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A Novel Robot Neurorehabilitation for Upper Limb Motion

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Abstract—**Our goal is to apply robotics and automation technology to assist, quantify, enhance, and verify neuro-rehabilitation. In this paper a novel robot neuro-rehabilitation for upper limb, with many merits, is developed. Mechanism and control of the robot are introduced in detail. By a clinical trial involving 30 stroke patients with three months at Rehabilitation Center of China, some results are obtained 1) robot-aided therapy does not have adverse effects, 2) patients can accept the procedure, 3) the therapy may reduce muscular tension, and 4) manipulation of the impaired upper limb may influence brain recovery. Some new ideas are also presented to make rehabilitation therapy more effectively. These ideas will be helpful to further quicken the development of the robot neuro-rehabilitation.**

I. Introduction

THE leading causes of the permanent disability in China are cerebral vascular accident and cerebral trauma at present. According to existing figures, there are 1500 000 patients with stroke every year in China [1]. The consequences were devastating. It is the second main death reason in our country, and the estimated cost of care was RMB10 billion [2]. From the global view, vascular accident is regarded as one of three deaths in 40 states, according to the inquisition of WTO to 57 states in 1979[3]. Speaking for it, hemiplegia may bring family and society heavy burden and badly affect disabled survivor living. The neuro-rehabilitation process is labor-intensive, relying on therapy and evaluation procedures that are administered by a clinician working with a single patient. The procedures, which may control motion accurately, enhance documentation, provide training methods according to the clinic fact, increase productivity and reduce cost, are a primary application field for robotics.

In the article, the feasibility of robotics and automation technology used in the new field of neuro-rehabilitation is expounded for robot-aided upper limb motion. Research goal is to apply robotics technology to assist, cure, and quantify neuro-rehabilitation in the therapy of upper limb extremity of patient with hemiplegia.

By a clinical trial involving 30 stroke patients and three months at Rehabilitation Center of China, the patients may draw circle or line better and need less auxiliary force in the training. The muscular tension of patients may be reduced apparently. Four kinds of basic training mode are presented in the control system, namely initiative motion mode, passiveness motion mode, resistance motion mode and assistant motion mode [4]. These motion modes may be used at different stage of the hemiplegia. It can be found from this research that patients may tolerate the new procedure and do not have adverse effects, the robot-aided therapy may reduce muscular tension, and it may enhance motion function of the impaired upper limb by iatrical assessment procedures.

It is suggested that the robot assistance should be paid more attention to train the impaired upper limb qualitatively and quantitatively.

II. Design of the novel Robot Mechanism

A. Working principle

This one-one interaction, in which a clinician works with a single patient, characterizes much of the practice of clinical neurology. The novel robot is designed by Tsinghua University for clinical neurological applications [Fig.1].

Fig.1 A novel robot neuro-rehabilitation for upper limb motion

The robot may simulate clinician arm to assist patient arm training in clinical. This device is different from machines that have been built by other groups. It is made up of two bar-linkages, like an arm of the clinician, and may move freely in given workspace. Two motors drive the two bar-linkages respectively to fulfill the set track of the robot end. The workspace of the robot end may be calculated by equation (1), [Fig.2].

$$\begin{cases} x = L_1 \sin\theta_1 + L_2 \sin\theta_2 \\ y = L_1 \cos\theta_1 + L_2 \cos\theta_2 \end{cases} \qquad (1)$$

where θ is composition of angle at the end of the robot, θ_1 is output angle of big arm, θ_2 is the output angle of small arm, $L1$ is the bar-length of big arm, L_2 is the bar-length of small arm, x is position of the robot end along X axis, and y is position of the robot end along Y axis.

