Novel Human-Centered Rehabilitation Robot with Biofeedback for Training and Assessment

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Abstract. We present the novel human-centered rehabilitation methods from the research as well as literature to provide the robot assisted rehabilitation control strategies and motor function assessment methods. The research is based on the upper extremity compound movements (UECM) rehabilitation training robot [1], which is applied to the rehabilitation of upper extremity functions in patients with movement disorders. So called “human-centered” [2]or “patient-cooperative” strategies can take into account the patient’s individual situations, intentions and efforts rather than imposing predefined instructions. It is considered that such robot-assisted methods can improve the therapeutic outcome compared to classical rehabilitation methods.

Keywords: Human-centered; Rehabilitation robot; Control strategy; Biofeedback.

1 Human-Centered Rehablilitation Methods

Many clinical studies support the effectiveness of the robot-assisted rehabilitation training, particularly patients after stroke [3]. Repetitive movements can improve muscular function and neural activity in patients, as well as prevent complications such as muscle atrophy, osteoporosis, etc.

Manually training by therapist has several limitations, such as high labor intensity, lacks of experience, training duration, assessment and so on. In contrast, the rehablilitation robot is consistent and customized to the patient, thus the appropriate afferent sensory input, which is believed to be important in improving the status of limb muscular activity and nervous activity [4], can be activated in the normal way.

In recently years, there is an increasing emphasis on “human-centered” robotic system for human rehablilitation after neurological injury[2]. The “human-centered” strategy means close interaction between the rehablilitation robot and the human, meanwhile the human is always in the center of the therapy. As the abnormal muscular tone may cause strain or dislocation of patient’s joint[5] and other problems, rehabilitation robot should be safe, flexible, interactive and gentle toward the patient and therapist[6]. In consideration of the synergies of joints and muscles, the robot should also assist the patient’s movemont adaptability and behave in a patient-cooperative way.

C. Stephanidis (Ed.): Universal Access in HCI, Part IV, HCII 2011, LNCS 6768, pp. 472–478, 2011.

The development of novel rehabilitation strategies such as virtual reality[7] and automatic adaptation control method can improve the interaction between the rehabilitation robot and the patient with hemiplegia or aphasia. Optimal training effects also depend on appropriate feedback and assessment about patient's individual performance.

Several researchers and groups have developed different rehabilitation robots, for example, MIT-MANUS[8] by MIT, LOKOMAT[9] & ARMin[10] by ETH Zurich, Intelligent Robotic Arm[11] by Chicago Rehabilitation Inst, etc.

In our study, the novel human-centered robot mentioned above has been developed. The robot provide different training modes(such as passive movement, impedance movement[12], patient-driven motion reinforcement movement[13],etc). The robot arm move the patient's limb in a defined trajectory , can also recognize and follow the patient's movement intention. Or allow the patient to deviate a certain range from a predefined reference trajectory in impedance control strategy. Allow the patient to reinforce the normal patterns of muscular abilities and give them feedback just like the therapist do.

We will present the human-centered principles that applied in the robot in this paper.

2 The Control Strategies

The robot consist of two-joint robotic arm that is used along with a limb-support display panel. The limb is actuated by a fixing bracket with bi-axes diver system. The panel can display the limb trajectory real-time and instructions ahead. The panel can also train patient in higher dimensions by changing its tilt angle.

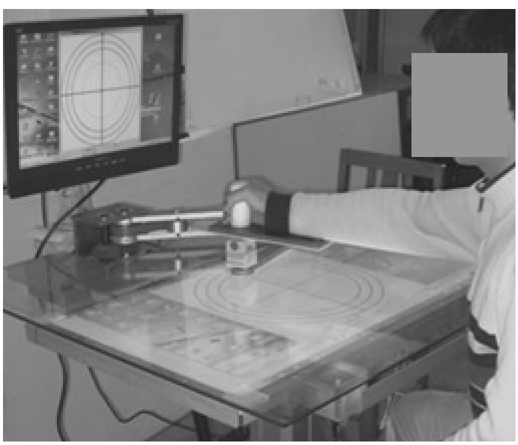

Fig. 1. The UECM rehabilitation robot[1]

The robot detect the patient's movement efforts and provide complex spacial trajectory training modes for the patients. Different control strategies are described and compared in this process: (1)The passive motion strategy, robot support patient's movements completely; (2) The motion reinforcement control strategy: robot assist patient's movements induced by patient ; (3) The impedance control strategy; (4)The adaptive control strategy[14] will be preformed in the future. The motion reinforcemen strategy and impedance control strategy are described in the following subsections.

