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Human Machine Interface in Assistive Robotics: Application to a Force Controlled Upper-Limb Powered Exoskeleton

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1. Introduction

The current work deals with Human-Machine Interfaces for assistive robotic systems. Such systems emerge to assist humans in their daily life tasks, such as in personal hygiene, eating, educational, and independent movement tasks. The goal is to improve the mobility of the disabled person while making the system transparent and non invasive to the user's comfort and mobility.

ESTA is a project that aims to develop an assistive exoskeleton for the upper limb. The work on this project took off in 2007. The exoskeleton has been designed to compensate for the loss of mobility in the upper limb, especially at the shoulder and elbow joints. Designing a proper Human-Machine Interface has been a primary concern in developing this system. Due to their many limitations and restricted operability, old usual interfaces were not convenient to use, and hence, the development of new adaptive interfaces that focus on optimizing the interaction between the user, the system and the environment is a main necessity.

In this chapter, a brief overview of some of the existing exoskeleton systems and the recent assistive robotic technologies for upper limb will be presented. Most of such control architectures use force sensors to control exoskeleton, and are based on motor torque calculation through dynamic laws, which require the knowledge of the mass and inertia matrix of each part of the orthosis, along with the presence of a dynamic model for the arm. However, in our proposed approach, motors are controlled with speed input instead. A description of our proposed system, along with the approach pursued to control the exoskeleton using pressure sensors will be presented in details through the flow of the chapter.

2. Designing a Rehabilitation System

The aim of assistive robotics is to reduce the human deficiency by enabling disabled people to be independent in carrying their daily life tasks. A key word to be underlined is that *capability* and *disability* are not opposites. As a matter of fact, disability should be seen as a reduced range of capabilities in a certain context, and this pattern of capabilities varies widely between individuals. This makes the design of a generic system a fundamental concern.

2.1 Requirement and challenges

When designing a rehabilitation system, two main notions should be considered: *Operability* and *Effectiveness*. While effectiveness measures the extent to which the deployment of the device improves the consumer's living situation, *Operability*, on the other hand, measures the ease of manipulating the device, and the response accuracy to the consumer's operative commands.

Simplicity and *Portability* are also major concerns when designing such systems. These notions require a rehabilitation robotic system to be adaptable, flexible, cost effective, and able to fit with the cognitive, perceptual and motor skills of the human operator. To fulfil these requirements, designing a proper system interface becomes a primordial issue since it represents the bridge connecting the user's intention and his/her action.

Usability is also an important part of user acceptance. According to Nielsen system acceptability includes a social and a practical part (Nielsen 1993, Birch & Cameron 1990). Usability includes easy learn ability, efficiency in use, remember ability, lack of errors in operation as well as subjective pleasure.

Hence, assistive systems should be endowed with interfaces that are specifically designed for disabled people in order to enable them to control the system with the most natural and less tiring mean. This is the primary concern of many researchers working in the field of Human-Machine Interfaces.

In the following, some of the challenges that emerge when designing a human-machine interface for assistive robotic systems are discussed.

2.2 The need of an adequate Human-Machine Interface

The major requirements when designing a HMI for disabled people can be summarised as follow (Hillman and Jepson 1992):

- **The need for simple and intuitive interface:** Both the robot and the user must be able to communicate and cooperate in a straightforward manner. This will require that the system is capable of indicating the intentions and/or the internal state of the robot to the user, and that the user can send commands back to the robots using intuitive and natural verbal and gesture tools.
- **The need for perception modelling:** In a natural human interaction, a person uses different ways for communication. For example, a person will look, point and simultaneously ask for a specific object to be brought to him. Meaning that intention is expressed through the gesture, gaze point, as well as the voice. Thus, sensing and predicting the intention of the user is a major step when designing natural human-machine interfaces.
- **Flexible and genuine interface accessibility:** Human factors and the ability of the operator should also be considered especially when dealing with assistive systems. In specific scenario, as in the case of a physically disabled person, the operator might be endowed with restricted margin of movement. It is in fact a considerable challenge to make interfaces that are most generic and accessible for all, especially when dealing with people with cognitive, sensory and mobility impairments.