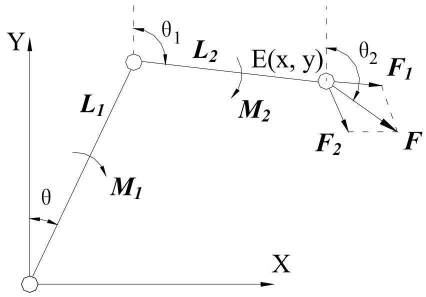

Fig.2 Mechanism of the robot motion

B. Mechanism characteristics of the robot

Some advantages of the novel robot include the simplicity and compactness of the mechanical structure, large workspace, and a hand-holder, which may fasten hand in four kinds of postures at the robot end [Fig.3]. These different postures of the hand-holder can possess different effects of rehabilitation in training. Hand may stretch and be placed on horizontal plane (Fig.3.a.) or vertical plane (Fig.3.b). Moreover, hand may also get hold of a horizontal axis (Fig.3.c) or vertical axis (Fig.3.d). Not only may the different postures of fastening hand use in different patient or different state of hemiplegia, it present a new condition for researching on rehabilitation theory.

（a） （b）

（c） （d）

Fig.3. Four kinds postures of fastening hand

The workspace of two bar-linkages mechanism is bigger than other equal size one, for example two degrees robot of five bar-linkages.

The robot mechanism is mainly made up of a reducer with four gears, two big arms, a small arm, and the belt gearing. The big arm consists of two bars with parallel structure for enhancing its rigidity. The robot can move, guide or perturb the movement of the patients upper limb and record motions and mechanical quantities such as the velocity, position, and moment applied. The robot may provide three degrees of freedom for forearm motion, elbow, and shoulder. The mechanism driven by two servomotors may fulfill two of 3-dof in horizontal plane. For abnormally low muscle tone, modest forces applied to upper limbs can result in excessive motion of the limb. Likewise, excessive muscle tone might misguide the clinician to apply very large robot forces to move upper limb. If applied improperly, the shoulder joint can be injured even in standard force.

Hence, robot rehabilitation for upper limb capable of activating elbow and forearm must also be able to adjust the height of the shoulder position. As a result, a pusher on what the mechanism is mounted may fulfill the shoulder movement in vertical direction. Because of applying characteristic structure of mechanism, the two servomotors that drive the reducer may be aligned on the same side, and then the mechanism gets more compact and is also easily mounted on the pusher. By applying two bars-linkage structures, not only the mechanism becomess simple, but also its workspace is bigger than other robot for neuro-rehabilitation with equal size.

III. CONTROL

The control system is made up of two alternating current servomotors with 4Nm of rated torque, 400W of rated power, and 16-bit resolvers for position and velocity measurements, a standard personal computer (PIII1.0G CPU-256M) with 16-bit A/D, D/A, and the servo control card.

Four kinds of basic training mode, which are initiative motion, passiveness motion, resistance motion and assistant motion, are presented in allusion to different state of hemiplegia in clinical. Initiative motion mode means that patient may move freely in no force field or velocity field, and the servo control card needs to adopt velocity control mode. Passiveness motion mode means that the patient arm is driven fully by the velocity field of the control system, and the servo control card needs to adopt the velocity control mode. Resistance motion mode means that the direction of a force field is in opposition to the direction of patient moving, and the patient needs to get over the set force for moving. Servo control card needs to adopt the moment control mode. Assistant motion mode means that a force field will help the patient movement in the set track. If there is no assistant force field, patient is hardly to fulfill motion in the set track. Servo control card needs to adopt the moment control mode. A force field may be calculated by equation (2).

$$\begin{cases} F^2 = F_1^2 + F_2^2 + 2F_1F_2\cos(\theta_2 - \theta_1) \\ \theta = \dfrac{\pi}{2} + \theta_2 - \arccos(\dfrac{F^2 + F_1^2 - F_2^2}{2FF_1}) \\ F_1 = \dfrac{M_1}{L_1} \\ F_2 = \dfrac{M_2}{L_2} \end{cases} \quad (2)$$

where $\boldsymbol{F}$ is the composition of forces at the end of the robot, F1 is the output force of big arm, $\boldsymbol{F_2}$ is the output force of small arm, $\boldsymbol{M_1}$ is output torsion of big arm, $\boldsymbol{M_2}$ is output torsion of small arm [Fig.2]. Velocity field may be calculated by kinematics equation.

