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The LabVIEW -Based Control System for the Upper Limb Rehabilitation Robot

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Abstract - **In this paper, a control system of upper limb rehabilitation robot based on LabVIEW was proposed, and the structure of the control system was also provided. Through using the LabVIEW, the system had a good software interface and control effect. In addition, with the communication protocol between the robot and LabVIEW, the system can realize the real-time transmission of control signal and control character analysis, and then select the corresponding function to achieve rehabilitation training of upper limb rehabilitation robot control. LabVIEW had the rich library function and many advantages such as easy debugging, programming and so on. The control system of the upper limb rehabilitation robot rehabilitation training based on LabVIEW can be extremely convenient to control the robot's rehabilitation training, moreover, the man-machine interface was friendly and easy for the operator to use. Finally experimental results showed that the the system based on LabVIEW software can make exercises rehabilitation training of the upper limb rehabilitation robot more stable operation.**

Index Terms- Upper limbs Rehabilitation Robot; Rehabilitation Training ; Control System

I. INTRODUCTION

In our country, every year due to accidents, diseases, disasters and other factors there are millions of people losing part of the motor function, of which, the people whose limb motor function loss, because of the disease caused by stroke is the primary. It is reported that the incidence of stroke in China is 120-180 every 10 million people, of which about 75% of stroke patients have obvious squeal [1], so that patients with varying degrees of loss of labor, more seriously lead to life cannot take care of them, affecting their quality of life [2]. According to statistics, about 80% of stroke patients with motor dysfunction and self-care ability, in addition, the majority of patients with hemiplegia [3]. Limb deformity not only affects the patient's life and work, but also is a heavy burden to the patient's family and society. The traditional way of rehabilitation is mainly for doctors to patients with "one-for-one" or even "several-for-one" of the auxiliary therapy, which is time-consuming, laborious, and costly. [4-7]. Repetitive training is very boring, and it is a labor intensive and inefficient work for the therapist, because the therapist only treats the patient and assists the patient in a full range of rehabilitation training. Robots are capable of working long hours of repetitive exercise, moreover, the force exerted on the patient can be controlled flexibly, and the robot can be used to assist the rehabilitation training, which can greatly save the cost, improve the rehabilitation efficiency and bring the gospel to the general patients [9].

At present, the human upper limb motion control system has evolved through a long process of evolution. The human upper limb motor system is a one-to-many system. For the same task, there are many control strategies for the nervous system of the human body. In 1935, Bernstein proposed the human motion redundancy and coordination control theory that pointed out that there is no or only definite relationship between the human movement and the nervous system (motion instruction) that determines the movement, what's more he also proposed that the number of degrees of freedom of the human body was much larger than the dimension of the space in which the motion is located and the parameters needed by uniquely determine the position of the motion. Haruno et al divide the human motion control system into four control modules [10]. Wolpert summarized the various computational methods used in human upper extremity motion control studies and illustrated how these methods could be used to explain the four control modules of the upper extremity motion control process, which can realize the basic planning of upper limb motion. Hogan systematically analysed the elastic and stiffness problems of the upper limb of the upper limb and proposed the stiffness ellipse and trajectory reconstruction control theory of the upper limb motion, and considered that the mechanical characteristics (stiffness) of the musculoskeletal system is the optimal trajectory planning for the upper limb motion and the internal mechanism of motion control [11]. Rehbinder and Martin proposed the optimal two - order control model of upper limb movement. In the optimal control of attitude and motion, the muscle activity is taken as the control signal, and the optimal control theory is used to solve the reference trajectory at a given time interval. The results were consistent with the experimental results of arm motion, which was considered as a more typical modern control theory research methods [12]. Todorov et al. proposed an optimal control theory based on stochastic optimal feedback control theory. In the control system, the optimal feedback controller was coupled with the controlled object to form a special dynamic system to solve all the control problems, and it can coordinate the change of the control task in the limb movement control, and the relation between the directional control of the target and the coordination of movement [13].

