Applications of Robotics to Assessment and Physical Therapy of Upper Limbs of Stroke Patients

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1. Introduction

Cerebrovascular accident or stroke is one of the major causes of debilitation in the world. The major symptoms of stroke are loss of muscle power, spasticity and in-coordination of muscle activation. In the past, the assessment of above symptoms were quite subjective by using Medical Research Council scale, Brunnstrom's stage and modified Ashworth scale and the rehabilitation of these patients was a labor intensive work. In the past decade, a series of researches was conducted at National Cheng Kung University (**NCKU**) for applying robotic technology to biomechanical assessments of spasticity and the neuro-rehabilitation of stroke patients in chronic stage. In particular, applications of robotics to the assessments of functional recovery, the individualized rehabilitation program and modeling of the motor learning of normal subjects and stroke patients treated by a de novo robot developed in Taiwan will be presented. The advantages and impact of utilizing robots to assist physicians on treating stroke patients will be discussed.

1.1 Symptoms of stroke

Stroke is the primary cause of disability and the second leading cause of death in many countries, including Taiwan. Although the mortality rate of stroke has declined, the incidence and prevalence of stroke continue to rise. The goal of rehabilitation is to help stroke patients to achieve as much functional independence as possible and to maintain quality of life. Rehabilitation has an important role in reducing the burden of long-term stroke care on society. By definition, stroke is a non-traumatic brain injury, caused by occlusion or rupture of cerebral blood vessels, and manifests as sudden appearance of neurological deficits characterized by loss of motor control, altered sensation, cognition or language impairment and disequilibrium. Intracranial hemorrhage accounts for about 10-15% of all strokes, and the remaining 80-85% is caused by infarction.

Disability in stroke affects physical, cognitive and psychological functions in variable severity. No two strokes are identical and no two patients respond to treatments identically. Therefore, the therapeutic approach requires assessment of every individual patient and demands specialized professional knowledge, skills and creativity. Hemiplegia or hemiparesis caused

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by a stroke in the middle cerebral artery distribution area is commonly seen within the rehabilitation setting. Initially, limb weakness and poor control of voluntary movement are noted and associated with reduced muscle tone. As voluntary movement improves, non-functional mass flexion and extension of the limbs becomes apparent, i.e., synergy patterns and mass contraction of multiple muscle groups. Later, synergistic movement patterns gradually disappear and, following the neurological motor recovery, more isolated joint movements gradually develop (Sawner & La Vigne, 1992). Spasticity is a velocity-dependent increase in resistance to muscle stretch that develops after an upper motor neuron lesion (Lance, 1981; Katz, 1992). Spasticity develops shortly after a completed stroke and usually persists if recovery is incomplete and it contributes to pain, motor impairment and disability. Jackson classified symptoms after a central nervous system lesion as positive or negative. Positive symptoms are spontaneous and exaggerated version of normal functions that reacts to specific external stimuli. They include spasticity, increased deep tendon reflexes and hyperactive flexion reflexes. In contrast, negative symptoms are deficits of normal behavior or performance and they include loss of dexterity, loss of strength, and restricted ability to move. Therapeutic interventions are performed under the assumption that a cause-and-effect relationship exists between these two groups of symptoms. And the major focus is to decrease the positive symptoms and improve the negative symptoms.

1.2 Biomechanical assessments of stroke

The motor deficits and functional capability of stroke patients are usually evaluated by qualitative and semi-quantitative scales, such as Brunnstrom’s stage and Fugl-Meyer assessment. Spasticity, the abnormally increased muscle tone, is evaluated similarly by the modified Ashworth scale. Though quantitative assessment of motor functions in stroke patients is less developed due to its complexity, many biomechanical methods have been employed to quantify spasticity by measuring the muscle response to the passive stretch (Firoobakhsh, 1993, Otis, 1983, Rebersek, 1986). Three types of stretch methods are commonly utilized, i.e., pendular motion (Lin, 1991, Rack, 1983), sinusoidal excitation (Agrawal, 1977, Lehmann, 1989) and constant velocity stretch (Powers, 1989).

1.3 Therapeutic Exercise Training for Motor Recovery after Stroke

In consequence of lacking inhibition within the central nervous system, abnormal coordination of movement patterns combined with abnormal postural tone are two of the major plastic responses that impede restoration of motor functions for patients with post-stroke hemiparesis (Bobath 1990). On account of weakness-related neurological deficits, the patients would rely unconsciously on various compensatory attempts to move limb segments that result in atypical synergy patterns and enhanced hypertonus during the rehabilitation process (Lum et al., 2003). Therapeutic intervention therefore focuses on relearning normal movements through experience with active participation of the patients. Correct movement patterns can be facilitated with appropriate application of proprioceptive, cutaneous, or reflexive inputs in the beginning of the recovery phase. Reinforced successful sensorimotor experiences could expedite recovering from upper limb paralysis of stroke patients with manual stretch (Carey et al., 1990), tactile stimulation (Mark et al., 2005), or joint compression (Brouwer and Ambury, 1994). As the individual becomes more effective and independent in the motor task, this handling of external sensory inputs is gradually withdrawn, in replace of strengthening exercises against resistance (Ada et al., 2006) with designed patterns and training of goal-oriented and skilled movements (Bobath 1990).

