Yan-zhao Chen*, Yu-wei Zhang

Research and Development of Upper Limb Rehabilitation Training Robot

Abstract: This paper studies rehabilitation mechanisms and the inadequateness of traditional clinical means rehabilitation of stroke patients. Related progress and the research status of upper limb rehabilitation robot aided rehabilitation are discussed. The results show that self-training has become a promising rehabilitation method, sEMG based upper limb motion recognition is becoming a key interaction technology, and a task-based training mode in the environment combined robot and VR is the trend of future development.

Keywords: rehabilitation training; robot; hemiplegia patient

1 Introduction

Hemiplegia is usually caused by stroke and other diseases, and blocks the activities of daily living abilities (ADL) of most patients [1-3]. The patient's daily work and life are seriously affected, which bring a burden on society and family. The incidence of stroke is high, and it has become one of the common causes of human death [4-6]. Clinical studies have indicated that in the early stage of illness, some exercise training for patients is helpful to the recovery of the activity of daily living [7-9]. The commonly used traditional clinical rehabilitation training method is a one to one style between patients and rehabilitation therapists. Due to the fact that the number of patients is large, and the number of rehabilitation therapists is limited, the actual implementation of rehabilitation training, training intensity, training time and training accuracy and other aspects are not guaranteed, and so the patients' rehabilitation is poor.

The rehabilitation robot emerged with the development of modern science and technologies such as robot technology, signal processing, pattern recognition and clinical technology. Robot aided rehabilitation training can overcome the shortcomings of traditional clinical rehabilitation methods, facilitate the generation of new rehabilitation models and ultimately improve rehabilitation [10,11].

***Corresponding author: Yan-zhao Chen,** School of Mechanical and Automotive Engineering, Qilu University of Technology, Jinan, China, chyzh_ql@126.com
Yu-wei Zhang, School of Mechanical and Automotive Engineering, Qilu University of Technology, Jinan, China, zhangyuwei_scott@126.com

Through the mechanism of stroke rehabilitation research and considering the clinical deficiency of traditional rehabilitation methods, this article analyzes the current research development of rehabilitation robots used for assisting patients doing rehabilitation training. The development status of upper limb rehabilitation robots and the corresponding recovery mode changes are reviewed.

2 Changes in the Way of Rehabilitation and Rehabilitation Mechanism

Stroke is a central nervous system disease, its causes are generally a sudden hemorrhage or ischemia in the brain, resulting in damage to the cerebral cortex. Thus it affects the control instruction formation in the central nervous system or blocks the pathways for nerve control instruction, and eventually leads to the patient's movement intent formed incorrectly or the nerve control instruction can not transmit to the movement terminal to achieve movement. The human body's motor function, especially the upper limbs are blocked. Medical studies have shown that the human nervous system has a certain degree of plasticity [12], as well as the ability to re-learn motor skills [13].

Practice shows that rehabilitation therapy in the early stages of the patient's sickness is more conducive to the recovery of their motor function [7], and the most effective way to promote motor function reconstruction of patients is repeated exercise training [8]. Now the rehabilitation training methods often used in clinics are traditional, namely the one to one style between patients and rehabilitation therapists, such a training method has a lot of drawbacks. The first is place restriction, the process of rehabilitation is generally only executed in a hospital or rehabilitation center, it lacks without of flexibility. Secondly, because of the high incidence of stroke, the number of patients is numerous, and the number of rehabilitation therapists is relatively limited, causing many patients to not get timely and stable treatment, which affects the rehabilitation. On the other hand, patient rehabilitation usually takes a long period of repeated training in training processes. In this case, the workload of rehabilitation therapists will increase and easily lead to fatigue, training may cause errors, inadequate training efforts and other phenomena, which will produce adverse effects on rehabilitation patients. Due to the poor effect of the traditional clinical rehabilitation method, which is not conducive to the promotion of rehabilitation clinical practice as well as the research on the rehabilitation mechanisms of stroke patients, a new and modern rehabilitation method is in urgently needed as a complement to traditional rehabilitation methods to promote the development of clinical rehabilitation theory and practice. In addition, clinical studies show that patients' active participation is more helpful to enhance the rehabilitation effect. In this context, patients' independent rehabilitation, especially in the home environment becomes a meaningful self-rehabilitation method, while research on the self-rehabilitation based on rehabilitation robot has broad applications [14,15].