- **The need for an adequate feedback:** The importance of feedback to assist the user has long been recognized as a fundamental principle in the design of good interfaces. Offering adequate feedback for user's actions is thus essential in designing HMI.
- **Keep the user in the control loop of the system:** Using the "user in the loop" paradigm is essential when designing assistive systems. Though interfaces dedicated to disabled people should be intelligent enough to sense the intention of the user, they should not control the system autonomously and exclude the user from the loop. The user should always feel control of the system.
- **Cost:** Designing sophisticated interfaces requires sophisticated tools and technologies which might be of very high cost. Therefore, a proper compromise between cost and operability of the system should be addressed.

Many efforts have been pursued to develop assistive interfaces. In the following, we will only focus on interfaces that fit the need of physically impaired persons. Such interfaces can be classified into the following classes:

The first class of interfaces is represented by the modified "usual" devices, such as keyboard, trackballs and joystick. These devices were transformed to be more ergonomic to fit the person's disability (Hobday 1996). However, disabled people may not conform to a standard pattern; in fact, while some classes of disability are more common than others, there cannot be a single pattern which fits everyone. Thus considering individual solutions is exceedingly expensive in practice. Moreover, this kind of devices is only adapted to people who retain a good measure of manual dexterity. Therefore, having interfaces that are intelligent enough to react differently and appropriately to different stimuli are of big importance when tackling the problem of assistive devices.

The second class of interfaces represents those that sense signals from the user to predict and synthesise an adequate control command. The major examples of such interfaces are the ones that sense not only the user's eye movements (Ohno and Mukawa 2003), head gestures, and body movements but also EEG or EMG signals (Ferreira et al. 2008, Rani & Sarkar 2005, Artemiadis & Kyriakopoulos 2006). These interfaces have the advantage that their input device (sensor) is kept unmodified, and the whole intelligence and adaptability module consists of processing the signals in an adequate manner to extract/synthesise the control command. Thus, by the mean of intelligent algorithms and processing tools, and without remodelling the hardware, the essential requirement for matching the system's and the user's need can be fulfilled without incurring a prohibitive cost of constructing each system individually.

3. Force Controlled Exoskeleton: "ESTA" Project

In this chapter, we address assistive systems that are dedicated to help impaired people to interact with their external world by providing them with the ability of taking physical actions, as well as manipulating other objects. Two classes of systems can be distinguished: the "robotic manipulator" and "assistive exoskeleton".

The robotic manipulators have been first extensively used for industrial applications for repetitive tasks; then recently, they were used as a manipulation aid for disabled people. Such systems mainly consist of actuated joints and an end-effector for grasping objects.

On the other hand, assistive exoskeletons are systems that are worn by the operator as an orthotic device. Their joints and links correspond then to those of the human body. Assistive exoskeletons are used to amplify the user's fragile power, thus keeping the grasping task under the full control of the operator. The operator provides control signals, while the exoskeleton provides most of the mechanical power required to carry out the task.

3.1 Exoskeleton for Rehabilitation

3.1.1The History of Assistive Exoskeleton

In this section, a brief overview of the most assistive robotic systems introduced in the last half century will be presented.