In this paper, a control system for upper limb rehabilitation robot based on LabVIEW is proposed. In the system the exoskeleton upper limb rehabilitation robot, as the moving platform, can provide the three degree of freedom passive upper limb rehabilitation exercise for the patients, what's more, it also can support the rehabilitation exercise training in the family environment, which help patients increase the time and intensity of rehabilitation and reduce the cost of rehabilitation [14]. The LabVIEW software is used to realize the interface control of the robot. LabVIEW not only has excellent software development environment, but also is a powerful automated testing tools. The upper computer control system of upper limb rehabilitation robot based on LabVIEW is realized by LabVIEW combined with single chip microcomputer, in this way patients can be targeted rehabilitation training, shorten the development cycle. Many experiments shows that the specific function training can promote the reorganization and compensation of the central nervous system, as a result the limb movement function of the patients can be restored, which provides important medical basis for robot assisted rehabilitation. Rehabilitation training combined with robot technology can effectively solve the problems existing in the traditional rehabilitation training methods. Firstly of all, the robot can meet the training requirements of different patients, and reasonable design can ensure the safety of patients. Moreover, the implementation of the robot rehabilitation system allows the hemiplegic patient to perform rehabilitation exercises autonomously at home. Secondly, the robot can objectively record the data and curves produced by the training process [15].

So in order to obtain accurate robotic position information, the control system proposed by this paper consider the motor speed obtained by photoelectric encoder as the translational speed and rotation speed of robot in global coordinate system. The results of our experiments showed that this algorithm can obtain the position of the robot and the rotation angle in real time. The control method was verified in experiments, the results showed that the robot can follow the reference trajectory and the position control to meet the rehabilitation requirements.

II. STRUCTURE OF THE REHABILITATION ROBOT SYSTEM

The purpose of the design of upper limb exoskeleton rehabilitation device is to restore the upper extremity motor function. This paper describes the robot's main help for patients to achieve rehabilitation exercises including the elbow, wrist and fingers' rehabilitation. The upper limb rehabilitation robot (including 5 fingers) has 17 degrees of freedom(DOF), among them 3 degrees of freedom are designed for arm including elbow flexion/extension, bending/stretching of the wrist, wrist pronation/supination, the fingers of the 14 DOF including 2 DOF for thumb and other four fingers, each of finger has 3 DOF. The total weight of the robot is 1.5 kg, the quality is light, and it is designed to be combined with human engineering, so it is very comfortable to wear and easy to carry.

Throughout most of the upper limb rehabilitation robots are at home and abroad, most of the rehabilitation robots have complex structure and low integration. A new exoskeleton rehabilitation robot is proposed in this paper and it not only has the advantages of simple structure, beautiful appearance and high degree of integration, but also contains seventeen degrees of freedom of fingers and arm, what's more, modular design can be carried out separately on the upper limb and finger rehabilitation training. In this way, the upper limbs and fingers not only can be trained separately, but also can be trained simultaneously, which is convenient for patients to have a targeted rehabilitation training and the rehabilitation effect will be better.

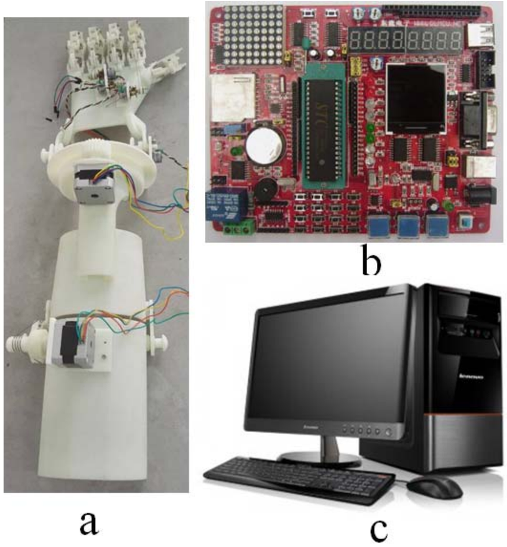


Fig. 1 Structure of rehabilitation system: (a) the rehabilitation robot; (b) AT89S52 singlechip (SCM); (c) PC computer.

