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A LabVIEW-based Human-Computer Interaction System for the Exoskeleton Hand Rehabilitation Robot

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***Abstract* - Exoskeleton upper limb rehabilitation robots are more and more applied to help hemiplegic patients to implement rehabilitation training, which makes up the shortage of rehabilitation only depend on doctors. Aiming at the training of patients' hand exercise, in this paper a kind of human-computer interaction of exoskeleton hand rehabilitation robots based on LabVIEW system was proposed, which was mainly composed of exoskeleton fingers robot part, data acquisition system, serial assistant receiver, and the virtual hand. When the patients wore the exoskeleton hand rehabilitation robots, and once his (her) fingers moved, the shape of bend sensors glued the robots would change. The changed electrical signals were shifted by A/D conversion system and delivered to the serial assistant port, impelling the hand in virtual environment to move synchronously. This course was human-computer interaction. In this paper, the PTC Creo (Parametric Technology Corporation) software was used to design a model of exoskeleton hand rehabilitation robot, and then single chip microcomputer and A/D converter were carried out to accomplish data acquisition. While the virtual environment was built with LabVIEW software, which could call the fingers model and program a serial assistant. This system could swiftly deliver the data to the virtual fingers and then implement synchronized movement between hand robot and virtual hand.**

Index Terms* - *Exoskeleton Finger rehabilitation robot; A/D conversion; Virtual environment; Human-computer interaction.

I. INTRODUCTION

Cerebral apoplexy, commonly known as stroke, is a symptom of cerebrovascular disease, which is mainly refers to a series of diseases caused by acute cerebral vascular disease, such as persistent cerebral hemisphere or part of brain stem nerve function defect, occlusion or rupture, leading to the loss of limb motor function and related complications, especially the loss of upper limb motor function. Undamaged brain tissue will then take over the functionality of the damaged tissue and the lost functionality caused by the stroke or spinal cord injury will be regained [1]-[2].The treatments adopted modern medicine for hemiplegic patients is mainly acupuncture, massage and electrical stimulation, which mainly relies on therapists' one-to-one treatments, so that patients are prone to feel fatigue and dull even loss interests in rehabilitation therapy. Robots can support movement therapy of the limb [3]-[4], such as MIME [5], ARM Guide [6], MIT-MANUS [7], and UECM [8]. For patients with stroke, hemiplegic and other related diseases, it can effectively assists rehabilitation doctors to help patients recover upper limb's movement and rebuild nervous system, which greatly reduces the workload of doctors and makes up for the shortage traditional rehabilitation.

In general, the motor function of stroke patients' arms and the fingers are very important part to recover. Therefore, in the medical field, some researchers regard the recovery of finger function as the standard of upper limb rehabilitation state [9]-[11]. In the past twenty years, due to the rapid development of rehabilitation robots, many famous research institutions have begun to develop a variety of exoskeleton finger rehabilitation robots. For examples, In 2006 Delft University studied an exoskeleton hand robot with force feedback function [12], whose main joint angle sensor adopts a potentiometer. The prominent characteristic lies in its ring structure, which made it possible to make the finger joint angle and the center of the semicircular ring together at all the time during exercise, avoiding complex transformation between the measuring angle from potentiometer and actual motion angle of joint. In 2009, the finger exoskeleton rehabilitation equipment was studied by Beihang University [13]. It used an exoskeleton joint unit based on a parallel slide block structure moved by finger joints that are driven by micro rope transmission. Its distinguish feature was realizing active rehabilitation therapy in virtue of signal feedback from joint position sensor and strain type force sensor. In 2010, American scientist Sasha Blue Godfrey studied a set of exoskeleton finger rehabilitation robot system named HEXORR [14], which can assist the patient exercise with the spasmodic fingers. This system can provide two modes: free motion and constrained motion. And it can improve the users' enthusiasm to recovery and training effect through interactive virtual reality game. In 2015, a finger rehabilitation training device named RELIVER RL-100 was studied by Korea famous rehabilitation medical company and MAREF was installed pneumatic driving power source[15], which is able to drive finger rehabilitation training device so that the robot can help patients do finger rehabilitation exercises. Patients' five fingers could be trained simultaneously. Besides, users can adjust the pressure according to the actual needs to adapt to different intensity training mode.