IV. EXPERIMENT RESEARCH

A. Subjects

Consecutive patients (N=30) with a single stroke and hemi-paresis caused by a CT-verified cerebral vascular accident in the cortical motor area served as the subjects for the study, in accordance with the guidelines and approval of Tsinghua University and Rehabilitation Center Of China. Written consents were obtained from all subjects or designated guardians. A detailed description of patient's characteristics, i.e., sex, age, affected limb, lesion location, size, assessment scores, and complications, can be found in reference [5]. These patient's states of the illness are all very serious. Their upper limbs have no consciousness; and five-fingers and correlative muscles are in hyperkinesias. The average point of patients F-M is 7, the high point is 10, and the low point is 6 before training.

B. Experimental Procedure

In this clinical trial involving 30 hemiplegia patients with 1 moth/person, each one was trained 1hour/day and may have a rest of five minutes in the period. The 4 training modes, which are initiative motion, passiveness motion, resistance motion and assistant motion were used at different stage of hemiplegia which include phases of very week muscle tension, exceptional strong muscle tension, and function mending well. According to these phases, we take on the training mode of passive motion, initiative motion, resistance motion, and assistant motion respectively. Motion tracks of training are from line to circle and from simple to difficult rule, which is the motion of human growth. Velocity of being drawn or pulled becomes gradually big from 150mm/s to 600mm/s in passive motion. Traction impaired limb move along fiducially track 10 times/return in low velocity, while the impaired limb is moved 5times/return in high velocity. From the view of neuro-rehabilitation, it is the virtual that exceptional strong muscle tension is eliminated and activating hemiplegia patients move on one's own initiative in training. Hence, it is given so small traction force that patients must apply enough force to fulfill scheduled motion in passiveness training mode. It is the most important training mode that we think it for neuro-rehabilitation. At the beginning of 12 days of training, the robot provided very big traction force, but it only provided very small force at the end of days.

C. Robot-Aided Assessment Method

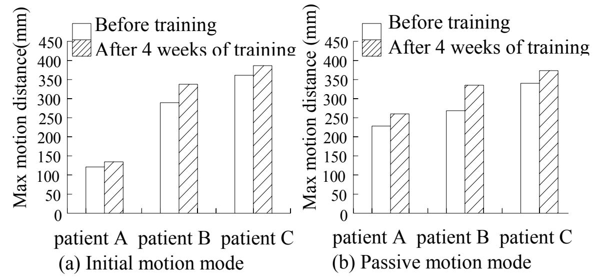

Fig.4. (a) drawing denotes max motion distance of patient A, patient B,and patient C in initial motion mode; while (b) drawing is in passive motion mode.

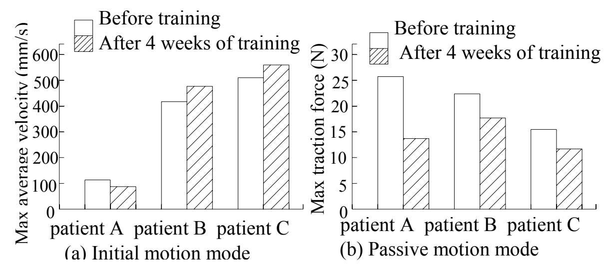

Fig.5. (a) drawing denotes max average velocity of patient A, patient B,and patient C in initial motion mode; while(b)drawing denotes max traction force of patients A, patients B,and patients C in motion mode.

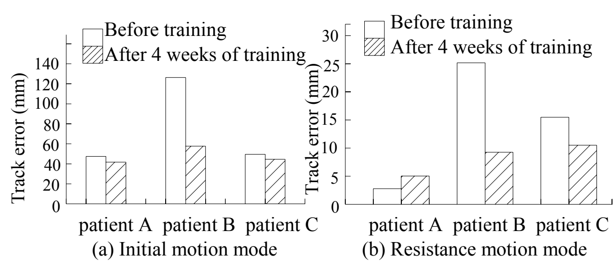

Fig.6. (a) Drawing denotes track error of patient A, patient B,and patient C in initial motion mode; while(b)drawing is in resistance motion mode.