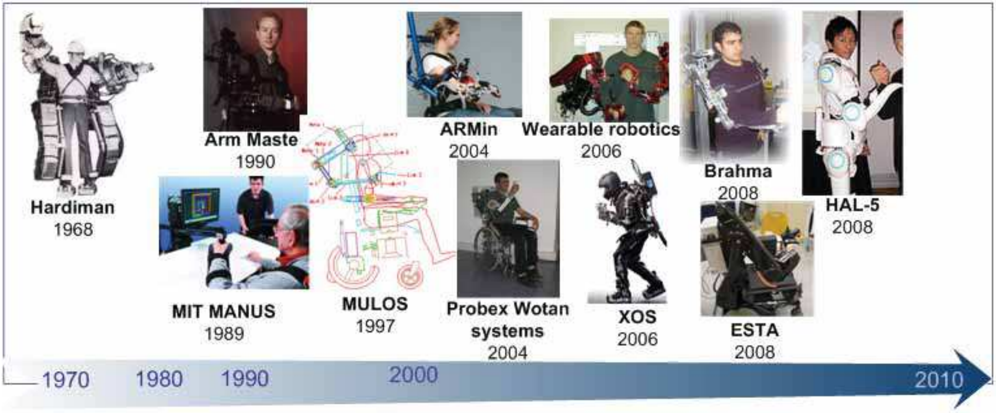


Fig. 1. The History of assistive exoskeleton

The first attempt to build a powered exoskeleton appears in 1968 with the exoskeleton Hardiman presented in Fig. 1. Hardiman is a 30-DoF exoskeleton composed of two legs and two arms. This system was initially designed for military purposes.

The first articulated upper limb orthosis dedicated for assistive purposes was the 'Balanced Fore Arm Orthosis' (BFO) (Alexander and al; 1992). Developed in 1965, this passive exoskeleton mounted on a wheel chair is intended to help disabled persons to accomplish movements on a horizontal plane. A motorized version of the BFO was developed by the Burke rehabilitation centre in 1975, but no significant results were achieved.

The first illustrative model for assistive exoskeleton systems are the ArmMaster (1990) and MANUS. The "Exoskeleton Force ArmMaster", developed by Exos corporation, is a five motorized DOF for shoulder and elbow joints. The system is completely back mounted and can exert a torque that able to go from 13Nm on the forearm to 40Nm on the arm (Burke 1992).

Another important system is the MIT MANUS (Kwee et al. 1988, Hogan et al. 1992), which is an articulated arm designed for the physical therapy of stroke victims. Although the first version of the MIT MANUS permitted to enable movement on a horizontal plane, the robotic arm was not parallel to the human one, and the orthosis was not mobile. MIT kept improving their system and upgraded it to possess an exoskeleton with 6 degrees of freedom.

The EU Telematics program started in 1997 the MULOS project (Motorized Upper Limb Orthosis System) MULOS is a 5 DoF powered upper limb orthosis, which allows the movement of the shoulder (3 DoF), the elbow, and the forearm. The orthosis was designed to work in three different modalities: assistive, continuous passive motion, and exercise (Johnson & Buckley 1997). However, despite the good potential of this orthosis, the development was discontinued in 1997.

The French company Wotan Systems has developed since 2000 a prototype of force controlled arm exoskeleton (Probex). The system is equipped with force sensors that sense the effort exerted by the operator on the system. The exerted force is then analyzed by a PC located in the wheelchair, and then amplified by pneumatic artificial muscles.

A more recent developed system is the exoskeleton ARMin. It supports spatial movements of the shoulder and elbow joint. Its control strategy takes into consideration the patient effort.

The most current exoskeleton systems are XOS, Brahma, and HAL. However, both XOS and HAL gained most of the interest and fame. Although such systems were dedicated for military purposes, we chose to briefly present them because of their high level of impact within the research community. XOS, a project initiated by DARPA, was developed to help doing some military work in the battlefield. The first prototype of the exoskeleton was designed in 2008 by Sarcos company.

HAL system is designed by a spin-off company from the Tsukuba University and will be commercialised under the name of “Robot Suit HAL”. Two versions of this system exist: HAL-3 for the lower limbs, and HAL-5 for the full body.

3.1.2 How are they controlled?

Clearly, designing a proper interface is crucial in rehabilitation robotics. But the question remains, how do we define “proper”, and what kind of interface should be used?

Exoskeleton system	Human Machine interface used
HAL system Kawamoto & Sankai 2002)	operator's intention estimated using EMG and impedance adjustment
ARMin (Nef & Riener 2005)	EMG signals : "patient-cooperative" control that recognizes the patient's movement intention in terms of muscular efforts
Werable Robotics	EMG signals
MIT MANUS (Hogan et al. 1992)	A six degrees-of-freedom force sensor is mounted on the robot end-effector. Motors torques were computed using dynamic laws applied on the robotic arm.
Golden Arm, (Allen et al. 1972) Rancho Los amigos Hopital	(1) Joint per Joint control using seven tongue operated switches ; (2) eye trackers[Moe1973].
Case Institute of Technology (LeBlanc & Leifer 1982)	(1)Pre recorded tasks;(2) a head-mounted light source that triggers light sensors in the environment.