Subjects were instructed to do exercise in circular trajectory with the robot arms in different training modes. The biofeedback and motivation method is applied in the process. Several training parameters, such as panel postures and movement speed, are varied to assess the effectiveness. They were also asked to change their performances and activity levels by observing visual feedback.

2.1 Motion Reinforcement Control Strategy

The actual movement induced by the patient is feedback into an inverse dynamic model to determine the robot contribution. So patient need to do some voluntary efforts to maintains the movement supported by the robot, and a scaling factor is used to change the supporting force.

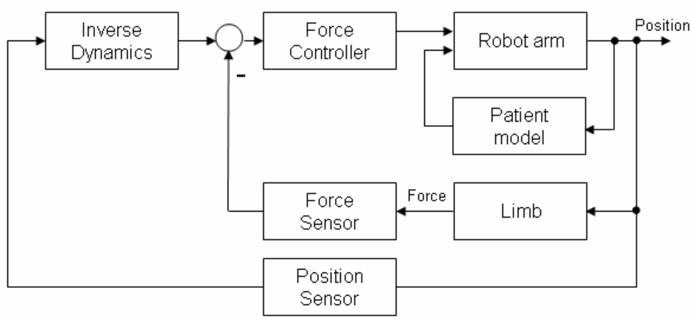

Fig. 2. Block diagram of motion reinforcement control strategy[15]

2.2 Impedance Control Strategy

Commonly, the impedance control strategy in rehabilitation robot allow deviation from a given trajectory and makes the robot compliantly[12]. Under such condition, the patient need to apply force to achieve the deviation trajectory. The deviation magnitude depends on the patient's muscular contribution, and keep the end of limb stay in a defined range along the trajectory by the impedance force .

It's considered that patients with paraplegia may be restricted and get less possibilities to change the muscular activation pattern bacause of the spasms[16].

2.3 Adaptive Control

In order to suit for the patient in severe spasm ,the adaptive control algorithms will be used and compared in the future. In this control strategy, patient will contribute voluntary muscular efforts to do his preferred trajectory under a reference [16]. Robot minimizes interaction forces between the patient and the robot, adapt the different impedance force to the individual patient's desired motion.

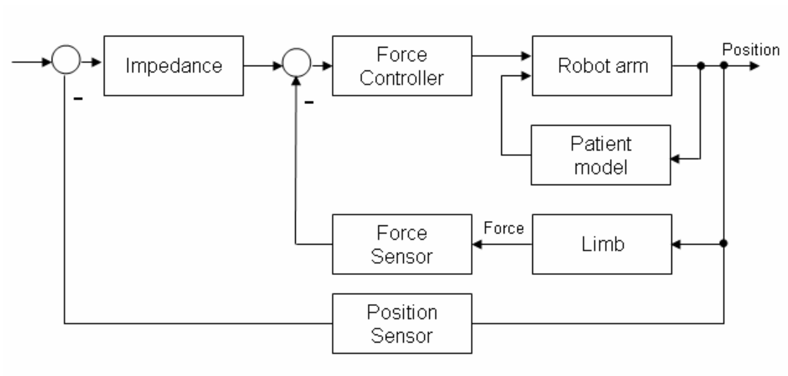

Fig. 3. Block diagram of impedance control strategy[15]

3 Biofeedback and Assessment

3.1 Overview

To promote the patient's active participation, several biofeedback elements are activated: stimulating patient's interest and neural activity; providing training status for the patient through real-time display of limb trajectory, speed, interactive force and tactile input; muscular activity and cardiopulmonary activity recordings; different control strategy for the individual patient.

The robot measures the track of upper extremity, movemont duration, range of motion by position sensors, as well as the reaction forces by force sensors on the fixing bracket. The muscular activity are also recorded by electromyographic (EMG). The recorded parameters of biomechanical and neurological states are processed and feed back to the patients via both the displays in front and the displays below the limbs [1].

Other parameters, such as heart rate, blood pressure, the spasticity evaluation, can also be measured and used as biofeedback values. These values are coonsider to be adequately important for presenting training condition and making rehabilitation plans for the therapist.