A number of neurological treatment approaches have been proposed to facilitate motor recovery of stroke patients, including Bobath (Bobath 1990; Davies 1991), Brunnstrom (Sawner and Lavigne, 1992), Proprioceptive Neuromuscular Facilitation (PNF) (Dickstein et al., 1986), Motor Relearning Program (MRP) (Carr and Shepherd, 1989; Langhammer and Stanghelle, 2000), constraint-induced movement therapy (CIMT) (Blanton and Wolf , 1999; Taub and Uswatt 2006), task-related training (Dean and Shepherd, 1997; Jang et al., 2003) and bilateral training (Mudie and Matyas, 2000;Whitall et al., 2000; Tijs and Matyas, 2006). Forms of the rehabilitative practices claimed effective regain of motor control based on different conceptual assumptions that lead to a variety of technical emphases. For example, the Brunnstrom PNF and bilateral training approaches made use of resistance-induced associated movements or widespread mass synergies to strengthen unresponsive muscles (Whitall et al., 2000; Hwang et al., 2005). On the other hand, the Bobath approach which persisted to restore motor functions with functional activities according to neuro-developmental sequences and considered reflex-inhibiting patterns to counteract abnormal postural tone (Bobath 1990). According to the MRP, training in motor control of stroke patients contained two fundamental elements, i.e., anticipatory actions and ongoing practice (Carr and Shepherd, 1989). The patients practiced motor task of environment specific to enrich relearning (Davis et al., 2006). The CIMT approach addressed massed practice with the affected limb. The shaping technique was extensively employed in CIMT by using operant conditioning, so that successful performance was consistently rewarded to reverse of the “learn non-use” mechanism (Taub et al., 1999; Liepert et al., 2000). Although those different approaches showed some degree of improvements in multiple physiological domains and longitudinal outcomes after stroke, recent studies have not reached a consensus for any of prevailing prescription to optimize performance outcomes and neuromuscular adaptations (Pollock et al., 2003; Van Peppen et al., 2004).

1.4 Robot-aided Assessment and Rehabilitation

For the rehabilitation of stroke patients, many robotic systems have been developed (Noritsugu, 1997, Krebs, 1998, Ju, 2002, Cozens, 1999, Reinkensmeyer, 1999). One of the major difficulties in realizing robot-assisted rehabilitation is the controller design. Manual treatments usually involve complex maneuvers with resistive or assistive force imposed at specific points along a specific direction of the movement. Circular or more complex movements with predefined imposing force are difficult to implement by using either conventional position or force control alone. Three types of controllers have been employed, isotropic or impedance control that maintained a constant stiffness and damping at the end effector, hybrid position/force controller that controlled position in one direction and force in the orthogonal direction, and hardware method to constrain position in the direction orthogonal to the tangential velocity (Reinkensmeyer, 1999, Raibert, 1981, Suh, 1991, Lum, 2002, Burgar, 2000). In a robot-assisted rehabilitation program, the subject is part of the man-machine system and dynamic model of the subject is not as clear and invariant as the manipulator. To solve this problem fuzzy control was employed to develop a hybrid position/force control for a shoulder-elbow rehabilitation robot (Ju et al, 2005).

In recent years, the fast advancement in robotics has made the appearance of many sophisticated robots in industrial, home, entertainment and medical industries. Most of these robots are equipped with vision system, tactile sensors and hearing system and the control system even has some kind of artificial intelligence. It is believed that robotic technology may have a contribution to the assessment and neuro-rehabilitation of stroke patients during the acute and the chronic stages. The long-term goals of these researches are three-folds. First, devices for biomechanical assessments of the syndromes of stroke are developed. Second, neuromuscular mechanism of the syndromes has to be explored. Third, based on the mechanism, a neuro-rehabilitation robot is developed to assist physicians and physical therapists to provide objective assessments and treatments of the stroke patients.

Organization of this chapter is summarized in the following. In section 2, two spasticity measuring systems for quantifying the degree of spasticity of stroke patients are presented. In section 3, a rehabilitation robot developed at NCKU and its applications to the assessments of motor functions and clinical treatment of patients is introduced. In section 4, a recent improvement of the above-mentioned robot for quantifying the abnormal synergistic forearm movement and model simulation of the subjects for monitoring the motor adaptation progress is presented. In the last section, the advantages and disadvantages of applying robotics on the assessments and treatment will be discussed followed by a description of the future aspects of neuro-rehabilitation robots.

2. Spasticity Measurement Systems

2-1 Single-axis manipulator for biomechanical assessment of spasticity

At NCKU, two devices were developed for the assessments of spasticity and tracking performance of stroke patients for time course study. Figure 1 shows the schematic and the control block diagram of a single-axis manipulator system for quantifying spasticity of stroke patients. The system was designed to perform passive stretch on spastic muscles of upper and lower limbs. The mechanism was capable of positioning and manipulation of elbow, knee or ankle joint. The DC servomotor could drive the manipulandum to perform constant velocity or ramp-and-hold, sinusoidal and arbitrary movements. A very sensitive torque sensor was utilized to measure the stretch reflex torque exerted on the manipulandum by the spastic muscles. The subjects were tested in the supine position. The hypothesis to be examined was that tonic stretch reflex of stroke patients was first decreased at the acute stage and latter increased at the chronic stage. Figure 2 shows the ramp-and-hold stretch of the elbow of a stroke patient. A simple method to eliminate the gravitational torque was developed. First, a baseline was measured when the manipulandum was driven at an average speed of 5 deg/s. Then, by subtracting the baseline from the reflex torques measured at 20, 40, 60 and 80 deg/s, we could eliminate the gravitational torque of the manipulandum and the forearm. Four stroke patients were recruited for a time course evaluation. The subjects were tested on the spasticity measurement system 72 hours, 1 week, 1 month, 3 months and 6 months from the onset of the last stroke. The protocol of the human tests was approved by the human study ethics committee of National Cheng Kung University Hospital. A biomechanical model for the spastic joint was written as:

$$\tau_r = I\ddot{\theta} + B\dot{\theta} + K\theta - \tau_g(\theta) \tag{1}$$

in which I was the inertia of forearm and manipulandum, B was the viscous damping coefficient of the robotic system, K was the stiffness constant, θ was the angular displacement of the manipulator, τ_g was the gravitational torque and τ_r was the stretch reflex torque. Figure 2 shows the stretch reflex torque of a typical stroke patient. Note that the area between the dotted baseline and the measured torque at various stretch speeds was proportional to the stretch speed. The averaged stretch reflex torque (ASRT) was found to be a suitable index for quantifying the degree of spasticity and the single-axis robot system provided an on-line examination of spasticity. Details of the development can be found in (Ju et al, 2000).

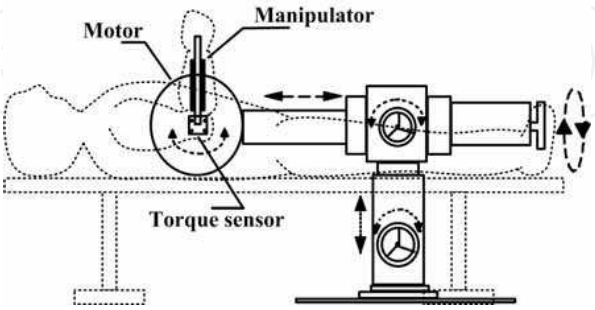


Fig. 1. Schematic diagram of a Spasticity.

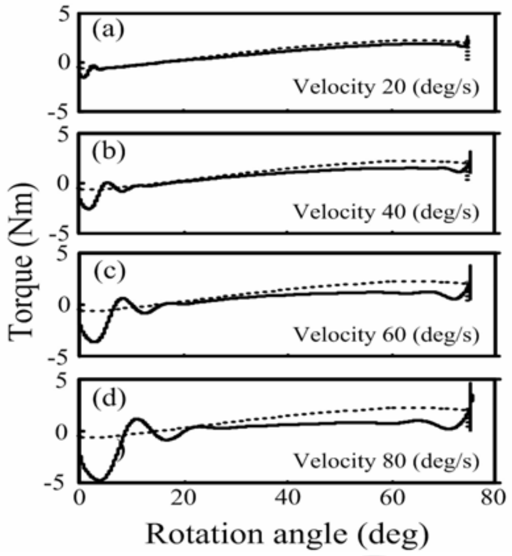


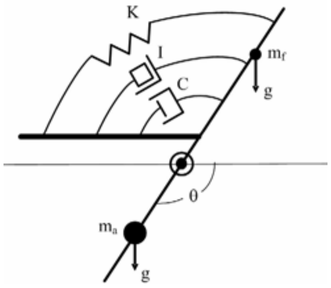
Fig. 2. Stretch reflex torques of a Stroke Patient Measurement System.

2-2 Pendulum test system for muscle tone

The other system that we developed was a pendulum test system for estimating the degree of spasticity of the elbow of the strokes. Figure 3 shows a picture of the pendulum system. In the past, the pendulum system was developed for the knee joint. The main difficulties of applying the conventional method to the elbow were the relatively small inertia of the forearm and the uncomfortable testing posture. The system was similar to a clock pendulum and a biomechanical model similar to Equation (1) was employed for off-line estimation of model parameters of the elbow. From the estimated parameters one could quantify the degree of spasticity. Eleven stable stroke patients and eleven normal subjects were recruited for the testing. Figure 4 shows the biomechanical model of the man-machine system. In this model, m_f was the mass of forearm, m_a was mass of the apparatus, K and C were stiffness and damping coefficients respectively. The subjects were asked to relax and the pendulum was released from an angle of 130° (full extension 0°). The angular trajectory of the pendulum was recorded and filtered with a fourth order Butterworth low pass filter (cutoff band 10Hz). The model was simulated with the same initial state as the experiment and the mean squared error between the model output and the experiment data was minimized by finding the optimal parameters K, C and θ_c. The sequential quadratic program method was utilized. Figure 5 shows that the damping ratio derived from the proposed model could differentiate spasticity from normotonus and it increased as spasticity increased. The system was also applied to a normal subject group and to a diabetic neuropathic patient group. The results from the normal group (n=192) showed that the biomechanical properties of the elbow joints (K and C) was similar in men and women when the body weight was adjusted and did not change with age until 70 years old. The results from the patients with diabetic neuropathy (n=53) indicated that the pendulum test could be used in this patient group to monitor the decreased muscle tone. Details of this development can be found in (Lin et al, 2003, 2005, 2006).

$$I\ddot{\theta} = -\tau_g - K(\theta - \theta_c) - C\dot{\theta}$$

$$I = I_a + I_f$$



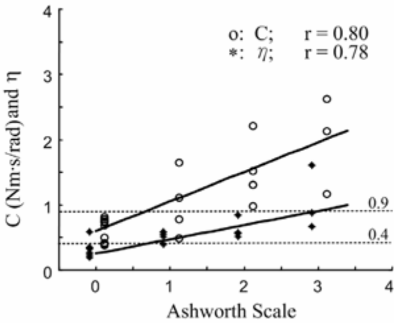


Fig. 3. Pendulum Fig. 4 Biomechanical Model Fig.5 Damping ratio vs Ashworth Scale.