In the aspect of power, combined with the power source used by various research institutions at home and abroad, the exoskeleton rehabilitation robot adopts stepping motor as power source. Stepper motor can not only achieve a more accurate position control, but also can save more cost and promote the production of exoskeleton rehabilitation robot. In the choice of materials, in addition to connecting bolts and the motor, all parts are made of ABS material. The material has many advantages such as small density, light weight, and it also has a good stiffness, which can meet the needs of the robot. In term of parts processing, the technology of 3D printing is carried out. 3D printing technology can print out the more complex parts, and the cost is relatively low. As shown in Figure 1 a.

The entire control system through the PC terminal (Figure 1 c) LabVIEW front panel input rehabilitation instruction, and the LabVIEW software is used to make the computer parallel port to generate the corresponding signal; singlechip (SCM) (Figure 1 b) always monitor the parallel port of the computer, when the parallel port's output changes, the output of the corresponding pulse signal to the motor will drive chip, and finally through the drive module to achieve the control of the robot. For each module, LabVIEW can realize data acquisition and transmission, which is to achieve the role of convenient control, while the control information sent through the parallel port. SCM module control the acceptance and processing of information, resulting in the control of the robot control command signal.

III. DESIGN OF THE UPPER LIMB REHABILITATION ROBOT

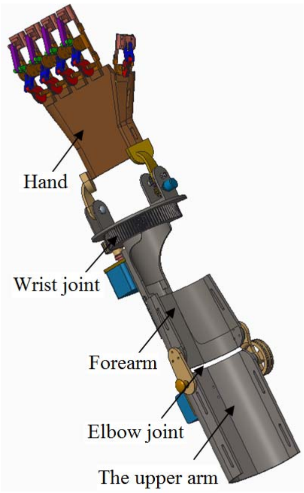


Fig. 2. 3D model of upper limb rehabilitation robot.

The 3 dimensional model of upper limb rehabilitation robot based on the principle of human body engineering PTC-Creo (Parametric Technology Corporation Creo) three-dimensional solid modelling design, among them, in order to simplify the design, in addition to the thumb part of the finger, the other four fingers are the same design. Taking into account the internal/external rotation of the wrist of the robot and the movement of the wrist drive system will directly become the system load. Therefore, the structure should be compact and lightweight. Under the case that the transmission ratio can meet the requirements of small power motor drive, the internal and external rotation and bend/extension mechanism of the robot wrist are designed respectively for the gear transmission ratio of 5:17 and 9:10 in order to achieve its intended action. The main advantages of gear transmission are: constant transmission ratio, high work stability, strong bearing capacity, high transmission efficiency, simple structure, easy disassembly and assembly, compact installation, easy maintenance and so on. The elbow extension/flexion drive distance is relatively large, with the gear drive is increased when the size and weight of the robot, so the driving rope is selected. Wire rope drive is a kind of under actuated mode it has advantages of light weight, low impact, low friction, the utility model has the advantages of the high load transmission wire rope to achieve long-distance transmission. The three-dimensional model is shown in the figure 2.

According to the initial state of each joint as shown in the figure 3, considering the safety of patients to rehabilitation training, combined with the structure of the robot and rehabilitation training on hemiplegic patients require different degrees of freedom, the scope of activities, as shown in the table I. Figure 4 is the 3D model of upper limb rehabilitation robot worn by human model, from the figure we can see the structure of the robot design is more reasonable, in line with the principles of ergonomics.

Ⅳ. EXPERIMENTS AND RESULTS

In this system SCM and PC communication are achieved through the microcontroller serial port and PC serial connection between the hardware. Because the LabVIEW is

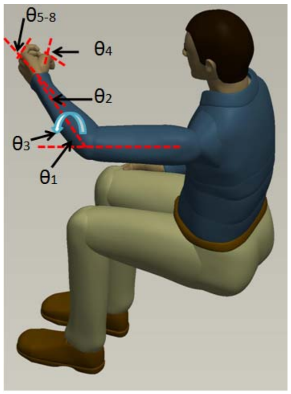


Fig. 3 Schematic diagram of human upper limb rehabilitation training.