The upper arm plays an important role in people's daily life, so an upper limb rehabilitation robot assisting the upper limb to execute rehabilitation training in order to achieve functional reconstruction of the movement is particularly important. An upper limb rehabilitation robot is a mechanical structure used for assisting patients with limited upper limb motor function, such as hemiplegic patients to implement the rehabilitation of their ability of daily living, which is guided by rehabilitation medicine theory, and based on the integration of robotics, human anatomy as well as disciplines of computer science and other technologies.

Upper limb rehabilitation robots have good fatigue resistance, have high controllability, which can achieve high-precision control and ensure safe and reliable control during the operation process. The manner that upper limb rehabilitation robot for upper limb rehabilitation training is adopted can change doctor-patient relationships and provide a new rehabilitation training for patients, and has become a promising field of research and application.

3 Upper Limb Rehabilitation Robot

With the development of science and technology as well as rehabilitation medicine theory, the rehabilitation concepts and methods of stroke patients have changed. The means of upper limb rehabilitation training have transformed from the traditional way to the robot aided manner, which brings a series of changes from robot mechanism design of upper limb to rehabilitation mode.

3.1 The Mechanism Design for Rehabilitation Training

In the related research on upper limb rehabilitation robot started earlier, in the design of mechanical structure, some efforts have been made by many scholars in related fields, the researchers designed a variety of rehabilitation training devices, from an early simple assisted rehabilitation tool with single degree of freedom to an automated multi-DOF rehabilitation robot. The early rehabilitation training device appears, such as hand-object-hand in master-slave means developed at the American University of Pennsylvania [16], which can assist a patient's hand do simple movements with the mirror training. Shortly after, Researchers in Stanford University designed a series of upper limb rehabilitation devices to assist upper limbs to do rehabilitation training, known as Mirror-image Motion Enable [17]. In recent years, the development of upper limb rehabilitation robots tend to more freedom, intelligence and porTable. It is more and more user-friendly, and the wearable style has become a research trend. Arizona State University developed an upper limb rehabilitation training mechanical structure called Robot Upper Extremity Repetitive Therapy Device [18]. Researchers of the University of Washington studied wearable neurological rehabilitation exoskeletons

robots called Cable-actuated Dexterous Exoskeleton for Neurorehabilitation [19], and so on.

3.2 Interactive Mode

A rehabilitation robot is a mechanical device used to assist patient rehabilitation, its interaction with the patient is an important aspect of this rehabilitation. Since it is usually one body side of the patient with stroke that has lost voluntary movement functions. Guiding disabled upper limbs to do movement using the upper limb on the healthy side become a viable rehabilitation training manner, at the same time become a trend. The general process of this approach firstly identifies the movements of the healthy arm, and then, converts the recognition result to rehabilitation robot motion control instruction and drives the robot, at last, the disabled upper limb executes movement with the aid of the robot in order to achieve rehabilitation. The action of the healthy arm becomes one of the core technologies.

Since the 1980's, the motion tracking used for rehabilitation has become a hot area of research. Motion recognition tracking technologies currently available for rehabilitation can be summarized into three classes:

First, the tracking technologies for body motion based on physical sensor.

This type of technology mainly refers to adopting various physical sensors for human movement identification and tracking. The physical sensors commonly used include gyroscopes, acceleration sensors, gravity sensors, acceleration sensors, etc. [20,21].

This can get physical parameters of the upper limb movement directly, such as posture, freedom of movement, velocity and acceleration. However, when using the contact sensors to track body movements, it necessary to install the sensors in the human body permanently, due to the special nature of human physiological structure, the sensor is not easy to mount with the location and angle are difficult to fix. Moreover, due to the randomness of body movement, such physical sensors are prone to shift, delay and jitter as well as generate other issues. Thus, human motion tracking method based on contact sensors does not apply to robot-assisted upper limb rehabilitation.

Second, the tracking technologies for body motion based on the non-contact physical sensor.