In this study, a Human-Computer interaction system of the exoskeleton hand rehabilitation robots based on the LabVIEW is proposed, the remainder of this paper is organized as follows: Section II describes the data acquisition module of finger motion using bending sensor; In section III the programming of the serial assistant based on LabVIEW was presented; Section IV gives the build process of virtual scene under LabVIEW software, then we discuss the experiment results; Finally this paper is concluded in Section V.

II. Overview of The Exoskeleton Hand Rehabilitation Robotic System

Fig. 1 depicts the framework of human-computer interaction system of the exoskeleton hand rehabilitation robot, which consists of a robotic hand, data collection system, serial assistant and a virtual hand. And every detailed part is shown in Fig. 2.The specific procedure and functions are shown in Fig. 3.

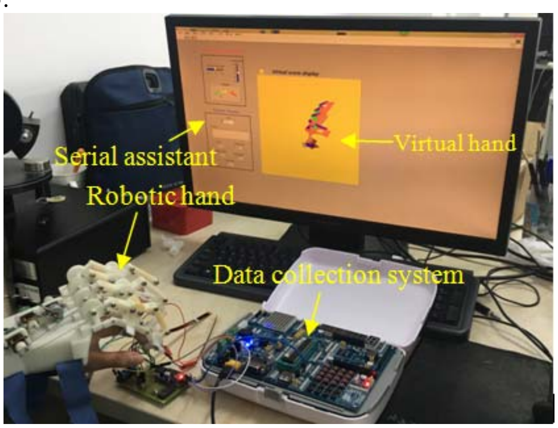


Fig. 1 Framework of human-computer interaction system

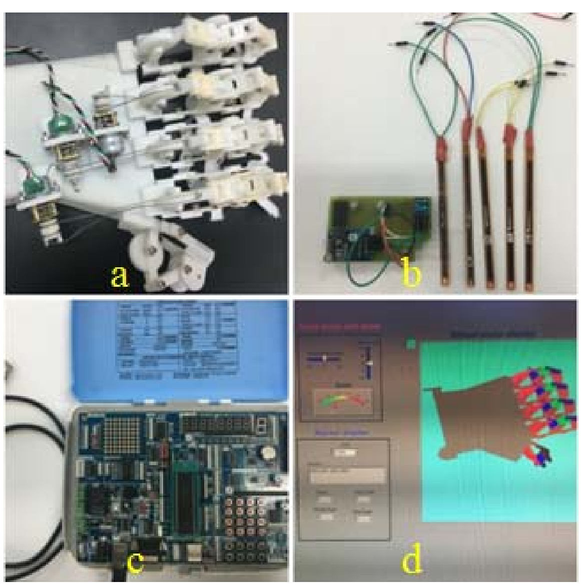


Fig. 2 Components of the system (a. exoskeleton hand robot, b. bending sensor and data acquisition circuit, c.STC89C52(SCM) d. virtual hand in LabVIEW)

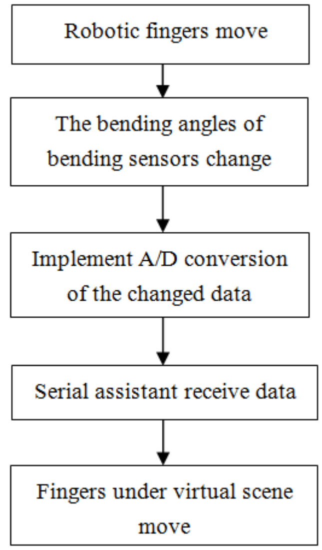


Fig. 3 The system flow chart

With operators wearing the exoskeleton hand robot, once fingers do flexion and extension movements, the robotic internal bending sensor will produce deformation. At the same time, the changing electrical signal will be transmitted to the serial receiving port of the LabVIEW through the data acquisition part. In the LabVIEW environment, the data receiving serial port will respectively display the electric signals of the five bending sensors angles in real time. The virtual scene shows the fingers in the window movement with the operator's fingers according to the changing electrical signals. Besides, the amplified voltage values at both ends of the bend sensor are shown in the LabVIEW in real time.

