Bimanual Haptic–Desktop Platform for Upper-limb Post–Stroke Rehabilitation: Practical Trials
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Bimanual rehabilitation has been pointed out as an effective way for the rehabilitation of patients with poor motor impairment of one upper extremity because of the bimanual nature of the therapy, i.e. the natural way to initiate and control the therapy and the mechanical-neurological coordination between two hands in human activities of daily living [1]. This study presents the development of a new bimanual rehabilitation system for the rehabilitation of upper–limb post stroke patients.

The bimanual haptic desktop system (BHDS) is an integrated system which merges haptic functionalities and Video Display Terminal (VDT) systems into standalone application, shown in Fig. 1. The hardware integration has been designed to show ergonomic features and provide high-quality performance of human-computer-interaction (HCI) [2].

Figure 1 The BHDS System while used by an healthy subject

Figure 2 Example of a robot assisted bimanual task. In the left panel it is shown the box, that is asked to be picked up with two hands and lifted up. In the right panel, the blue line is the grasping force, while the red line is the box position.

Two basic exercises, based on tracking task and lifting task, were carried out for the recovery of basic arm motion–coordination skills and steadiness of patients’ upper-limb. Secondly a catching task, was developed to compare online the performance of healthy upper-limb with impaired ones wherein hand-eye coordination exercise of the patient is included. To this end, the proposed exercises provide patients the potential methods to train their post–stroke upper-limbs malfunctions while reporting the quantitative parameters obtained to evaluate the improvement of patients recovery. Experimental results of a preliminary evaluation on healthy subjects are reported and discussed to visualize in near future a pilot medical trials of the system on impaired people.

References
Joint coordination and muscular activation in robotic-assisted rehabilitation

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Approaches to the rehabilitation of movement in stroke patients depend on knowledge of the underlying mechanisms of movement deficits and on the evaluation of the execution of the movement. The goals of the study were to characterize joints trajectories and joint coordination of arm movements to three different targets on a horizontal planar surface and to correlate disruptions in motor control in the affected arm of hemiparetic subjects with the degree of functional impairment, measured clinically with different scales.

Participants
Arm movements and muscle activation were studied in a group of 9 chronic stroke patients that were enrolled for the robotic assisted therapy.

Interventions
The subjects were treated with a robotic therapy in Virtual Reality with the L-Exos system. L-Exos (Light Exoskeleton) is a force feedback exoskeleton for the right human arm[1]. The exoskeleton is designed to apply a controllable force of up to 100N at the center of the user’s hand palm, oriented along any spatial direction and it can provide active and tunable arm weight compensation. The protocol consisted of 3 one-hour rehabilitation sessions per week for a total of six weeks (i.e., 18 therapy sessions). Each rehabilitation session consisted in three different VR mediated exercises [2].

Main Outcome Measures
Data from the affected arms of impaired subjects, recorded before and after the therapy were compared. Subjects were seated in front of a horizontal surface. They made planar arm reaching movements to three different targets located directly in front of them and in the ipsilateral and contralateral workspace. Kinematic data from the wrist, elbow, shoulder and stern were recorded with a three-dimensional optical tracking system.

Results
Results showed that movement times were significantly prolonged in the affected arms and movement regularities were quite compromised. Elbow-shoulder coordination was disrupted and the range of active joint motion was increased significantly compared with the healthy subject. Statistically significant improvements after the robotic therapy were observed for the total time for the execution of the whole motor task, the times for the outward and the inward phases, the oscillations number evaluated during the outward and inward movements on the tracks of displacement and the evaluation of the T-angle regularity during the reaching movement and in terms of Fugl-Meyer scores, Ashworth scale and increments of active and passive ROMs on shoulder, elbow and wrist joints of the impaired limb.

References
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DEVELOPMENT OF A MULTIDEVICE ROBOT-AIDED REHABILITATION ARCHITECTURE USING PROGRESSIVE ASSISTANCE REGULATION

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BACKGROUND: Stroke patients exhibit a reduced ability or incapacity to selectively activate muscle fibres and consequently motor performance is impaired at the upper and/or lower limbs. The best behavioural outcomes after stroke are associated with the greatest return of brain function toward the normal state of organization. The recently proposed techniques are based on the motor learning phenomenon in relation to activities that are repetitive, task oriented and attention-demanding. In particular, adaptive treatment that continuously challenges and assists patients to improve coordination can yield substantial benefits. This work presents a multidevice architecture for robot-aided rehabilitation able to implement progressive assistance regulation.