Robot-assisted assessment and feedback can extend and improve robot-assisted training therapy. The therapists can adapt the therapy and give further instructions to the patients. Combining robot-assisted training and assessment with biofeedback will make future therapy easier and more efficient.

3.2 Results

Results about the effects using different visual feedback method have been also obtained via experiment by healthy subjects. Variance analysis of the trajectory as follows (Heavy line: Desired trajectory; thin line: Actual trajectory; dotted line: Fitting average of actual trajectory).

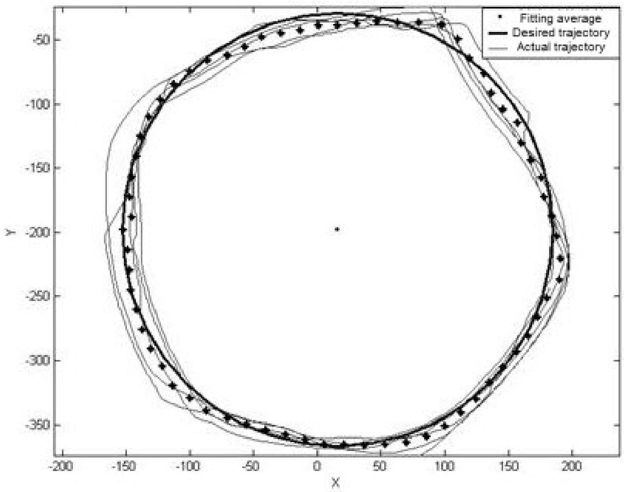

Fig. 4. Motion trajectory using visual feedback below limb (Visual feedback method 1)

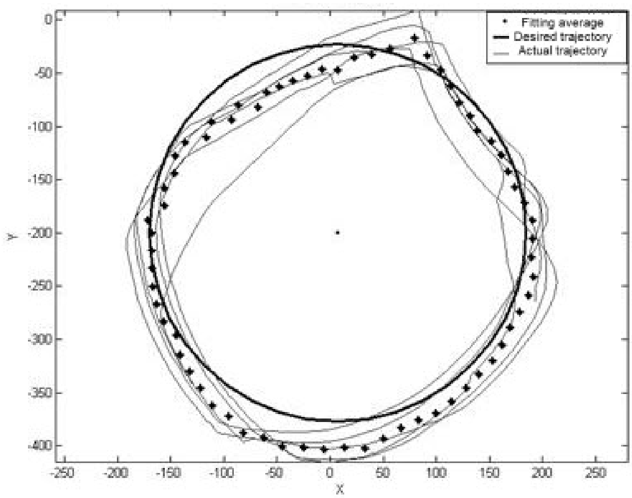

Fig. 5. Motion trajectory using visual feedback in front (Visual feedback method 2)

Table 1. Statistical deviation of trajectory[1]

Tilt angle of support panel	Horizontal (0°)	Lean to human side(35°)	Lean to other side (-10°)
Visual feedback method 1	0.7893±8.2095mm	-0.9773±13.735mm	0.7443±14.9341mm
Visual feedback method 2	4.4482±22.159mm	3.7021±21.7491mm	-4.8251±22.4571mm

We can see that the error band using visual feedback below limb (method 1) along with impedance control strategy is less as comparing the data using visual feedback in front (method 2) along with impedance control strategy. Meanwhile, the influence of the support panel tilting angle is more distinct in method 1 than method 2. In method 2, error is mainly composed of visual feedback factor rather than tilting angle. In the tilting panel condition, shoulder and elbow joints will stretch more, and deltoid muscle could get more training because of gravity□verified by Motion Analysis systems[17] and SIMM module[18] in our previous experiments [19]□.

4 Conclusions and Outlook

The common feature of control strategies mentioned above is the cooperatively interactive performance of the robot, including the compliant behaviour in impedance control strategy, supporting behaviour in motion reinforcement control strategy, adaptive behaviour in adaptive control strategy. All these strategies try to activate natural and muscular activities induced by the patient.

More function of the rehabilitation robot should be developed by imitating human therapist: for example, the rehabilitation robot can take appropriate treatment even when patient is passive and weak in the early stage of the rehabilitation.

Future clinical evaluations should be performed with a large population of different patient groups, including patients with hemiplegia after stroke, and others such as patients with Parkinson's disease.

Acknowledgments. We thank Lining Chen and Yupeng Ren for their contributions to this paper.

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