III. The Achievement of Data Transmission

A. Data acquisition module

In the human-computer interaction system, the motion of the fingers model in the virtual environment is controlled by the bending angle data that is acquired by the bending sensor. The bending angle sensor is attached to the robot fingers model, thereby fingers' movement of the robot is controlled, the fingers in the virtual environment will move synchronously, which realizes the human-computer interaction. Due to the bending angle data is analogy quantity, so it is needed to be converted digital quantity and then be collected by single chip. After that through the serial port to accept data, the finger model under virtual environment could move simultaneously.

A/D converter is a device that converts analogy quantity to digital quantity. In this paper we use pcf8591 chip as the A/D converter, as shown in Fig. 4, which is a 8 bit CMOS data acquisition device with a single supply and low power consumption, and has 4 channel analog input, 1 channel analog output and a serial I^2C bus interface that has communication function. Its three address pins: A0, A1, A2 are used to program the hardware address. It is allowed 8 devices to connect to the I^2C bus rather than linking additional chip select circuit. The control instruction to device, address, and data are all transmitted via the I^2C bus. This A/D converter adopts successive approximation conversion techniques. A/D conversion cycle always begins after the effective read mode address being sent to the pcf8591.The A/D conversion cycle is triggered at the back edge of the response clock pulse and performed at the end of previous transmission. Once a conversion cycle is triggered, the channel of input voltage sampling selected will be saved to the chip and converted to the corresponding 8 bit binary code. Conversion results stored in the ADC data register wait for transmission. If the auto increment flag is set 1, the next channel will be selected. The conversion results of previous read cycle are included in the first byte of the latter read cycle. The physical figure is shown in Fig. 5.

The four bending sensors are connected in parallel to the circuit and it is needed to notice that a resistor is connected in each of the branches with a bend sensor, that is, four resistors are added. Because each bending sensor resistance changes in the range of 9 KΩ~ 22 KΩ (Bending angle range from 0° ~ 180°), as shown in Fig. 6. So it is calculated that the resistance in series should be set about 20KΩ, whose function is to amplify the voltage signal collected by the bending sensor so as to observe the numerical variation of different degrees better and improve accuracy. As shown in Fig. 7, it is one way amplifier circuit designed.

Finally, we respectively labeled the output voltage of each path and connected them to the pcf8591 chip's ain0, ain1, ain2 and ain3 pins. After A/D conversion, four numerical transmission results are sent to the serial port assistant and received. The overall design of the data acquisition circuit diagram is shown in Fig. 8.

