b). A comprehensive FES control system for mobility restoration in paraplegics. In: A. Pedotti, M. Ferrarin, J. Quintern and R. Riener,eds., Neuroprosthetics - from basic research to clinical applications. Berlin, Springer - Verlag. pp. 163-169.

Veltink PH, Koopman HFJM, Van der Helm FCT and Nene AV (2001): Biomechatronics - Assisting the Impaired Motor System. Archives of Physiology and Biochemistry : in press.

Veltink PH, Ladouceur M and Sinkjaer T (2000): Inhibition of the triceps surae stretch reflex by stimulation of the deep peroneal nerve in persons with spastic stroke. Arch. Phys. Med. Rehabil. 81: 1016-1024.

Willemsen AT, Bloemhof F and Boom HB (1990a): Automatic stance-swing phase detection from accelerometer data for peroneal nerve stimulation. IEEE Trans Biomed Eng 37: 1201-8.

Willemsen AT, van Alste JA and Boom HB (1990b): Real-time gait assessment utilizing a new way of accelerometry. J Biomech 23: 859-63.