Proceedings of 2017 IEEE
International Conference on Mechatronics and Automation
August 6 - 9, Takamatsu, Japan

Characteristics Evaluation of a Rehabilitation Robot for Upper Limbs

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***Abstract* - The development of robot technology provides a good opportunity for the development of robots in rehabilitation. As a result, robot for upper limbs has become more and more popular. Rehabilitation robot can use the related technologies to monitor and evaluate the rehabilitation process or the training condition, improve the training pertinence and science. Moreover, it can free physicians from heavy and repetitive work. Then make the efficiency of the rehabilitation better. In this paper, we developed a new exoskeleton rehabilitation robot system for upper limbs, which can achieve 3 degree-of-freedom (DOF) movements including elbows and wrist. And a new system with multi-sensors has been created to control our device. We use this control system to implement the motion and information collection.**

Index Terms –Rehabilitation; Control System; Gyro

I. INTRODUCTION

Stroke is a highly prevalent disease in the world and it's also the second disease that results in death [1]. High costs and many medical staff were needed in the cure for stroke. One main purpose of cure for stroke is the recovery of human body function, especially the activities of daily living (ADL) [2]. In the last few years, many kinds of exoskeleton rehabilitation robot system has been developed and this trend shows that rehabilitation robot has many advantages in this area.

Because of the lack of medical staff and the boring rehabilitation process, development of rehabilitation robot seems to be a good choice to solve these problems [3]. First of all, the rehabilitation guided by robot system can free the therapists from heavy and repetitive work. Secondly, robots can guide the patients with the scheduled movement without getting tired. Thirdly, with other sensors and evaluation system, robots can implement the accurate amount of exercise and reliable evaluation of rehabilitation [4]. Finally, the rehabilitation system can be remotely operated and monitored, which can realize home- rehabilitation. According to the research, many researchers pay their attention to lower limbs instead of upper limbs and there are also some problems need to solve in upper limbs rehabilitation robot. As a result, it's important to develop a new rehabilitation robot for upper limbs and study on the evaluation of the system.

In this paper, a new rehabilitation robot (Fig.1) for upper limbs was developed and we analysed the characteristics by the motion experiments. These experiments test the characteristics of the new device and the new control system, in which the new device proved to be effective in rehabilitation of upper limbs. By using the gyro and photoelectric encoder sensor, it proved to be well to estimate continuous joint angular displacement and velocity in elbow flexion/ extension. In our experiment, subjects need to move their upper limbs as told mainly by using their elbow. In order to decrease error and pay more attention to the device itself, the action was in a low speed.

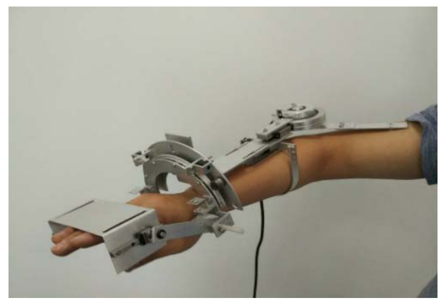

Fig.1 The rehabilitation device.

The first section of the paper introduces the research background about stroke and rehabilitation system; the second section introduce the new rehabilitation device and control system, and shows the research methodology including the experimental approaches and experimental procedure. The third part shows the experimental results and last part shows the conclusions.

II. SYSTEM DESCRIPTION

This new rehabilitation robot for upper limbs was designed as a bilateral rehabilitation system, which is composed of the mechanism system, multi-sensor system and control system. These three components work together to achieve that three Degrees of Freedom (DOFs) can move in the correct trajectory. Fig.2 is a schematic diagram describing the interactions of system components.

The multi-sensor system collects the information (EMG signals and position) from therapists or healthy side. Then information obtained by computer will be processed in control system. The communication between multi-sensor system and control system is conducted by API. In our control system, data processing unit is used to integrate information, discriminate the signals and send messages of control to the mechanism system, where rehabilitation device can act as command. At last, another multi-sensor system collects the EMG signals and position information from the patient, then sends these to the control system. As a result, an evaluation of the rehabilitation system is created by the comparison of the commands and the patients' movements.