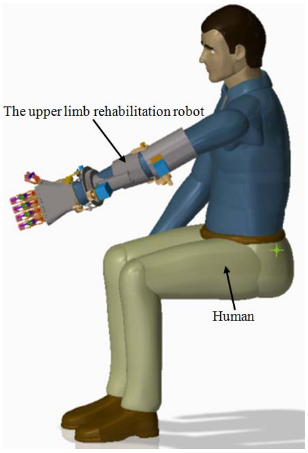
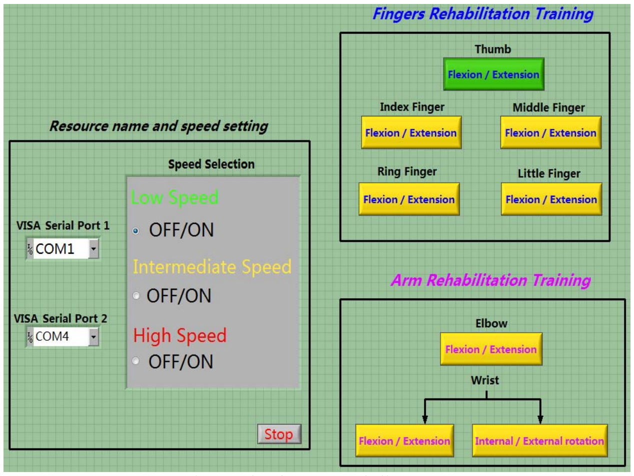


Fig. 4 The 3D model of upper limb rehabilitation robot that worn by human model.



VISA Serial Port 1 COM1

VISA Serial Port 2 COM4

Fig. 5 The front panel diagram.

Table I Range of rehabilitation training

Joint		Movement	Angle Range
Elbow		Flexion/Extension (θ_1)	0～120º
Wrist		Flexion/Extension (θ_2)	-70º～80º
		Internal/External Rotation (θ_3)	-90º～90º
Fingers	Thumb	Flexion/Extension (θ_4)	0～30º
	Index Finger	Flexion/Extension (θ_5)	0～50º
	Middle Finger	Flexion/Extension (θ_6)	0～50º
	Ring Finger	Flexion/Extension (θ_7)	0～50º
	Little Finger	Flexion/Extension (θ_8)	0～50º

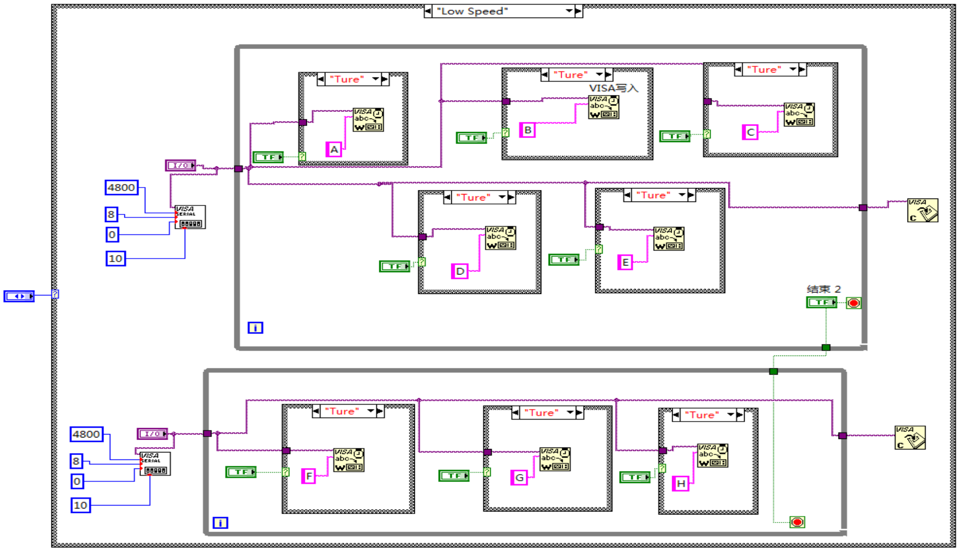


Fig. 6 The block flow diagram.