Table. 1. Summury of the control strategy

Therefore, many challenges should be taken into consideration when designing a human machine interface. Table 1 shows some of the interfaces used to control the different assistive systems.

The skin surface electromyogram (EMG) is often used to detect the user's motion intention in the latest systems. These biological signals directly reflect the user's motion intention.

HAL exoskeleton operates by sensing weak electrical impulses from muscles via electrodes on the skin of the operator. An onboard computer analyzes them and activates the servos of the suit, mimicking the motions of the wearer.

Other systems use force sensor to synthesise the control law. MANUS was the first one controlled by force sensors. From the force applied on the extremity of the arm, motors torques were calculated by using dynamic laws applied on the robotic arm.

Less conventional interfaces have been used, such as tongue switches, light sensors, as well as image based control (Madentec 2008, Vaidyanathan et al. 2007, Betke et al. 2002).

3.2 ESTA system

"ESTA" project emerged from different reflections and specifications of the user. The goal was to design a low-cost exoskeleton controlled by force sensors that allows disabled population to achieve arm movements.

Myopathy is a neuromuscular disease in which the muscle fibres do not function, resulting in muscular weakness. This project is an industrial project conducted between different partners and consists in developing an innovative 4DoF assistive exoskeletal orthosis. It aims to develop an assistive technology for people suffering from myopathy, by assisting their upper limb movements.

The exoskeleton has been designed to compensate for the loss of mobility in the upper limb, especially for joints at the shoulder and elbow. The specifications were developed by the AFM, and they involve mainly the architecture, the control command, as well as the security and energy consumption of the orthosis.

Fig. 2 . the prototype of the exoskeleton

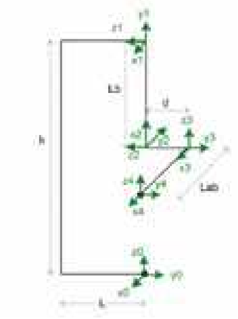


Fig. 3. Coordinate systems for D-H parameters

Each joint of the orthosis is actuated with a 50 Watt DC brushless motor that is powerful enough to allow the exoskeleton to lift a 3Kg weight. We use digital servo drive supplied by Elmo to control these motors. The low-level speed control of the motors is done by the Elmo whistle.

3.2.1 Force measurement

FSR sensors (Force Sensing Resistors), placed into two bracelets (Fig. 4), are used to measure the forces exerted by the patient on the orthosis. The bracelets are attached around both the arm and the forearm of the patient as shown in Fig. 5.

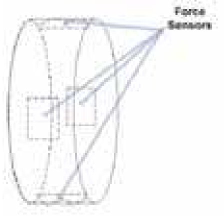


Fig. 4. Bracelet equipped with force sensors

Fig. 5. Model of the system

When analysing the signals coming from the sensors, it was noticed that (Fig. 8) they represent the superposition of the following components:

1) Very low-frequency components:
   - an offset due to the sensor intrinsic properties and the variation of temperature.
   - an offset due to the pressure exerted by the bracelet on the arm (this pressure is not constant, due to the relaxation of the bracelet materials).
2) Low-frequencies components:
   - a low frequency signal due to the mass of the arm (the mass perceived by the sensors depends on the position of the exoskeleton).
   - the inertia of the arm.
3) The command signal frequency that we want to extract.