3. Neuro-Rehabilitation Robot and Treatment Movements

3-1 Single axis robot for elbow

To investigate the influence of external constant torque on voluntary elbow movements of stroke and normal subjects, the spasticity measurement system was modified (Figure 6). A control system that could compensate gravitational torque and generate a constant-torque from the manipulandum was developed. Two groups of subjects were recruited, including six stroke patients and six normal subjects. Selection criterion of stroke patients were normotonic hemiparesis caused by one episode of stroke, clear consciousness and good cooperation and free from other central nervous system diseases. A voluntary tracking control test was designed for quantitative evaluation of the active tracking capability of the subjects. Target and actual elbow trajectories were displayed on a monitor. The target trajectory was a ramp-and-hold movement with a speed of 20°/sec. Both the intact and affected sides of the stroke patients were tested. The subjects were asked to extend the elbow joint from 55° to 110° under three, i.e., free, assistive and resistive, loading conditions. The intensity of the assistive/resistive torque was controlled to be 10% of the maximum isometric flexion/extension torque. Three tracking performance indices, namely, root mean squares (RMS) error, integration of squared jerks, integration of rectified electromyogram were compared. Figure 7 shows the comparison of the intact side with the affected side of a stroke patient. One may observe that the tracking performance of the affected side could be improved by either the resistive or assistive torque. Details of the developed techniques can be found in (Ju et al, 2002). The findings of this work paved the way for the development of a five-bar robot which could apply either assistive or resistive force to the wrist of a subject who was instructed to actively perform a therapeutic movement on the horizontal plane at the shoulder level.

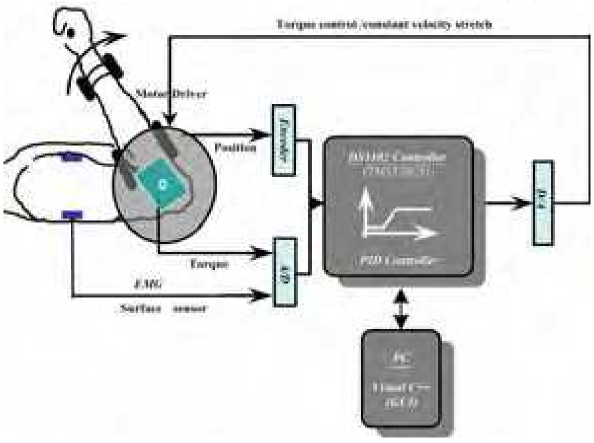


Fig. 6. Single-axis rehabilitation robot.

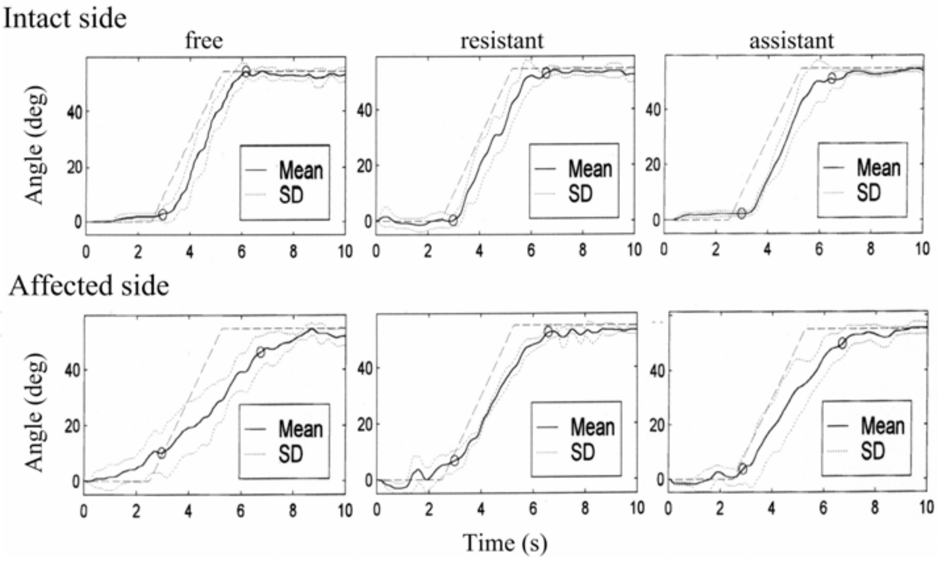
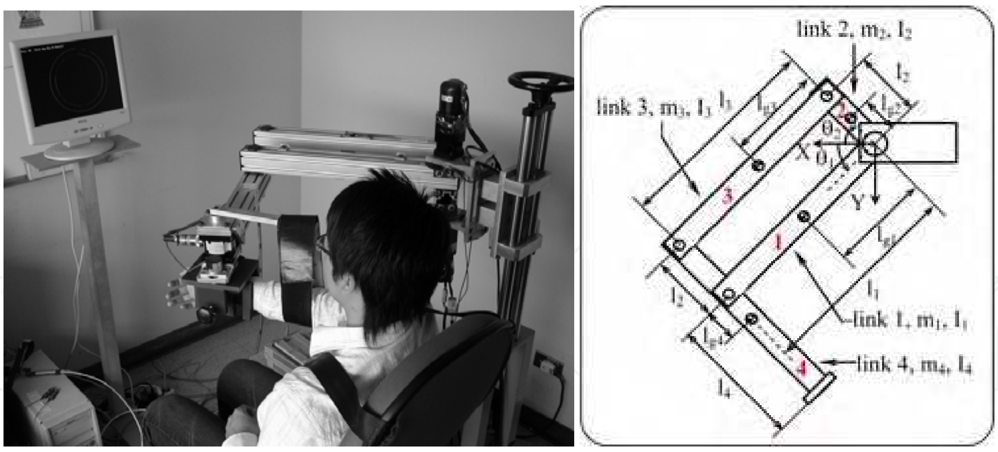


Fig. 7. Affected versus intact sides.