simple and intuitive, powerful and flexible software, the control program of the upper monitor base on LabVIEW. LabVIEW is a virtual instrument platform developed by instrument National Instrument. It is a graphical programming language, and has a powerful function, provides a wealth of data acquisition, analysis and storage functions; it also has more advantages than the traditional programming language. However, the development of virtual instrument with LabVIEW usually requires expensive data acquisition hardware, the data acquisition and processing system based on SCM is lower cost, but the development process is complex, programming workload. If the small system of SCM is considered as a front-end data acquisition system, through the serial port LabVIEW provided by the VI to collect the data sent to the upper monitor. And then in the LabVIEW environment data processing and analysis can be realized, and related control also can be applied for, in this case, not only the powerful function of LabVIEW can be made full use of, but also the development's cost of the system can be reduced, which is a way to expand the scope of LabVIEW applications.

A．*Implementation of PC control*

The system exploits AT89S52 SCM as the front-end data acquisition signal processing system. The control system is composed of a single chip microcomputer and a stepper motor driver (7TPSM4220 micro stepping motor driver). Upper monitor program is written base on LabVIEW. Programming involves VISA, which is an essential standard I/O library. These library functions are used to write the driver of the instrument, complete the command and data transmission between the computer and the instrument, in order to achieve the control of the rehabilitation robot.

Serial communication related to the VISA function is located: Functions→ALL Functions→Instrument I/O→Serial sub template. Among them, the VISA configuration serial function is used to set some parameters, and the specified serial port to initialize the specific settings；the VISA write function writes the "write buffer" data to the specified serial port; the visa reads the data from the specified serial port. In this paper, the stepper motor control program is designed by using the above communication function combined with "while" loop structure and condition structure, then through the program debugging, the rehabilitation training of the rehabilitation robot is realized [16]. The front panel and block flow diagram are shown in Figure 5 and Figure 6 respectively.

The upper limb rehabilitation robot is proposed in this paper in the design of another important feature is the use of modular design of integrated part and the upper part of the fingers can be integrated to comprehensive rehabilitation training, rehabilitation training can also have to separate. So in the design of the upper monitor control interface, there are two serial ports being used for rehabilitation training instruction sent. In addition, in the process of rehabilitation training, according to the patient's situation, the system also provides low speed, medium speed, and high speed mode selection. As shown in the figure 5.

B．*Results*

Stepper motor control of the robot use manual control. When manual control works, it can realize the control of rehabilitation training for the specified joints. The realization of the method is through the serial port to send control characters, the analysis by the microcontroller, and select the appropriate function. The corresponding relationship between the control character and the step motor is shown in Table Ⅱ. For example, the sent character "A" means the thumb part of the thumb flexion/extension exercise rehabilitation training, "F" forms the elbow joint of the arm flexion/extension exercise rehabilitation training. The motor control module can be flexibly applied to change the control strategy according to different control requirements. In order to avoid the occurrence of second damage for the patients during the process of rehabilitation training, so the system can only realize rehabilitation training for one joint at once

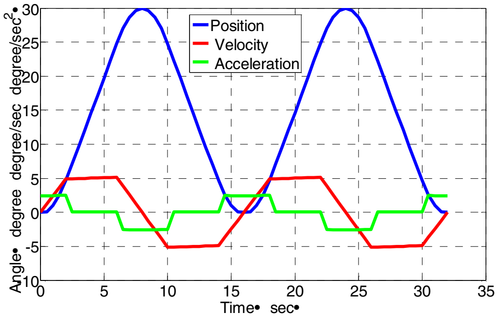


Fig. 7 Movement curve of thumb flexion/extension.