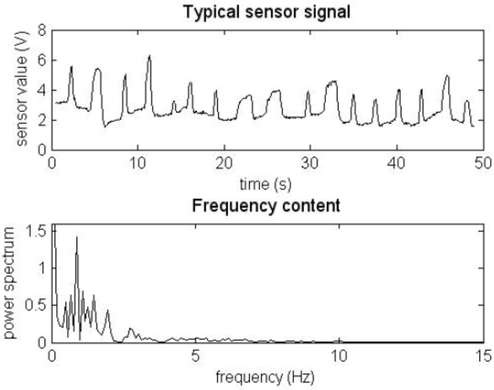


Fig. 6. A typical command signal and its spectrum

Figure 6 presents a typical sensor signal and its Fast Fourier Transform (FFT). The computation of the FFT shows that all the energy is concentrated in the low frequencies, ranging from 0 to 5 Hz.

In the following, we propose a new approach to control the exoskeleton using pressure sensors. Most of the existing control architectures that use force sensors to control exoskeleton are based on motor torque calculation through dynamic laws. Such control systems require the knowledge of the mass and inertia matrices of each part of the orthosis, as well as a dynamic model of the arm. In our approach, we propose the design an algorithm that control the motors with speed consigns instead of torque consigns. Therefore, evaluating the mass and inertia matrices of the orthosis become unnecessary.

A free-delay digital filter is first used. This filter removes non-interesting information coming from the sensors, such as offsets, and forces due to the mass and inertia of the arm of the patient. The filtered signals from each sensor are then interpreted as speed vectors. Each of these vectors corresponds to the desired speed of the orthosis at the point where the sensor is mounted.

3.2.2 Filter design

The analysis of the signal should be done in real time. Signal processing tools would introduce an unacceptable delay such as wavelet analysis, and hence cannot be used to extract the command signal. In the following section, we will describe a filtering method that is used to extract the information without introducing any delay.

As we have seen earlier in power spectrum of the signal, the frequencies corresponding to the command signal (1.5 to 5 Hz) are very close to the undesirable frequencies that we would like to remove (0 to 1.5 Hz). The signal component that is due to mass and inertia of the arm can be removed by filtering the frequencies below 1.4 Hz. We draw the window of the filter in Fig. 9. To have a significant attenuation of the offset, the arm weight, and inertia, we choose:

$$\begin{cases} a = -3 ; b = -20 \ \% \\ \dfrac{f_0}{f_1} = \dfrac{2}{1.5} \end{cases} \tag{1}$$

We compute the FIR (finite Impulse Response) filter coefficients that minimize the weighted, and integrated squared error between the ideal piecewise linear function and the magnitude response of the filter. To match with the designed window, the order n of the filter should be at least 30. The delay introduced by such a filter can be then calculated as:

$$\frac{n}{f_{sampling}} = \frac{40}{100} = 0.4\, s \tag{2}$$

3.2.3 Motor speed calculation

Finally, we use an inverse kinematics module to compute each motor speed.

The high-level control loop of the system is presented in the Fig. 7. After filtering the signal from the sensors, the kinematic model of the orthosis is used to compute the appropriate motors speed. The control loop is finally feedback closed by the mean of a PID (Proportional Integral Derivative) controller.

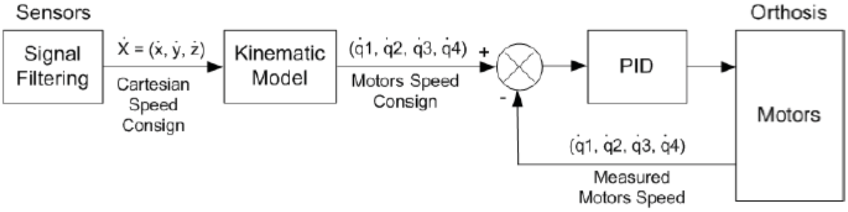


Fig. 7. High level control loop

The force applied by the user on one sensor is interpreted as a desired speed of the exoskeleton at the point X_{sensor} where the sensor is mounted. $\dot{X}$ represents a vector that is orthogonal to the plane of the sensor. We can then calculate the corresponding speed of each motor by using the Jacobian in the following equation:

$$\dot{X}_{sensor} = J\,\dot{q} \tag{3}$$

Where:

- $\dot{X}_{sensor}$ represents the velocity
- J represents the Jacobian of the orthosis
- $\dot{q} = \left\{\dot{q}_1, \dot{q}_2, \dot{q}_3, \dot{q}_4\right\}$ represents the joints speed

Instead of using the pseudo inverse of the Jacobian matrix to solve the system, we compute each joint speed by minimizing the following function :

$$f : (\dot{q}, \dot{X}_{sensor}) \rightarrow f(\dot{q}, \dot{X}_{sensor}) = \dot{X}_{sensor} - J \cdot \dot{q} \tag{4}$$

For a system composed of **n** sensors, it is first necessary to calculate the **n** Jacobian matrix J_i that corresponds to each sensor position X_{sensor}. Then, the motors speed consign vector $\dot{q}_i$ is calculated for each sensor as shown in equation 3. Finally, the vector $\dot{q}$ is obtained by taking the average of all $\dot{q}_i$.

4. Conclusion

The work in this chapter deals with Human-Machine Interfaces for assistive robotic systems that aim to improve the mobility of the disabled people. Many requirements and challenges rise when designing such systems, such as operability, effectiveness, simplicity, and portability. These notions require the rehabilitation robotic system to be adaptable, flexible, cost effective, and able to fit with the cognitive, perceptual and motor skills of the human operator.

This chapter presented ESTA as an example of assistive systems. It is a project that aims to develop an assistive exoskeleton for the upper limb. The work on this project took off in 2007. The exoskeleton has been designed to compensate for the loss of mobility in the upper limb, especially at the shoulder and elbow joints.

A novel HMI interface has been designed for ESTA orthosis based on pressure sensors. While most of the existing control architectures that use force sensors to control exoskeleton are based on motor torque calculation through dynamic laws, which requires the knowledge of the mass and inertia matrices of each part of the orthosis, as well as a dynamic model of the arm, our new approach to control the exoskeleton uses speed consigns instead of torque consigns; Therefore, evaluating the mass and inertia matrices of the orthosis become unnecessary.

5. References

Nielsen, J. ; (1993). Usability Engineering. *Academic Press Inc*. pp. 362

Hillman, M. ; Jepson, J. (1992) Evaluation of a robotic workstation for the disabled. *Journal of Biomedical Engineering* ,Vol. 14, No.3 , (187-192)

Beitler, M.T. ; Stanger, C.A. and Howell, R.D. (1994) The design of an integrated interface to an educational robotic system, *Proceedings of the RESNA 94 Annual Conference*, Nashville, pp. 448-450, USA

Birch, G.E. and Cameron, W. (1990), User Acceptability in Robotics Assistive Devices, *Proceedings of the International Conference of Rehabilitation Robotics*, pp. 83-94, (1990).

Hobday, S. W. (1996) The Maltron Keyboards, *Proceedings of the IEE Colloquium on Interfaces*, Dundee, UK, pp. 1-8.

Rani P. and Sarkar M. (2005) EMG-based high level humanrobot interaction system for people with disability, *Proceedings of the IEEE International Workshop on Robot and Human Interactive Communication*, Nashville, Tennessee, pp. 280-285

Artemiadis P. and Kyriakopoulos K. (2006), EMG-based teleoperation of a robot arm in planar catching movements using ARMAX model and trajectory monitoring techniques, *Proceedings of the IEEE International Conference on Robotics and Automation*, Orlando, Florida, pp. 3244-3249

Ferreira, A.; Celeste, W, C; Cheein, F. A.; Bastos-Filho, T. F.; Sarcinelli-Filho, M. and Carelli, R. (2008) Human-machine interfaces based on EMG and EEG applied to robotic systems, *Journal of NeuroEngineering and Rehabilitation* 03 pp. 5-10

Ohno, T. and Mukawa, N. (2003). Gaze-Based Interaction for Anyone, Anytime. *In Proceedings of HCI International 2003*, Crete, Greece, June 22-27, Vol. 4, pp. 1452-1456.

Alexander, M.A.; Nelson, M.R. and Shah, A. (1992) Orthotics, adapted seating and assistive devices. *In Pediatric Rehabilitation*, 2nd ed. Baltimore, MD: Williams and Wilkins, pp. 186–187.