Various facilitation methods have been developed for the neuro-rehabilitation of paretic muscles. Up to now, the true mechanism of neuromuscular facilitation remains obscure. A possible explanation of the rehabilitation process was suggested (Reinkesmeyer, 2004). When the upper neurons are injured, the planner, controller and sensing elements of the neuromuscular system may loss their functions and the paths between the limbs and the sensing elements may be broken. The self repair of the human body is an adaptive process which can adjust the unused neurons in the planner, controller, sensing elements and limbs. To accelerate this adaptation process there are two approaches, one is to manipulate the paralyzed limbs and the other is to instruct the patient to move his/her paralyzed muscles and induce the desired movement. The facilitation processes of neuromuscular system include passively guiding the spastic limb movement, imposing resistance to strengthen muscle power and patterning of treatment movements.

3-2 Five-Axis Planar robot for shoulder and elbow

At NCKU a five-bar planar robot was developed for neuro-rehabilitation of shoulder and elbow joints of stroke subjects. Figure 8 shows a picture and the schematic diagram of the robot. The robot was able to guide patients' wrists to move along the planned linear or circular trajectories on the horizontal plan when the upper arm was abducted by 90º. A hybrid position/force controller incorporating fuzzy logic was implemented to control the movement in the desired direction and to maintain a constant force along the moving direction. Figure 9 shows the tangential and normal directions of movement and a block diagram of the hybrid controller. The circular trajectory, with a radius of 14cm, was chosen as the treatment movement. The movement involved coordination between shoulder and elbow joints and major muscle groups such as deltoid, pectoralis, biceps and triceps were all facilitated. A treatment protocol was developed and clinical tests on normal subjects and stroke patients have been performed at NCKU Hospital since 1999. Figure 10 shows the treatment protocol, in which graded resistive force ranged from 0N to 9N was applied by the robot on the wrist when the subject performed the horizontal circular movements.



(a) (b)

Fig. 8. (a) Picture of the shoulder-elbow rehabilitation robot and (b) schematic diagram of the five-bar mechanism.

The average RMS tracking error of the movement from the normal group was utilized to score the performance. When the RMS tracking error was smaller than a threshold of the age-matched normal group, the resistance force was increased. An index called dynamic stiffness was employed to evaluate the goodness of motor coordination. The robot could apply a radial perturbing force at ± 45 degree from the far point (0 degree) of the circular trajectory. The subject would react to this unexpected perturbing force. By measuring the maximum perturbed displacement of the wrist and the perturbing force. A stiffness matrix could be calculated as:

$$K_e = \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}, \quad K_{xx} \cong \frac{F_x}{\Delta x_e}, \quad K_{yy} \cong \frac{F_y}{\Delta y_e}, \quad K_{xy} \cong \frac{F_x}{\Delta y_e}, K_{yx} \cong \frac{F_y}{\Delta x_e} \tag{2}$$

Through the similarity transform the dynamic stiffness of the elbow and shoulder joints could be obtained,

$$K_j \equiv J^T \; K_e \; J = \begin{bmatrix} K_{ee} & K_{es} \\ K_{se} & K_{ss} \end{bmatrix} \qquad (3),$$

where K_{ee} and K_{ss} are the dynamic stiffness of the elbow and shoulder joints, respectively. Figure 11 shows the perturbed movement of a typical stroke patient and Figure 12 shows the time course variation of joint dynamic stiffness during the treatment period with the protocol depicted in Figure 10.

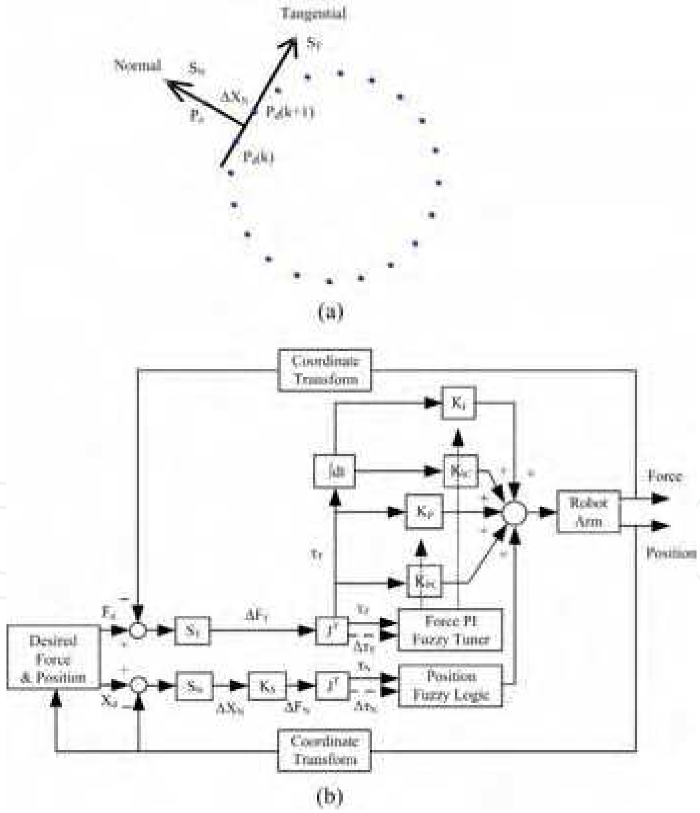


Fig.9 (a) Tangential and normal directions, (b) Control algorithm.