METHODS: The architecture consists of a hardware-software platform able to interface different haptic devices with two and three DoF. The software allows to select the device and implement specific training strategies. It is implemented using the open-source platform H3D API which provides graphic representation of the assigned motor tasks in a 2D/3D graphic environment, and generates the appropriate haptic effects. The haptic interface provides different types of tactile feedback such as object interaction, trajectory tracking and reaching in a force field. The system includes a specific module for the evaluation of the subject’s performance during task execution (quantitative evaluation metrics). In addition there is progressive guidance for training in the virtual environments. The progressive guidance scheme adjusts its control gains based on subject performance. In this way the performer is exposed to an appropriate amount of haptic guidance throughout training which optimizes both voluntary control of the subject and the quality of performance. If the performance increases the difficulty level of the task is also increased; conversely if the performance decreases the task is made easier.

RESULTS: A preliminary version of this architecture was developed within the European founded project HUMOUR. At present it supports the “Braccio di Ferro” and Falcon devices and includes the evaluation metrics measuring the patient’s performance.

DISCUSSION: The availability of this type of architecture should allow to speed-up the learning process of different motor tasks so facilitating the treatment of different pathologic conditions of the neuromuscular system. The inclusion of the progressive guidance regulation should promote patient motivation during the whole course of treatment. The approach is generalizable for haptic guidance based training of a range of complex tasks such as writing and surgery training.

REFERENCES:

DEVELOPMENT OF A USER INTERFACE FOR THE MANAGEMENT OF THE INMOTION ROBOTIC DEVICES IN A NETWORK CONFIGURATION

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BACKGROUND: Given the rapid increase in the aging of the population and the further increase that is expected in coming years, an important problem that has to be faced is the corresponding increase in chronic illness, disabilities, and loss of functional independence endemic to the elderly. For this reason novel methods of rehabilitation and care management are urgently needed. Among the various health problems affecting the elderly, there is no doubt that stroke shows no sign of relinquishing its status as the leading cause of adult disability. After the acute phase all patients require continuous medical care and labour intensive rehabilitation. Besides traditional physical therapy, task oriented repetitive movements can help patients recover motor function, improve motor coordination, learn new motor strategies and avoid secondary complications, as many studies using robot-aided therapy attest. Recently, two robotic devices have been installed in our rehabilitation Institute. In order to allow therapists to easily apply and manage these devices we developed a dedicated software.

METHODS: The architecture includes one InMotion2 shoulder-elbow rehabilitation robot and one InMotion3 wrist rehabilitation device. Both systems are connected in a network configuration including a supervising workstation and network storage for data collection. A dedicated user interface has been implemented using the Matlab™ development software environment. It allows to select different motor tasks and other features of the practiced exercise so as to adapt the training to the specific needs determined by the patient’s residual motor ability. The exercise configuration is stored in the patient’s database and easily recalled in the next training session. In this way the therapist is able to customize the treatment and easily modify the rehabilitation strategies. The data on movement kinematics and dynamics collected during training are stored in a shared disk. A dedicated workstation processes these data and computes some parameters providing quantitative analysis of the patient’s performance. In addition the parameters are included in specific charts plotting the time course of recovery throughout the treatment. Quantitative evaluation of the course of recovery by means of robot measured parameters makes it possible to characterize the rate of improvement of patients, and to precisely plan and, if necessary, modify the rehabilitation strategies so as to improve the patient’s motor outcome.

RESULTS: The developed user interface is a valid tool for therapists because it allows the implementation of highly customized training without incurring an increase of the costs involved. In addition, thanks to this software it is possible to obtain an evaluation metrics that allows a precise measure of the patient's performance so providing the therapist with a tool for implementing reinforcement techniques (such as giving positive feedback and commending patients for their efforts) that can promote patient motivation and enhance adherence to the training program.
EFFECTS OF METHODOLOGY AND MARKER PLACEMENT IN GAIT ANALYSIS

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Topic: Clinical trials

Abstract Gait analysis is recognised as a very powerful and useful diagnostic tool [1], although it is not yet widespread and it is used as a clinical test a very limited number of cases. One of the reasons is the opposite necessity of achieving reliable results with short lasting session [2,3], both for the patients and for cost reasons. An analysis on the effects of the positioning markers skill and on presence/absence of midtights and midcalf wands was carried out. While the first condition involves employment of less skilled therapist and/or reduction of the patient preparing time, wands absence allows to perform at the same time also muscle activity monitoring (electromyography).