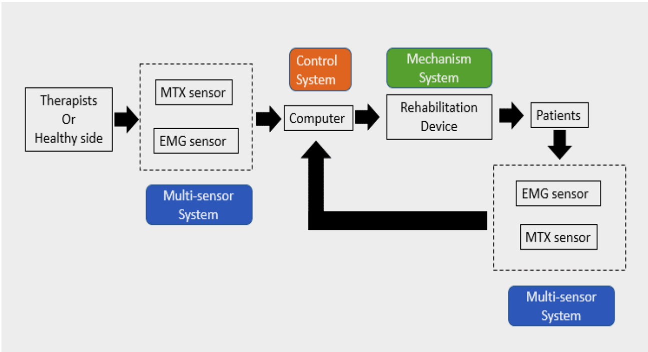

Fig2. The control system of the rehabilitation device

A. Mechanism system

The mechanism system, shown schematically in Fig.3, is composed of three degrees of freedom (DOFs), two in wrist joint and one in elbow joint. These three DOFs make the device work in a correct way as told.

1) Rotation in elbow

As is shown in Fig.4, the rotation in elbow has been designed as a two-pole structure and the two poles are linked by a reel. The upper pole was fixed on the upper arm and the upper arm is controlled to static. As a result, by the motion from the gear of motor, the forearm can move as required. The fixation between arm and mechanism is a strip of cloth, middle of which was fixed to the mechanism. And this design makes the subjects in rehabilitation more comfortable.

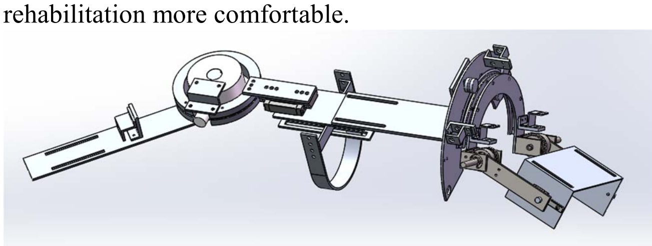

Fig.3 Mechanism system including elbow and wrist joint.

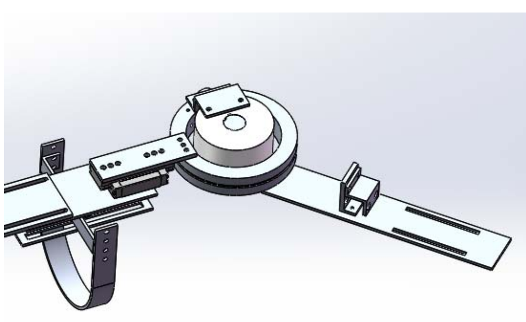

Fig.4 Rotation in elbow.

2) Rotation in wrist

The rotation in wrist is composed of two parts, including the fixation part and the rotation part. There are four reels between the two parts, which make it easily to move in 120 degree. (Fig.5)

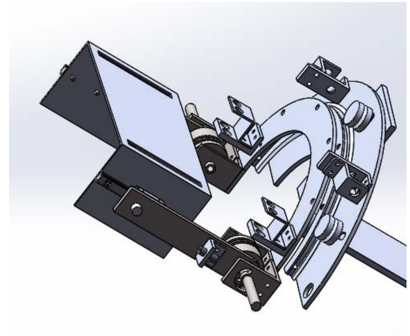

Fig.5 Rotation in wrist.

3) Flexion and extension in wrist

A motor is used to control the flexion and extension in wrist. Wrist can extend in a range from 0-120 degree so that it can meet the need of human movement in wrist.

B. Multi-sensor system

A multi-sensor system has been used in the rehabilitation system. Including Gyro sensor and EMG sensor, the multi-sensor system can collect information from the patients and the therapists. There are two Multi-sensor systems in the rehabilitation system. One for patients and the other for therapists or the patients' healthy part. Information sent to computer will be processed by some programs, including motion discrimination, mode discrimination, motion comparison and data processing.

Gyro, known as gyroscope, is a detection device to collect information about angle, acceleration, speed and so on. The combination of three or more Gyros can help us get all the moving status of the patients. Then the status information will be sent to the host computer through serial port. In host-computer-device system, ttl-to-usb conversion interface has also been used. But in ARM or DSP, the ttl-to-usb conversion interface will not be used.