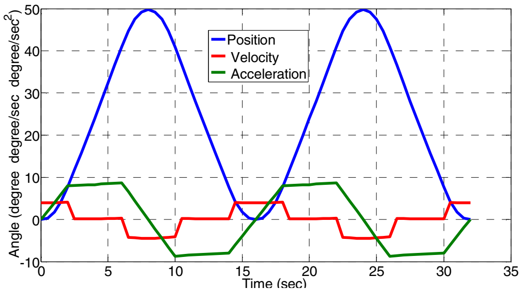


Fig. 8 Movement curve of index finger flexion/extension.

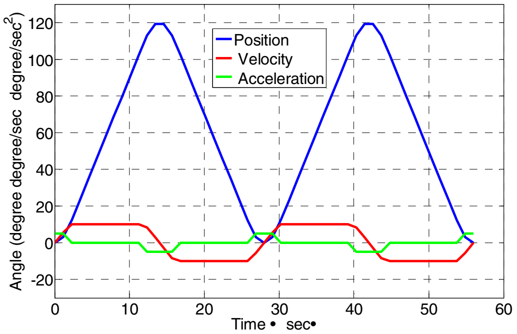


Fig. 9 Movement curve of elbow flexion/extension.

rehabilitation training. When multiple joint rehabilitation training is selected, the system will be used as the highest priority for the rehabilitation training. After the completion of a training cycle (twice flexion/extension or internal/external rotation as a cycle) after the next joint rehabilitation training, in this case, the security of the system can be increased [17].

Table II Rehabilitation training code repertory

Control Character	Implementation Function
A	Thumb flexion/extension
B	Index finger flexion/extension
C	Middle finger flexion/extension
D	Ring finger flexion/extension
E	Little finger flexion/extension
F	Elbow flexion/extension
G	Wrist flexion/extension
H	Wrist internal/external rotation

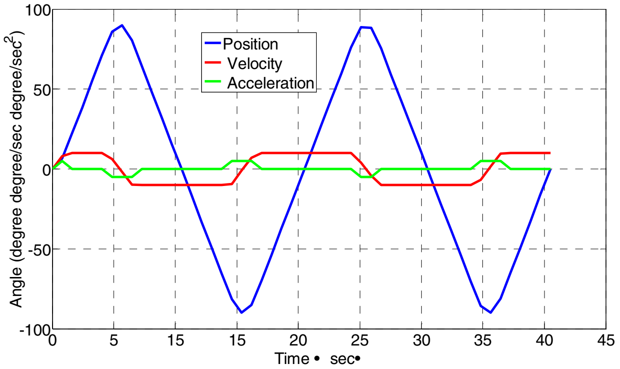


Fig. 10 Movement curve of wrist internal/external rotation.

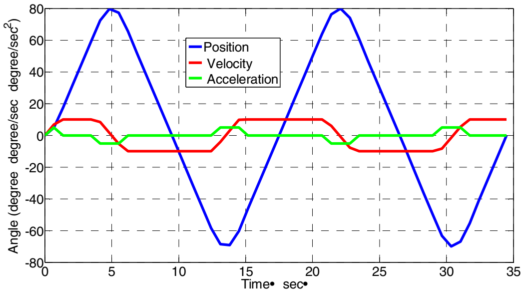


Fig. 11 Movement curve of wrist flexion/extension.

Figures 7-11 is the movement curve for moments of thumb flexion/extension, index finger flexion/extension, elbow flexion/extension, wrist internal/external rotation and wrist flexion/extension. Each joint of a rehabilitation training cycle is about 40s. From the graph we can see that the upper computer control program written in LabVIEW software can be well used to control the upper limb rehabilitation robot, and the movement can be completed smoothly for patients with simple rehabilitation training. Figures 12-16 is the 3D trajectory curve of each movement. Because the system can only achieve a joint rehabilitation exercise at once, so the 3D trajectory curve of each joint are arc. There is not much difference between those and our theoretical analysis.