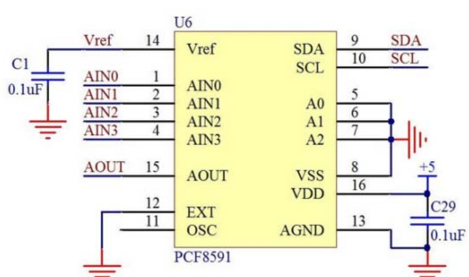


Fig. 4 The structure of pcf8591 chip

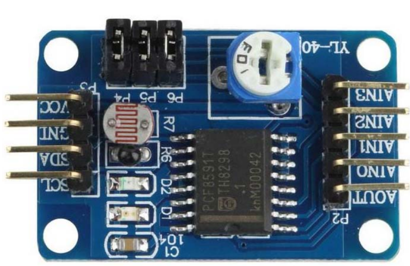


Fig. 5 The physical figure of pcf8591 chip

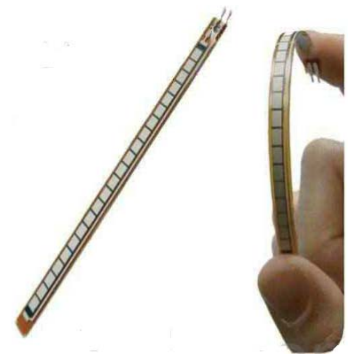


Fig. 6 The bending sensor

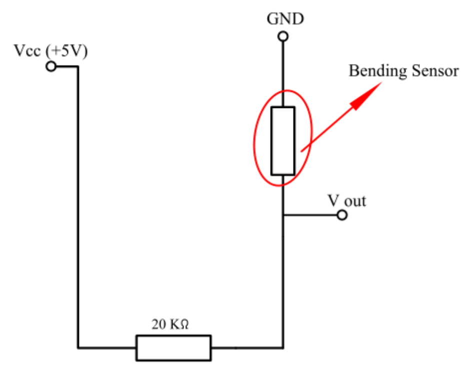


Fig. 7 One way amplifier circuit

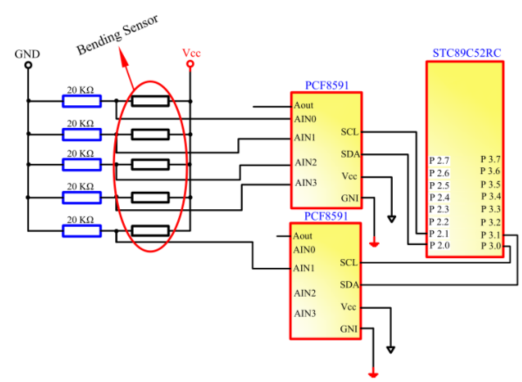


Fig. 8 The overall design of the data acquisition circuit diagram

The five circuits with bending sensor are labelled as 1, 2, 3, 4, 5. Because the pcf8591 chip has only four channels, so we add a pcf8591 chip to collect the data of fifth channel.

Taking all the data acquisition as an example (select the first road, the other four with the same), the serial data line (SDA) is connected to the P2.0 port of the microcontroller and the serial clock line (SCL) is connected with the P2.1 port of the SCM (The secondpcf8591 chip's SCL and SDA are connected with the microcontroller P3.0 and P3.1). The resistance value of bending sensor will change with its deformation affected by force and its both ends will change. Then the changing quantity will be sent to the pcf8591 chip's ain0 port through output port. After A/D conversion, the data will be delivered to the single chip. In the process of serial

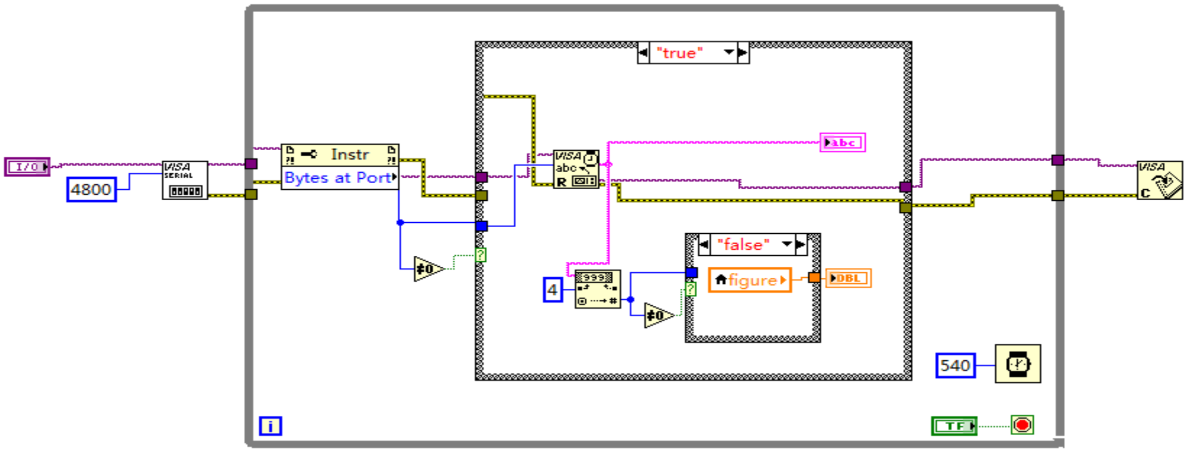


Fig. 9 Design sketch of rear pane

communication, data must be sent and received in the form of characters, so an integer is needed in order to split into each bit and transformed to character.