METHODS: Four clinically normal adult subjects were selected and markers were applied according to the Plug-in-Gait (Helen–Davis) protocol [4]. Subjects had been examined in three different sessions: markers placed by skilled therapist using KAD (Knee Alignment Device) and wands, the same set-up removing wands and finally markers placed by a non-skilled therapist without KAD.

For each session five trials with the subject walking at self-selected speed had been collected. A 6-camera VICON motion capture system (100 Hz) synchronised with 2 Kistler force plates (1000 Hz) and two digital video-cameras was used. Data processing were performed using VICON Workstation program.

Inter-therapist and inter-methodology comparison were made, using standard deviation (s.d.), while curves similarity had been evaluated calculating punctual differences between trends.

RESULTS: Trends obtained in second and third session had been compared with the first session ones. Generally gait time-space parameters show small difference; s.d. values fall within ranges considered acceptable for clinical gait analysis and, on average, it is larger for unskilled operator. Angular trends are similar and in any case they do not induce to false diagnosis, although for pelvic tilt, hip rotation and flexo-extension it is present an evident offset and curves are shifted to the limit of the normal range, especially for inter-therapist comparison.

DISCUSSION: Results obtained in the different sessions present in most cases very small angles differences and hence trials have a clinical acceptable accuracy, with some reserve for pelvis and hip angles. Usage of KAD in with/without wands case bypass the problem of the thigh and knee rotation observed in the inter-therapist case. These are the major responsible of kinematics errors in addition to the pelvic markers placement. Hence, quicker markers positioning procedures are allowed, except for some specific markers that require more attention and a basic training and also the muscle activity monitoring is possible during gait analysis.

Further researches need to be addressed to analyse influence and weight of the single marker on gait kinematic results both with healthy and pathological subjects.

REFERENCES
PNEUMATICALLY ACTUATED EXOSKELETON FOR GAIT REHABILITATION

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Abstract text
This paper describes the mechanical and control system design of a 10 DOF (Degrees Of Freedom) lower limbs exoskeleton for gait rehabilitation of patients with gait dysfunction. The developed system has four double-acting rod pneumatic actuators (two for each leg), that controls the hip and knee joints. Motion of each cylinder’s piston is controlled by two pressure proportional valves, connected to both cylinder chambers. The pneumatic actuators are controlled by proportional-pressure valves.

The control strategy has been specifically designed in order to ensure a proper position control guiding patient’s legs along a fixed reference gait pattern. For this purposes Fuzzy controller with additional force compensator was developed. A numerical solution of the inverse kinematics problem based on video image analysis has been used. The controller was successively implemented and tested on embedded real-time PC104 system.

Laboratory experiments without patient are carried out and the results are reported and discussed. With these experiments, the first phase of the work was concluded. The second and third phases, which include the experiments with voluntary healthy patients and tests on disable persons, respectively, should be also done in the future.

Fig.1. Developed prototype of the overall rehabilitation system

A BIOMIMETIC APPROACH BASED ON PRINCIPAL COMPONENTS ANALYSIS FOR MULTI-DOF PROSTHETIC HAND CONTROL

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Topic: Robot design and development

The need for a prosthetic limb with intuitive control and realistic sensory feedback is impellent and its development is a must for the near future. The fundamental issue to address is to improve voluntary controlled dexterity without increasing cognitive effort, in order to allow amputees to perform tasks that are necessary for activities for daily living (ADLs) and that cannot yet be done with the state of the art artificial limbs. Since an increase in the prosthetic hand dexterity would translate in too many EMG channels/input signals hardly controllable by the amputee, actually myoelectric upper-limb prostheses available on the market are nothing more than similar to rough grippers with only one or two degrees of freedom (DoFs); even the more recent ones (e.g., the i-Limb hand) are still controlled as traditional devices are. The real objective should thus be to design an advanced myoelectric hand prosthesis provided with an intuitive and human-like control system, but at the same time with high dexterity and functionality.