At present, the standard assessment method is still F-M [6]. In the neuro-rehabilitation field. Other assessment methods will be found, because the F-M procedure possesses strong subjectivity and does not assess well and truly. It is a new method that the robot recording datum including position, velocity, track error and force may be applied to assess the grade of patients resuming. By experiment of three months, the motion distance [Fig.4], velocity [Fig.5.a.], track error [Fig.6] and force [Fig.5.b.] of patients at the end of the robot have obvious differences in numerical value. For example, patients may move longer distance and larger velocity, and apply smaller force to fulfill the scheduled motion after training by 1month/person. The relation between the robot recording datum assessment and F-M is still found, and then the grade of neuro-rehabilitation cannot be assessed directly, though the new assessment procedure has many merits that the assessment datum is exact and long-time records.

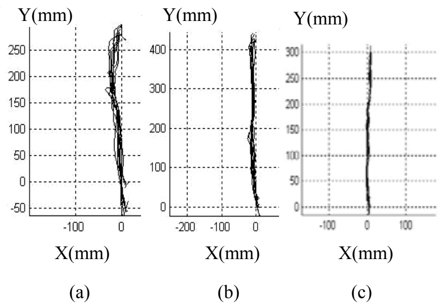

Fig.7. (a) Drawing lines of patients D after 10days of training; While (b) drawing is after 21 days of training, and (c) drawing is after 30 days of training.

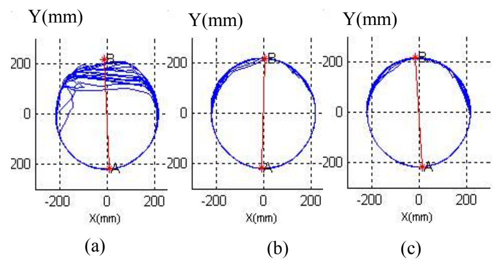

Fig.8. (a) Drawing circles of patient D after 10days of training; While (b) drawing is after 21 days of training, and (c) drawing is after 30 days of training.

An initial point of F-M Patient A is 6, Patient B 7and Patient C 7 before training. Their final point is respectively 8,9, and 8 after three months of training.

They all were well in some extent after patients (N=30) had taken part in the trial of three months. Only three examples of patient A, patient B, and patient C are given here. From the above points of patients F-M or from the above their kinematics parameters, the three patients A, B, and C all get well in some extent after they had been trained for three months. A kind of one-one connection between kinematics parameter and F-M point should be established. The former can be used to substitute for the latter as the assessment standard of rehabilitation, because the former is more impersonal. By 30days/persion of training, all patients drew circles or lines better, and the track error got smaller. This mean that the harmonious function of patients arm become better by training. Another example of patient D is given here, [Fig.7] and [Fig.8].

V. RESULTS

At the beginning, it was unclear whether the robot-aided therapy would not impede recovery or aggravate joint or tendon for shoulder, wrist, and hand [7,8]. By the trial including 30 patients with 4weeks/person, the robot for neuro-rehabilitation does not have any detrimental effects and all patients may accept the new therapy. By analyzing kinematics parameter and F-M point of 30 patients, the motion function of patients upper limb became well apparently in three months of training. Moreover, it is quite apparent that the robot-aided therapy may reduce muscle tension quickly and the symptom will not return. At present, reducing muscle tension is mainly provided by means of medicines, but the therapy effect is not satisfied. Hence, the new method of robot-assistance in clinical therapy is very important.

VI. CONCLUSION

From the view of the key technology of neuro-rehabilitation, some new ideas that robot-assistance should train impaired muscle tones on the basis of kinematics and dynamics models of human upper limbs are presented.

Moreover, sEMG should be conducted to control system in real time for providing some key datum to the system. The new ideas are so important that they may help us make better robot for neuro-rehabilitation and research on theory of neuro-rehabilitation. By clinical research, we think that robot-assistance will be wide foreground in neuro-rehabilitation field.

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