B. Serial assistant programming based on LabVIEW

Serial assistant based on LabVIEW could be more convenient and effective to data received. And the data can be quickly transferred to the virtual scene based on LabVIEW. Serial assistant programming mainly uses visa VI function in LabVIEW, which is a virtual architecture and we don't need to care about the use of the underlying composition. And it can be called directly without considering the interface type.

Configure VISA serial port: 1.In front panel, I/O port was found from the control panel and we selected the "VISA resource name", and then changed name to "port", then insert string input control, which was set to send window, the next step is inserting a receive window which can be found in string display control menu. Finally, we added two buttons named "send" and "receive". In order to read the voltage value of each bending sensor more conveniently, we split the string by transposing method and it will display to five windows.

Switch to rear panel, we placed the entire receiver unit in a while loop condition box. From the serial port, we found the VISA's configuration, VISA's writing, reading and closing and connect them logically. After the operation of the project, the bend sensor's change signal picked up by single chip will be received directly to five fingers in LabVIEW and displayed simultaneously in the receiving window. The last step is adding a delay to the while loop to avoid taking up system resources. As to signal processing, we used the command to numeric conversion of strings in LabVIEW. The extracted signal is transformed into the moving angle of the virtual finger, in order to controlling the virtual finger do the same movements. The design is shown in Fig. 9.

Ⅳ. THE REALIZATION OF HUMAN-COMPUTER INTERACTION SYSTEM

A. Virtual environment building

LabVIEW and PTC Creo engine technology is used to carry out the 3D visual graphic simulation, because this way is conveniently operated and the effect is close to reality. After using 3D modelling software PTC Creo to implement solid modelling, we combined the VRML virtual reality technology to complete the format conversion. Then we used LabVIEW 3D Picture Control Toolbox and simulation software package to implement three dimensional motion simulations of virtual machine parts.

The last step is connecting the serial assistant and the virtual fingers to implement the construction of virtual scene. The design sketch is shown in Fig. 10.

B. Experiments and discussion

In order to test and verify the feasibility of the system, we made experiments for five fingers.

After the experiment to this system, the discussion of the experiment is carried on; the main content of it is error analysis. In order to conveniently observed, the bending angle of the five bending sensors and the bending angle of the virtual fingers are respectively extracted by LabVIEW and produced to a waveform in Matlab, and then compare these data. The red line represents sensor bending angle and the blue one represents the finger movement angle. They are shown in the Fig. 11.

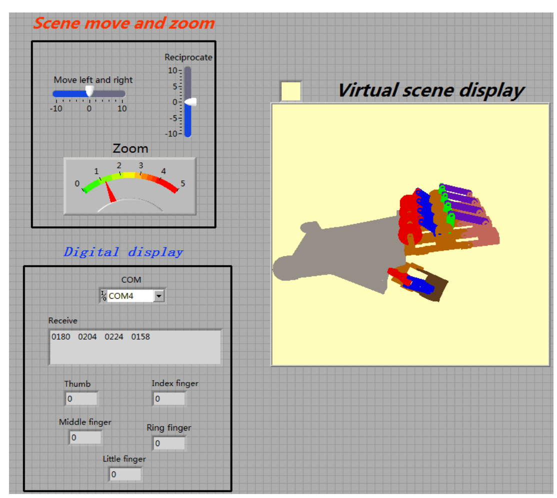
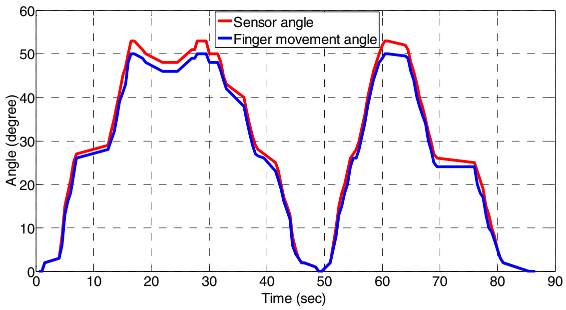