The EMG sensor we use is from BTS Bioengineering with eight channels in maximum. BTS FREEEMG 300 electromyograph consists of a receiving unit which utilizes a Pocket PC platform and wireless probes designed and developed by BTS SpA.

C. Moving status acquisition and experiments

In the first part we need to get the moving status signal. In this part, two Gyros were used in the detection system. As is shown in Fig.6, one of the Gyros was fixed in forearm and another was fixed in Rear arm. When the patient keep his/her arm straight, the positive x-axis of two Gyros are in the same line. As a result, we can use the signal that the Gyros detected to process and analyse.

The communication between Gyro and host computer is achieved by several interfaces, usb to ttl. The Gyros send the signal to host computer through interfaces and the host computer recognize the signal from different cluster communication ports (COM). One Com represents one Gyro and the host computer will receive and save the signal from it.

In the second part, we designed the control system including data processing system to get full use of the signal we get from our sensors.

D. RPY space transform

RPY space transform, known as roll, pitch and yaw, is used in the processing of moving information. Fig.6 shows these three angles of space to determine the moving status. The rotation angle of x-axis is yaw angle. The rotation angle of y-axis is pitch angle, And the last one, the roll angle, is the rotation angle of z-axis.

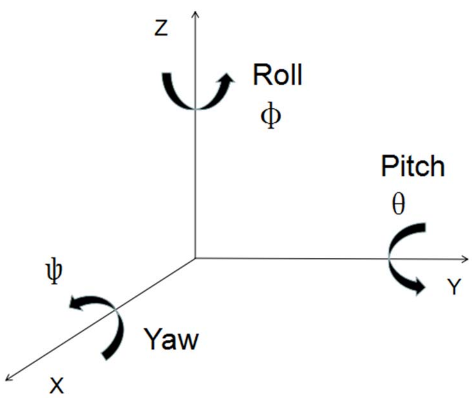

Fig.6 Using Yaw, Roll and Pitch to describe the motion Attitude of upper limb joints.

Using these three angles, we can calculate the moving status then we can get the moving information of one point. What's more, by using two or more gyros, the relative location can be calculated through (1) and (2). Then the joint's angle can be calculated and as a result, the moving of elbow, wrist can be describe by these angles.

$$\mathrm{RPY}(\varphi,\theta,\phi) = \mathrm{Rot}(z,\varphi)\mathrm{Rot}(y,\theta)\mathrm{Rot}(x,\phi) \qquad (1)$$

Where RPY represents the yaw, roll and pitch's moving space transform. That is to say, rotate ϕ degrees around the x axis, rotate θ degrees around the y axis and then rotate φ degrees around the z axis. And the matrix transformation which can explain it is shown as followed:

$$\mathrm{RPY}(\varphi,\theta,\phi)=\begin{bmatrix} c\varphi & -s\varphi & 0 & 0 \\ s\varphi & c\varphi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} c\theta & 0 & s\theta & 0 \\ 0 & 1 & 0 & 0 \\ -s\theta & 0 & c\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c\psi & -s\psi & 0 \\ 0 & s\psi & c\psi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$=\begin{bmatrix} c\varphi c\theta & c\varphi s\theta s\psi - s\varphi c\psi & c\varphi s\theta c\psi + s\varphi s\psi & 0 \\ s\varphi c\theta & s\varphi s\theta s\psi + c\varphi c\psi & s\varphi s\theta c\psi - c\varphi s\psi & 0 \\ -s\theta & c\theta s\psi & c\theta c\psi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

By using this matrix transformation between two gyros, we can get the moving status and the angle of joints, which is used to control the disabled part.

III. System Evaluation

To verify the robustness and efficiency of the new rehabilitation system, four subjects were invited into the experiment. They were asked to perform elbow flexion and extension slowly with upper arm relaxed. One time for each person and between two motions they have 20 seconds for the rest. Then we got the moving signals from the data acquisition device in motor and motion angle record from the gyro sensor. As the signals we got were in form of counts instead of angle, processing program was used to do the transformation. The moving signals from the data acquisition device in motor and motion angle record from the gyro sensor were compared to evaluate the robustness and efficiency.