H. Kwee; J. Duimel; J. Smit; A. T. de Moed; J. van Woerden and L. v. d. Kolk (1988) The Manus Wheelchair-Mounted Manipulator: Developments towards a Production

Model, *In Proceedings of the 3rd International Conference of the Association for the Advancement of Rehabilitation Technology,* pp. 460-462, (1988).

Hogan, N.; Krebs, H.I.; Charnnarong, J.; Srikrishna, P.,;and Sharon, A. (1992). MIT-MANUS: A workstation for manual therapy and training. *In Proceedings of the IEEE Workshop on Robot and Human Communication*, Tokyo, Japan, pp. 161–165.

Burke, J.; Exoskeleton (1992) Master Arm, Wrist and Effector Controller with Force Reflecting Telepresence, *Technical Report AL/CF-TR-1994-0146*, Odentics Inc., Anaheim, CA, December 1992, pp. 104.

Johnson, GR; Buckley, MA (1997) Development of a New Motorized Upper Limb Orthotic System (MULOS). *Proceedings of the Rehabilitation Engineering Society of North America.* Pittsburgh PA; June 1997 . p . 399-401.

Allen JR; Karchak A Jr.; Bontrager EL (1972) Final project report, design and fabricate a pair of Rancho anthropomorphic manipulator. *Technical Report, The Rancho Los Amigos Hospital Inc* ., 12826, Hawthorm Street, Downey CA 90242, 1972.

LeBlanc M; Leifer L . (1982) Environmental control and robotic manipulation aids . *Engineering in Medicine and Biology Magazine* 1982 ; December : 16-22.

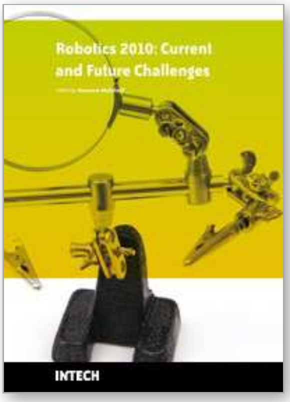
Kawamoto H and Sankai Y (2002) Power assist system HAL-3 for gait disorder person. *In Computer Helping People with Special Needs: 8th International Conference,* ICCHP 2002. Lecture Notes in Computer Science. Edited by: Miesenberger K, Klaus J, Zagler W. Berlin: Springer Verlag; 2002:196-203.

Nef T and Riener R. (2005) ARMin—Design of a novel arm rehabilitation robot. *In: Proceedings of the 9th International Conference on Rehabilitation Robotics*; 2005 Jun 28–Jul 1; Chicago, Illinois. Madison (WI): Omnipress; 2005. p. 57–60.

Madentec Inc. (2008), assistive technologies. *http://www.madentec.com.* Accessed January 2008.

Vaidyanathan, B.; Chung, L.; Gupta, H. ;Kook, S.; Kota and J. D. West; (2007) Tongue-Movement Communication and Control Concept for Hands-Free Human-Machine Interfaces. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans,* 37(4):533-546

Betke M.; Gips J.; and Fleming P. (2002) The Camera Mouse: Visual tracking of body features to provide computer access for people with severe disabilities. *IEEE T Neur Sys Reh* 10(1):1-10



Robotics 2010 Current and Future Challenges
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Without a doubt, robotics has made an incredible progress over the last decades. The vision of developing, designing and creating technical systems that help humans to achieve hard and complex tasks, has intelligently led to an incredible variety of solutions. There are barely technical fields that could exhibit more interdisciplinary interconnections like robotics. This fact is generated by highly complex challenges imposed by robotic systems, especially the requirement on intelligent and autonomous operation. This book tries to give an insight into the evolutionary process that takes place in robotics. It provides articles covering a wide range of this exciting area. The progress of technical challenges and concepts may illuminate the relationship between developments that seem to be completely different at first sight. The robotics remains an exciting scientific and engineering field. The community looks optimistically ahead and also looks forward for the future challenges and new development.

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