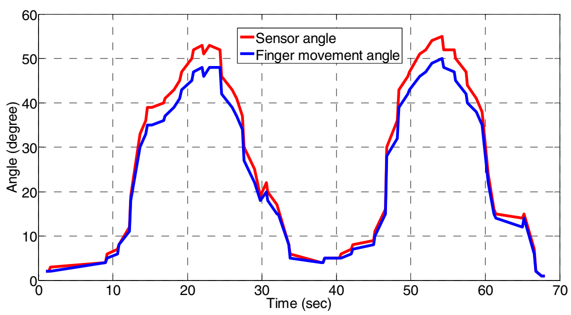
Fig.10 The design sketch of whole system construction

We searched for ten points evenly in each waveform and calculated the D-value between the two variables corresponding to these ten points and then divided by maximum range which is 50 degree.

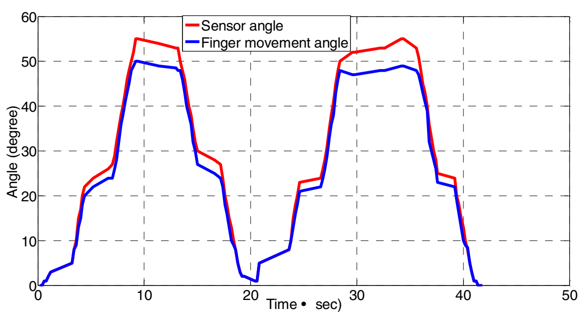
After calculating, it comes out that the average error of thumb movement is about 2.25%; the index finger movement's average error is about 4%; the middle finger movement's average error is about 3.42%; the forth finger movement's average error is about 6.7%; and the little finger movement's



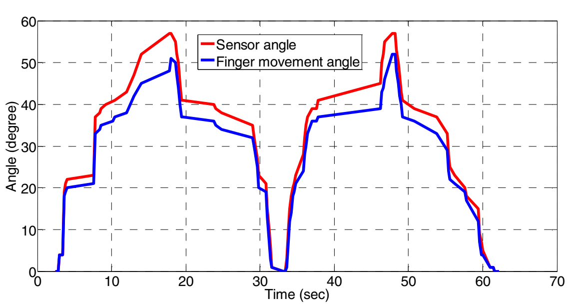
(a) Thumb movement angle



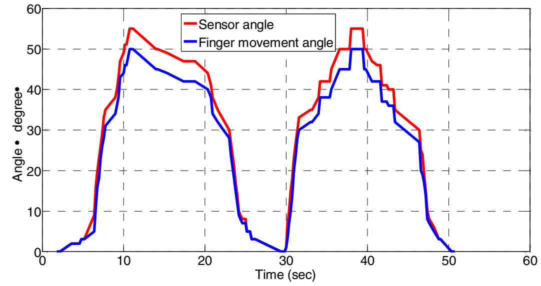
(b) Index finger movement angle



(c) Middle finger movement angle



(d) Forth finger movement angle



(e) Little finger movement angle

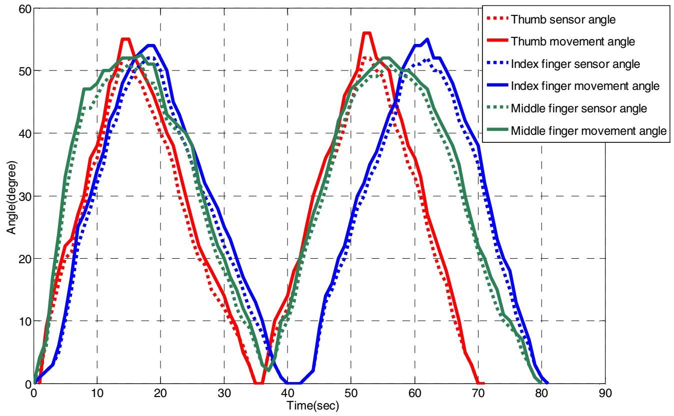
Fig. 11 The movement angle of five fingers

average error is about 5.4%. Generally speaking, the average error range of the five groups is roughly about 0～4.3%.