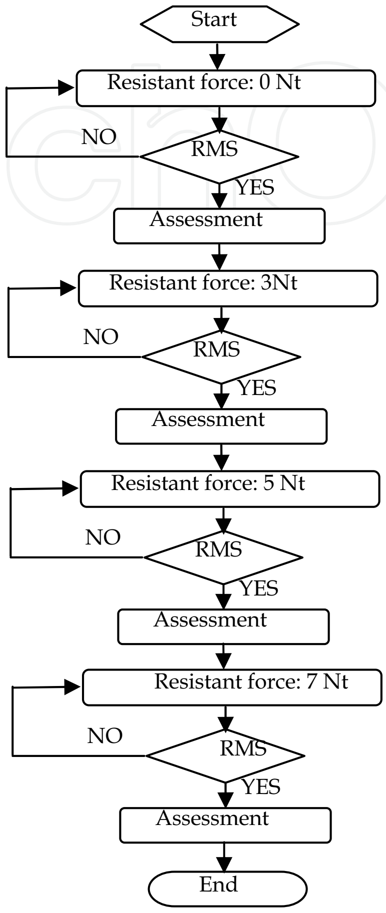


Fig.10 Clinical treatment protocol.

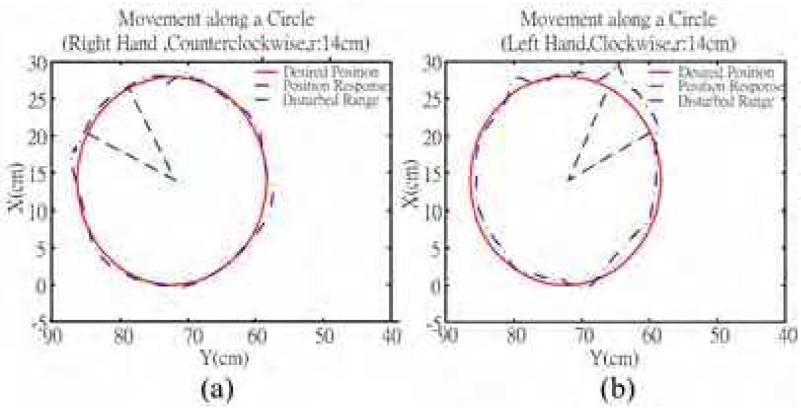


Fig. 11. Perturbed arm movement, (a)intact(b)affected.

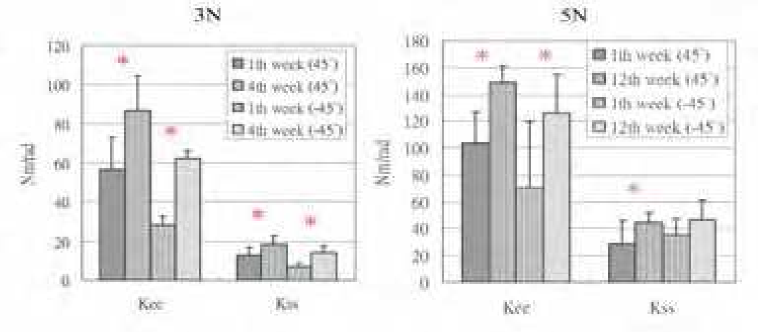


Fig. 12. Changes of dynamic stiffness.

3.3 Wrist Unit for assessing Forearm Synergistic Patterns

A new torque measurement system was developed to quantify the abnormal synergistic patterns of the strokes when they were performing upper limb movements on the horizontal plane. The same protocol for treatment was employed and the pronation/supination torque and the tracking trajectories were recorded. An index IADT (integration of absolute deviation torque) written as

$$IADT = \int_0^{2\pi} \left\| M_f \right| - \left| \overline{M}_f \right\| d\theta \tag{4}$$

was employed for quantifying the synergistic torque of the affected muscles. In Eqn. (4) Mf is the pronation/supination torque of forearm, over bar means the average, and θ is the angle that defines the position of wrist on the circular trajectory. We found that IADT could be utilized to quantify the degree of in-coordination of the affected joints. Two types of movements, namely, passive and active constrained movement were performed by the subjects. Figure 13 shows the comparison between four stroke patients and six normal subjects during the active constrained movements. The results showed that for three out of four stroke patients, IADT of affected side was higher than that of the intact side. Subject S3 had a motor capability very close to the normal level. We found that IADT could be used to quantify the degree of synergistic movement and the stroke patients manifested significant abnormal pronation/supination movements during the circular treatment exercise. Details of this research can be found in (Kung et al, 2005).