In this perspective, in this work a control algorithm based on Principal Components Analysis (PCA) (1, 2) is proposed, combined with the functioning mechanism of an underactuated robotic hand, namely the CyberHand prototype (3). Based on the assumptions of (4), who analyzed human hand postural data and stated that the first two principal components (PCs) can account for more than the 80% of data variance, our idea consists in “inverting” the PCA algorithm to couple two independent EMG signals with these two PCs and to use them to drive a multi-DoF hand. The PCs matrix obtained by Santello et al. in their research (4) has been used to drive the CyberHand by means of the mouse cursor x and y position over the monitor screen signals. Several grasping trials (respectively, power, precision and lateral grasps) were performed to verify whether this control algorithm could be successfully applied to a real robotic hand. Another solution has been also explored and compared to this first approach: a new set of PCs has been defined collecting data directly from the robotic hand sensors while performing several different grasping tasks, similarly to what Santello did in his experiments. In this case, the actually employed two first PCs succeeded in accounting for more than the 90% of the variance of motion and have been again used to drive the robotic hand. This way, it was demonstrated that the hand is able to perform most common grasping tasks when driven using both maps. The performed trials also showed that some better positions do exist, which can be used to obtain firm grasps, and which are reachable following linear mouse trajectories. Finally, better results are obtained using the CyberHand PCs map, which at best fits and reflects the robotic hand features: finger movements show less fluctuations and all the necessary fingers are correctly involved in each different grasp. Our ultimate target will be the setting up of a complete 2-channel EMG-based control system for a bio-inspired myoelectric prosthetic hand, more naturally and intuitively controllable by amputees.

EFFECTS OF AN UPPER LIMB ROBOT-AIDED THERAPY IN CHRONIC POST-STROKE SUBJECTS: A BIOMECHANICAL AND EEG-BASED APPROACH FOR FUNCTIONAL ASSESSMENT

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Topic: 3

Abstract text
Six subjects were recruited for this study: 4 healthy subjects, aged 24-48 (mean age 30.25±11.84), one man and three women, and 2 chronic post-stroke subjects, aged 59-61, both women, having suffered the acute event at least a year prior to the experiment. The InMotion² robotic system (Interactive Motion Technologies, Inc., Boston, MA, USA) was used for this study [1]: for each session, patients received 60 minutes of robot-mediated therapy, five sessions per week, four weeks. A 16 channels ActiveTwo electroencephalograph (BioSemi B.V., Amsterdam, Netherlands) was used for recording EEG signals during the execution of a simple unassisted reaching movement in three different sessions: (i) before, (ii) at halfway and (iii) at the end of the robot-mediated therapy. Each session was composed by 10 familiarization repetitions and 35 recorded repetitions. Healthy subjects performed the reaching exercise in a single session. Movement accuracy, movement efficiency, mean speed and the number of peaks in the velocity profile were computed. The mean force vector and its related force angular deviations were computed during the execution of the simple reaching movement.

Clinical scale scores (Motor Status Score for shoulder and elbow, Modified Ashworth Scale) and the Range of Motion on shoulder and elbow joints showed an improvement in the upper limb motor abilities at the end of the robotic therapy in both hemiparetic subjects. The movement efficiency and the numbers of peaks in the speed velocity resulted as the most significant parameters able to quantify the movement execution. The most significant parameter from the dynamic analysis is the mean force vector. A power desynchronization (ERD%) [2] in the ipsilesional hemisphere was observed during the movement planning and the execution phases in both hemiparetic subjects. The hemispheric activation index extracted from EEG signals, recorded during the simple reaching movement, shows a predominant activation of contralateral cortex hemisphere in healthy subjects, whereas during the robotic therapy treatment, a progressive overactivation of ipsilesional hemisphere was observed in both hemiparetic subjects.

The proposed robot-mediated therapy can contribute to the improvement of upper limb motor abilities in chronic hemiparetic subject, through the stimulation, and consequent activation, of cortex areas in the damaged brain hemisphere.

References
Il MEMOS2 è una versione avanzata del sistema MEMOS (MEchatronic system for MOtor recovery after Stroke), un robot sviluppato per fornire supporto al terapista, durante la terapia mirata alla neuro-riabilitazione dell’arto superiore in pazienti emiparetici (vedi fig 1) [1]. MEMOS2 è dotato di due gradi di libertà (GdL), per permettere al paziente di muoversi in tutte le direzioni sul piano orizzontale, ed è perfettamente capace di assecondare o guidare il movimento del paziente in tali direzioni. MEMOS2 permette inoltre di registrare dati per la valutazione quantitativa delle abilità motorie del paziente.