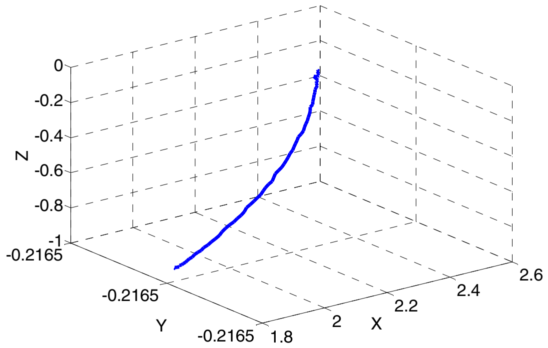


Fig. 12 3D trajectory curve of thumb flexion/extension.

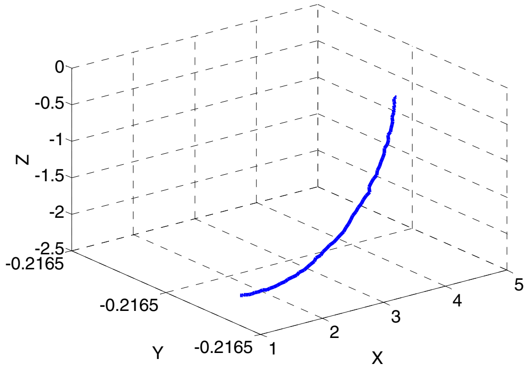


Fig. 13 3D trajectory curve of index finger flexion/extension.

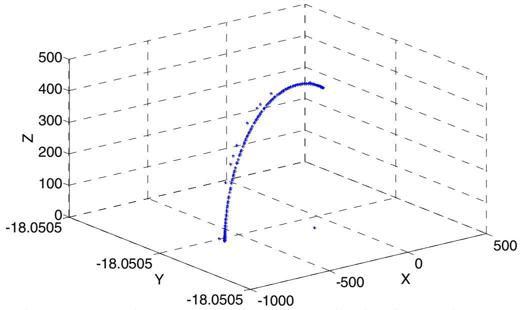


Fig. 14 3D trajectory curve of elbow flexion/extension.

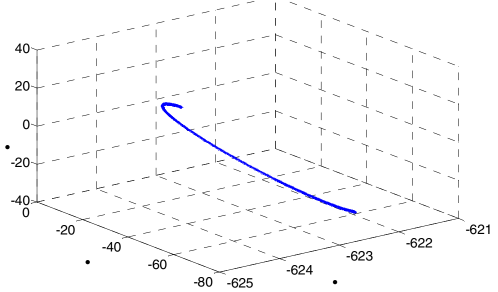


Fig.15 3D trajectory curve of wrist internal/external rotation.

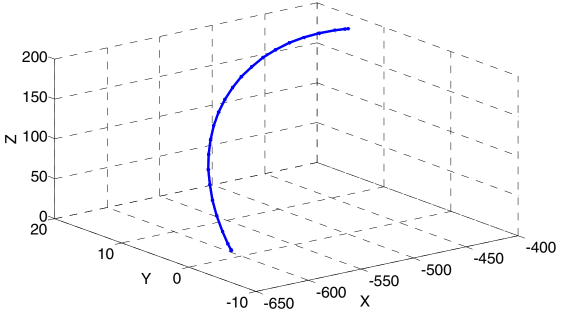


Fig. 16 3D trajectory curve of wrist flexion/extension.

V. CONCLUSIONS

In this paper, the control system for the upper limb rehabilitation robot based on LabVIEW was proposed and the serial communication between PC and the robot was also realized. Besides, the rehabilitation training of the upper limb rehabilitation robot was controlled through combining with the peripheral circuit of the robot. The experiments proved that the system based on LabVIEW had the characteristics of friendly man-machine interface, simple programming, and high efficiency etc. In addition, the control system based on LabVIEW had strong capability of transplant control, which can be easily invoked by other programs to form a more complete function of the procedure. In the design of upper limb rehabilitation robot, we adopted the integrated module design, which can be integrated with the part of the fingers rehabilitation training, and also can be targeted separately for rehabilitation training. Exercise rehabilitation training control of the robot used manual control, which can realize the control of the rehabilitation of the designated joint when the manual control was used. Actually, the method was to send control characters through the communicating module, and then the control characters were analysed, finally, the corresponding function was selected, in this case system was stable and easy to control.

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