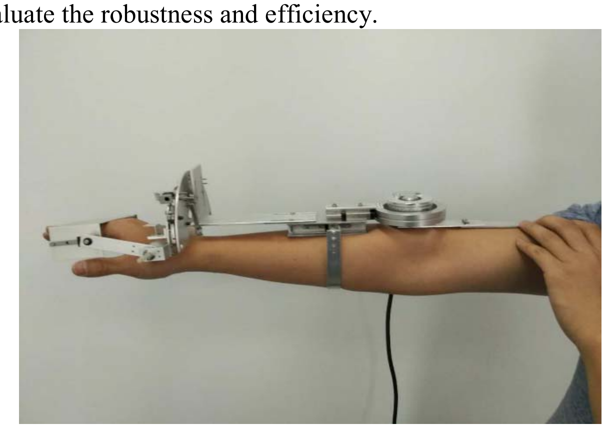

Fig.7 Rehabilitation device wore by a subject for experiment.

These four subjects were asked to do the elbow flexion and extension slowly with upper arm. Difference between these four subjects is their motion speed while the speed of B is twice as much as the speed of A, and the speed of C is three times as much as the speed of A. The speed of D is just as much as the speed of A, which is designed to find the error rate between different subjects.

The gyro angle calculated by (3) is shown in Fig.8 to Fig.11.

$$\boldsymbol{\alpha} = \begin{bmatrix} c\varphi1s\theta1s\psi1 - s\theta1c\psi1 \\ s\varphi1s\theta1s\psi1 + c\varphi1c\psi1 \\ c\theta1s\psi1 \end{bmatrix}$$

$$\boldsymbol{\beta} = \begin{bmatrix} c\varphi2s\theta2s\psi2 - s\theta2c\psi2 \\ s\varphi2s\theta2s\psi2 + c\varphi2c\psi2 \\ c\theta2s\psi \end{bmatrix}$$

$$\text{Gyro Angle} = \frac{\boldsymbol{\alpha}\cdot\boldsymbol{\beta}}{|\boldsymbol{\alpha}|\cdot|\boldsymbol{\beta}|} \qquad (3)$$

α represents the vector of the first gyro and **β** represents the vector of the second gyro.

φ , ϕ , θ represent yaw, roll and pitch angle respectively. And 1 represents the first gyro while 2 represents the second gyro. By using (3), we transform the RPY into the space status and then we get the motion angle.

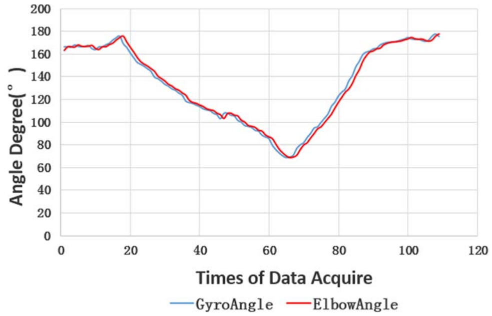

Fig.8 The moving differences of angle between Gyro-angle and Elbow-angle of A.

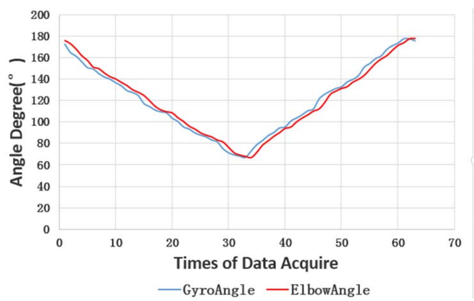

Fig.9 The moving differences of angle between Gyro-angle and Elbow-angle of B.

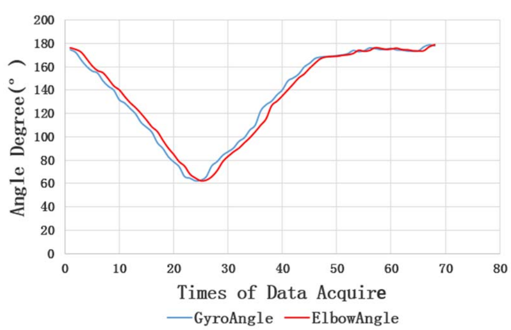

Fig.10 The moving differences of angle between Gyro-angle And Elbow-angle of C.