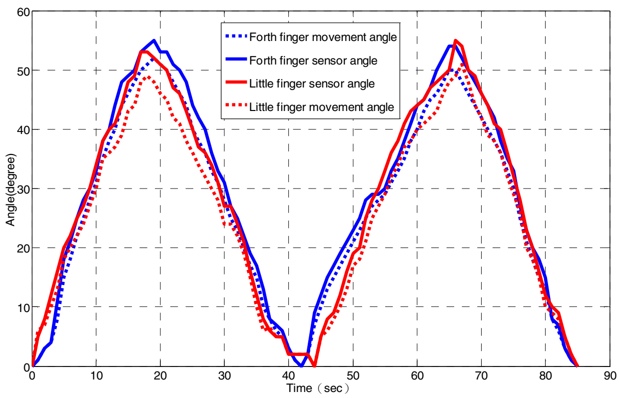
From the waveform, we could find that the deviation is smaller for thumb and index finger and bigger for middle finger and forth finger. We analyze the reason that there could exist error is as follows: 1. The resistance value of bending sensor does not coincide with the bending angle; 2.The accuracy of sensor is not high enough and induction is not sensitive enough, which leads to the deviation between the virtual fingers and the operators' fingers movement in a small range; 3. Relatively the middle finger and forth finger are inflexible than thumb and index finger, which results the movement isn't very smooth.

Then we discuss the results of experiment that multiple fingers move together, the real-time performance between hand robot and virtual fingers. The result is shown in Figure 12. According to the structure of the human fingers, because the boundary of tendon which control forth finger and little finger is not clear at the start of muscle, so the activity of these two fingers will have interaction effect. The thumb、index finger and middle finger in the process of movement are relatively independent, there is no obvious interference about time and error, so the result of experiment was recorded with two picture. The Figure 12(a) records the thumb、index finger and middle finger, the forth finger and little finger are recorded in Figure 12(b).

In Figure 12, solid lines represent the movement's angle of patients with finger robot, while dashed lines represent bending angle of sensor. In the diagram (a), a thumb、index finger and middle finger's movements are relatively independent on time, the average error of motion angle is about 4%. The error was about similar comparing with finger's separate movement, which explains the interference is not strong. In the diagram Figure 12(b), there is a correlation between the forth finger and little finger's movements in a certain time and motion angles, the average error of motion angle is about 6.7%, the error obvious increases compared with finger's single motion. It shows that in the progress of movement at the same time, the forth finger and little finger will produce interference.



(a) Thumb、index finger and middle finger



(b) Forth finger and little finge

Fig. 12 The experiment's curve line of five fingers

In a word, the experiment shows that among finger's movement, there exists a certain interference, but not so big. Each finger is different mainly related to the human body structure. It also illustrates the devices exist deficiencies. In future study some improvements will be made to reduce the error generated in the process of training.

V .CONCLUSION

In this paper, a LabVIEW-based human-computer interaction system for the exoskeleton finger rehabilitation robot was proposed， which had implemented real time acquisition to five fingers' movements of patients by collecting bending angle of the bending sensor stuck fingers and receiving bending angle data by serial assistant. The most distinct characteristic of this system was using LabVIEW software to program the serial assistant and the virtual fingers in LabVIEW can receive the bending angle data directly and move with real hand, which could improve receiver speed. The system could make it better to observe the rehabilitation training of patients. Besides, the system could be as the basic platform of designing some games for patients, which can bring about many interests during rehabilitation training. In order to make the system more practical and have less error, for the future work, on the one hand, higher accuracy and sensitivity bending sensors need to be used, the system will be considered to be improved and optimized, in this way it will have a wide application and development prospect in the future.

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