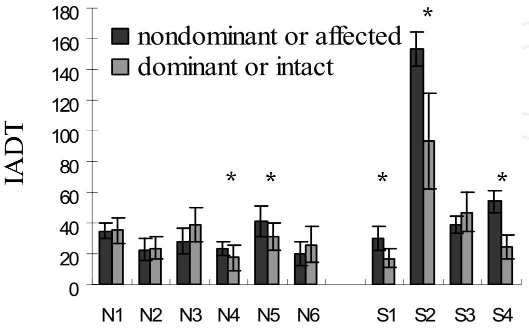


Fig. 13. IADT for normal group and stroke.

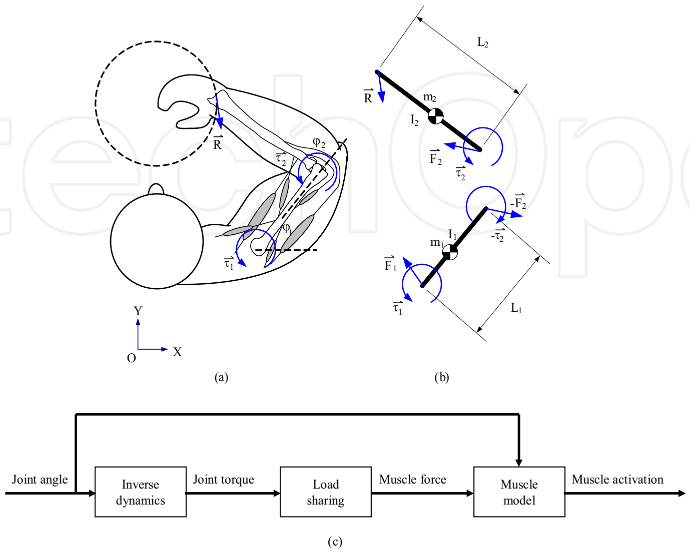


Fig. 14 Biomechanical model of subject.

4. Biocybernetic Models for Evaluating Motor Adaptation

4.1 Modeling of Subjects interacting with the Five-Axis Planar Robot

To explore the motor learning and adaptation of stroke patients during the time-course of robot-aided rehabilitation, a biomechanical model of the upper limb of a subject was developed (Figure 14). Simulations of the model could probe the interaction between the subject and the robot. The model consisted of the skeletal system and the Hill-type muscles. The inverse dynamics problem was solved by using the recursive Newton-Euler Equation to obtain the torque trajectories of shoulder and elbow. The static optimization problem was then solved to obtain the force distribution of the ten muscles. In the static optimization the objective function of sum of muscle stress squares which was an approach for minimum muscle fatigue was employed (Crowninshield et al, 1981). From the Hill-type muscle model and the angle trajectories of shoulder and elbow the neural excitation history of all muscles could be calculated.

4.2 Comparison of motor strategies between the normal and the stroke subjects

Seven subjects including a stroke and six normal subjects were recruited for a 6-week training program. All of them were new to the five-bar planar robot and they were asked to perform the transverse circular movement under a 10N resistive force. For the normal subjects, both speed and accuracy were improved progressively (Figures 15(a) and (b)). However, the performance of the stroke subject was not improved as steadily as that of the normal subjects (Figures 15(c) and (d)). Comparison between EMG signals and calculated activations showed that the normal subjects used minimum muscle fatigue strategy for the movements throughout the training program (Figures 16(a) and (b)). The stroke adopted a different strategy in the 2nd week and then returned to minimum muscle fatigue strategy in the later 4 weeks (Figures 16(c), (d), (e), and (f)). It might imply that the normal subjects could determine their motor strategies in the beginning for learning the movement and the training program might help the stroke subject to return to the "normal" strategy for the movement.

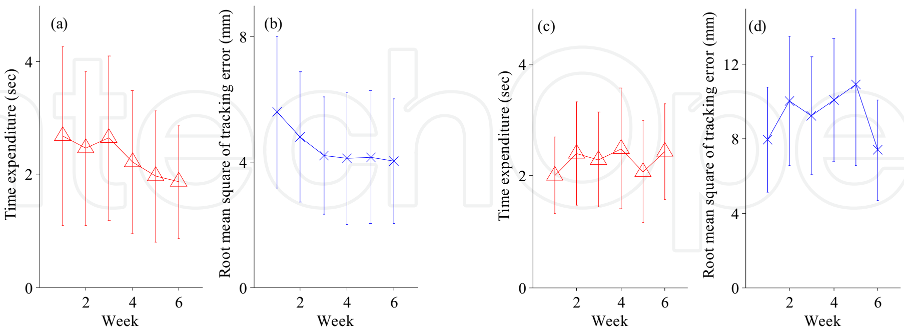


Fig. 15 Speed and accuracy of the subjects.

Normal, 1st~6th weeks Stroke, 2nd week Stroke, 3rd~6th weeks

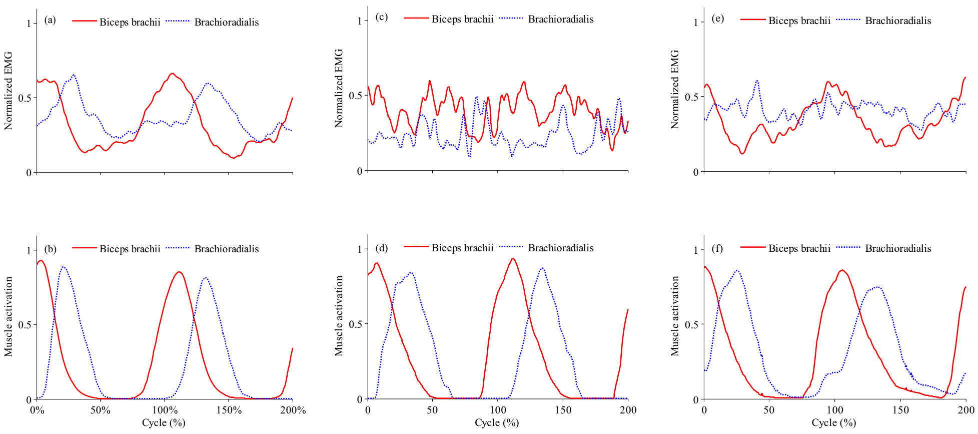


Fig. 16. Normalized EMG signals & calculated muscle activations.