**Materiali e Metodi:**
Il MEMOS2 è un robot planare in configurazione cartesiana, dotato di una maniglia fissata su un carrello che scorre su un piano orizzontale (XY: 550mm x 400mm). Due guide lineari perpendicolari permettono il movimento della maniglia all’interno dello spazio di lavoro. La maniglia è dotata di un sensore di forza, a due assi per la registrazione delle forze esercitate dal paziente durante il trattamento. Il MEMOS2 è attuato attraverso l’impiego di due motori in continua e la trasmissione viene fatta attraverso due viti a ricircolo di sfere. Il valore massimo della forza esercitabile sulla maniglia è 100N. *Compito motorio*: al paziente viene richiesto di spostare la maniglia del robot da un punto P1 ad un altro punto P2 dello spazio di lavoro senza alcun limite di traiettoria; se durante l’esercizio la forza applicata sulla maniglia divenne inferiore ad una soglia prefissata, per un prefissato intervallo di tempo, interviene il sistema di controllo spostando la maniglia e il braccio del paziente fino al punto P2, lungo una traiettoria lineare e a velocità costante.

**Risultati**
La nuova versione del MEMOS ha permesso di superare i problemi meccanici della prima versione, principalmente rappresentati da una inerzia delle guide lineari ed un’anisotropia della trasmissione. Una novità del MEMOS2 è la forma sferica della maniglia che consente al paziente emiparetico di fare una presa più ergonomica. Ulteriori peculiarità del nuovo MEMOS, oltre al costo ulteriormente ridotto, sono le dimensioni (900x800mm) e il peso (30 kg) contenuti.

**Conclusioni**
Nonostante la semplicità della sua struttura e il basso costo, il MEMOS2 è un robot estremamente sicuro robusto ed inoltre studi clinici, su pazienti affetti da emiparesi cronica, ne hanno dimostrato l’efficacia ai fini della riduzione dei deficit funzionali [2]. Complessivamente le sue caratteristiche di efficienza, robustezza, ingombri ridotti e basso costo, rendono il MEMOS2 un sistema di utile e facile impiego negli ambienti ospedalieri e anche in applicazioni di tele-riabilitazione.

**References**
NEUROBIKE: UNA PIATTAFORMA ROBOTICA PER IL RECUPERO FUNZIONALE DEL CAMMINO DI SOGGETTI ALLETTATI POST-ICTUS

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Background

Negli ultimi anni, sono stati sviluppati numerosi sistemi robotici dedicati alla neuro-riabilitazione, con lo scopo di ampliare le potenzialità della terapia tradizionale [1]. Nonostante le promettenti aspettative, è emerso che la terapia robotica, indirizzata al recupero funzionale del cammino, non ha prodotto risultati significativamente diversi da quella tradizionale [2]. In particolare, se da una parte, i meccanismi di recupero messi in atto dal Sistema Nervoso Centrale sono ancora in gran parte sconosciuti, dall'altra, i sistemi robotici non sono tuttora adeguati alle specifiche della neuroriabilitazione. La letteratura mostra che il recupero funzionale è favorito da un intervento riabilitativo intensivo, finalizzato ad un compito motorio, quale la locomozione, e somministrato quanto prima dopo il trauma [3]. In contrasto, alcuni sistemi robotici non sono progettati per indurre un movimento fisiologico [4], mentre altri, più complessi dal punto di vista strutturale, pur provvedendo alla manipolazione degli arti inferiori in accordo con la locomozione, necessitano che il paziente sia spostato dal proprio letto con conseguenti ritardi nella somministrazione della terapia [5, 6].

Materiali e Metodi

NEUROBike (fig. 1) è una piattaforma robotica mobile dedicata alla terapia neuroriabilitativa del cammino per soggetti post-ictus allettati. E' costituita da due manipolatori a tre gradi di libertà ciascuno in grado di guidare gli arti inferiori nel piano sagittale con escursioni articolari simili a quelle naturali del cammino e in accordo con velocità del passo e antropometria [7]. L'interazione tra macchina e paziente è limitata alla pressione plantare: nessun elemento attivo viene in contatto con la gamba per non influenzare negativamente il processo di riabilitazione neuromotoria con afferenze sensoriali non naturali.

NEUROBike è controllata in real-time da una piattaforma software open source (LINUX RTAI, scheda I/O Sensoray S626, drive Co.Me.Di.) e si presta alla modifica della logica di controllo in base alle diverse esigenze di terapia.

Figura 1: Rappresentazione dei moduli costituenti la piattaforma robotica NEUROBike
Conclusioni

NEUROBike possiede i presupposti per provvedere ad una terapia neuroriabilitativa somministrata quanto prima dopo l'evento traumatico. La piattaforma consente la manipolazione degli arti inferiori, secondo traiettorie personalizzate ed in accordo con il ciclo di passo. La movimentazione passiva indotta e un ritorno sensoriale comparabile con quello del cammino naturale, ridurrebbero il rischio di atrofia muscolare e promuoverebbero la plasticità neuronale.

Bibliografia