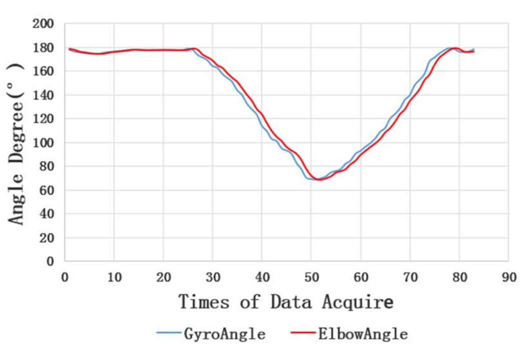

Fig.11 The moving differences of angle between Gyro-angle and Elbow-angle of D.

These four subjects make their motion as told, from 180 degree to 60 or 70 degree, then come back to the initial location. Fig.8 is the subject A's motion in our experiment. In 110 times we record the motion information of elbow angle and gyro angle, then we describe the motion in the form of the figure. The number of times we record the motion is not the same, according to the moving time and moving speed. When the subject moves in a lower speed, the record times will be more. So the number of record times have nothing to do with our data.

For subject A, in 110 times he moved from 180 degree to 70 degree and then come back to 180 degree. The red line represents the elbow angle, known as the angle of the disabled arm while the blue line represents the gyro angle, known as the angle of the healthy arm, detected by the gyros. The differences between the healthy part and the disabled part seem to be small. The possible reason may be mechanism error and time delay. The former comes from the rehabilitation device itself, as well as the transmission between motor and rehabilitation arm. The last one, time delay, comes from the program processing speed and the error in data calculation. In subject B, C and D, the difference between gyro angle and elbow angle, known as healthy part elbow angle and disabled part elbow angle, seems to be bigger than subject A. Considering that subject A motion is in the lowest speed, we can give the conclusion that if in a highest speed that the physician require, the rehabilitation device is still in an accurate motion, the rehabilitation device can satisfy the needs of patients.

To verify the accuracy of our rehabilitation device, the average error rate has been calculate to demonstrate the new rehabilitation device can meet the need of motion and training for patients.

TABLE 1
AVERAGE ERROR BETWEEN ELBOW MOTION AND GYRO MOTION.

Subject	Average Error Rate
A	0.02151
B	0.034408
C	0.037178
D	0.027682

Table 1 shows the average errors between elbow motion and gyro motion with four subjects. For subject A, B, C and D, we find that when the moving speed is higher, the average error rate will be bigger. The model we constructed had good performance in the motion following, while for B and C it still existed bigger errors. It might have something about the personality we didn't consider, which would be our future work to improve the robustness and stablity of our proposed method.

The results from Fig.8 to Fig.11 and Table 1 showed that the rehabilitation device can be applied into the rehabilitation training and the control system has been proved to be effective. The unhealthy subjects were not invited just to minimize the unpredicted individual variances during the motion process.
The error rates in Table.I implied our method that combined the gyros and photoelectric encoder could also implement the rehabilitation device evaluation effectively. It could help come up with effective strategies for the upper-limb rehabilition in our future research.

V. CONCLUSIONS

In this paper, we concentrated on the recognition of continuous elbow flexion and extension motion with two gyros in the healthy arm and rehabilitation arm wore by the disabled arm. RPY for space status and photoelectric encoder were used to detect and process the motion signals and to reveal the motion information hidden in the motion signal respectively.

To develop a rehabilitation device for upper limbs and make the following research undertake, we designed this rehabilitation system with three degrees of freedom and the control system to achieve an accurate control of our new device.

Table.I shows us different speed leads to different accuracy. If we want to achieve an accurate control not only in a low speed but also in a high speed, more research should be taken to improve the accuracy of motion. Different kinds of sensors could be used in this rehabilitation device to make the control in a more accurate way.

Four subjects participated in experiments and the results show our rehabilitation device and control system can help patients to let their disabled arm to work like the healthy one. And after training by the rehabilitation system, how to evaluate the rehabilitation effect should be discussed. In the average error analysis of the device, some bigger average errors occurs which would be the future work for us to improve the performance of our new device. That is to say, we need to improve the robustness and efficiency of our rehabilitation device. And we will focus on more degrees of freedom to achieve more motions.

ACKNOWLEDGEMENTS

This research is supported by National High Tech. Research and Development Program of China (No.2015AA043202).

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