Since the tracking technology for body motion based on the non-contact sensors does not require direct contact with the human body, the problems such as offset and installation are not be generated. The non-contact physical sensor most commonly used is based on optical devices such as Kinect, etc. [21,22]. Such technology is more convenient, however, in the process of human motion tracking and identification by optical sensor, the body location needs to be stable, which means a lack of flexibility. There are also special requirements for the environment and the light

level of application areas. In addition, it produces body part overlap, occlusion and other issues, especially with noisy backgrounds, such as in the home environment of remote rehabilitation, the motion recognition results are difficult to achieve at the desired level [23]. Moreover, 3D positioning requires high-precision mathematical calculations, which will result in delay and other problems and it is difficult to ensure real-time performance. So the technology is not applicable to this kind of robot-assisted upper limb rehabilitation.

Third, there is physiological signals based motion pattern recognition technology.

In addition to physical sensors, a physiological signal as an emerging tool has been brought to the field of human motion tracking with pattern recognition as its core technology. The physiological signals commonly used are mainly EMG (Electromyography) [24], EEG (Electroencephalogram) [25] and so on. EMG signal is the most commonly used. According to the work mode, an EMG signal can be divided into a needle electromyography signal and a surface electromyography signal (sEMG). The signal acquisition by needle electromyography needs to insert the needle electrodes into the muscle inside, which is inconvenient and will result in trauma to patients. The signal acquisition by sEMG just needs to stick the electrodes to the surface of corresponding muscles at the skin surface, with a non-invasive, real-time, wide collection area, and sEMG is weak potential difference signal collected on the skin surface, the signal is rich in information on body movements, and capable of reacting to human movement intent. Therefore, sEMG based human motion tracking is more suitable for clinical application, and this is the reason why it has received widespread attention and study.

Pattern recognition is usually used to establish the relation between sEMG and the upper limb motions. Its process can be described as follows: first perform the specified upper limb movement, while collecting the sEMG from the corresponding muscle at the skin surface; and then, perform a signal pretreatment which includes filtering and amplification, followed by the feature extraction; training pattern classifier and implement motion classification. The motion recognition results can be used as upper limb rehabilitation robot motion control instructions.

In summary, these three techniques can be used to track the motion, EMG, particularly sEMG is more in line with the special nature of the patient's physiological state, which is more suitable for clinical application, thus it is becoming a promising field for rehabilitation medicine and technology research.

3.3 Rehabilitation Mode

The introduction of rehabilitation robot brings changes in rehabilitation method. The purpose of rehabilitation is to restore the patient's activities, and a rehabilitation robot supported rehabilitation training is possible to promote the structural recovery of their nervous system, but it is not easy to transfer this restoration to functional

recovery [26]. Under normal circumstances, although the patient's neural pathways is opened to some extent, it is still not able to complete some functional movements independently, such as picking up a cup, this phenomenon called "learned disuse" [27]. The reason for this phenomenon may be that the previous training is only mechanical training without functional objectives.

Studies have shown that, task-based training can induce the transition from structural recovery to functional recovery of nervous system, and then, promote the functional rehabilitation of patients and rebuild their activities of daily living (ADL) [1]. Meanwhile, introducing the virtual reality technology into the field of rehabilitation medicine and letting patients performing task-based training in realistic virtual scene can enhance their training initiative, which will benefit their functional recovery and be more conducive to the recovery of their activities of daily living. In particular, with technological advances, remote recovery, especially in the home environment has drawn increasing attention. Virtual reality based task training provides support for the rehabilitation in this model. Combining the upper limb rehabilitation robotics, virtual reality technology and sEMG pattern recognition technology to achieve rehabilitation of patients with hemiplegia becomes a viable approach. In 2011, the researchers presented a robot ARMin III supported ADL rehabilitation training systems [28], and designed variety of tasks in virtual reality scene for patients' ADL training, such as cooking.

4 Conclusion

Stroke is a disease which has become one of the major causes of death. The voluntary movement ability of patient's body, especially the upper limb is usually impaired, the activities of daily living are impeded. The traditional clinical rehabilitation method depends on the rehabilitation therapist and hospital with a lot of drawbacks and restrictions. With the development of science and technology, robot-assisted rehabilitation research has created enthusiasm. The mechanism design from the early single degree of freedom and simple function to multi-degree of freedom, portability, automation, intelligent. In the aspect of interaction mode, the sEMG emerged as its various advantages. The rehabilitation method changed from a traditional mode with fixed time, fixed location, fixed form to remote recovery, family rehabilitation and other diversified methods. By the aid of a robot in a virtual reality environment, a task-based rehabilitation method is promising for future development.

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