5. Discussion

5-1 Advantages and Disadvantages of Robotics for Rehabilitation of Stroke Patients

One may find that robotics provides an integral solution to the treatments and objective assessments of some neurological diseases such as stroke. The robots can perform repeated treatment protocols without the need of continuous involvement of therapists. A robot can save therapists' arduous efforts by helping with heavy, challenging and repetitious movements. Physical strain and professional injury in therapists can be minimized. It is cost-effective to strengthen some basic elements, such as muscle strength, range of motion, and sensorimotor coordination, in preparation for higher skill-level movement patterns on a mass-practice basis. Robotic therapy techniques can mimic appropriate functional kinematics or apply novel patterns of force with precision, such as isokinetic contraction, that are potentially effective for muscle strengthening. More advanced robots can even provide tactile feedback that kinetically and kinematically corrects the impaired movements. Data collected during the robot training sessions can be quantified with ease to complement the subjective and qualitative observation of clinicians.

On the other hand, although biomedical robots have been used for surgery, life support and rehabilitation, the acceptance by patients and physicians are still low. There are several obstacles needing to be solved. Robotic training can just perform standard paradigm of limited combination of movement patterns in proximal joints. Currently, it cannot provide some sensory inputs, such as temperature, touch, stroking and psychological support. Robotic training is less flexible than hands-on therapy that most therapists consider essential to revitalize residual motor power of the arm and hand in neurologically impaired patients. The most central concern of patients about treatments is the beneficial effects on daily living activities, such as grooming, hygiene, dressing, undressing and toileting. The effects of robotic training might not be necessarily able to be translated into functional recovery. In the last, robotic therapy for shoulder and elbow joints can not be directly generalized to robotic therapy for the wrist and hand, which involves more degrees of freedom in joint space.

5-2 Future Aspects of Robotics in Rehabilitation Medicine

The challenge for the next step in robotic rehabilitation is to develop more creative, functional, interesting, task-oriented intervention with demonstrated effectiveness that maximize functioning and independence for stroke patients. The robotic system can be miniaturized for home and personal use and the interface can be more humanoid. Robotic therapy is convenient to combine several different prevailing techniques, such as functional electrical stimulation, biofeedback, and virtual reality, to optimize treatment effects for patients with different needs.

Studies of larger scale and more objective evaluating tools are necessary to firmly establish the efficacy of robotic rehabilitation. Recent development of function brain imaging methods such as the near infrared spectroscopy (NIR), functional magnetic resonance image (fMRI) and others have made possible the non-invasive functional imaging of cortex, especially the motor and sensory areas (Rolfe, 2000, Hu & Norris, 2004). We believe that direct observation of treatment effects on the specific areas of the cortex is essential for designing treatment protocols to provide more efficient rehabilitation of patients in the near future. However, there are several technical problems to be solved before the integration of rehabilitation robot with these imaging modalities. First, the strong magnetic field of MRI has a large disturbance on the sensors such as load cells, electromyography electrodes and electro-goniometer. Second, the metal structure and the actuators of the robots have high interference on the brain images and there is a need for developing rehabilitation devices that have less interference to fMRI.

6. Conclusions

In this paper a review on the biomechanical assessment of spasticity and the development of neuro-rehabilitation robots for stroke patients is presented. The robots provide precise physical therapy and objective evaluation of stroke patients. With the aid of emerging functional brain imaging tools and new robotic technologies, more effective treatments can be delivered in the future.

7. Acknowledgements

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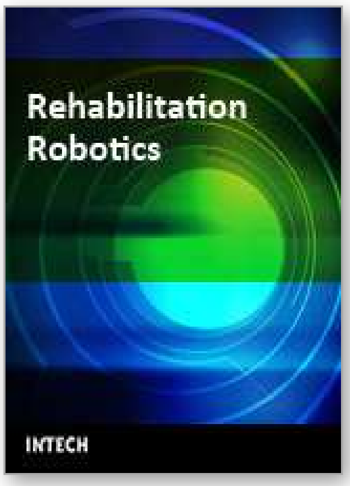

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The coupling of several areas of the medical field with recent advances in robotic systems has seen a paradigm shift in our approach to selected sectors of medical care, especially over the last decade. Rehabilitation medicine is one such area. The development of advanced robotic systems has ushered with it an exponential number of trials and experiments aimed at optimising restoration of quality of life to those who are physically debilitated. Despite these developments, there remains a paucity in the presentation of these advances in the form of a comprehensive tool. This book was written to present the most recent advances in rehabilitation robotics known to date from the perspective of some of the leading experts in the field and presents an interesting array of developments put into 33 comprehensive chapters. The chapters are presented in a way that the reader will get a seamless impression of the current concepts of optimal modes of both experimental and ap- plicable roles of robotic devices.

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