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A Human-machine Interface Software Based on Android System for Hand Rehabilitation Robot*

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***Abstract* - In order to provide patients with portable and user-friendly device, this paper develops human-machine interaction rehabilitation software based on Android system, including the user interactive layer, data access layer, virtual reality rehabilitation training layer, and individual rehabilitation layer. The software can control robot through Bluetooth and real-time display the parameters of rehabilitation in the chart collected from the control system. The software also can use virtual reality technology to build virtual environment which is playing the piano by a finger to induce patients to take rehabilitation training, and this could improve patients' rehabilitation results.**

Index Terms* - *Android, hand rehabilitation robot, human-machine interactive interface.

I. INTRODUCTION

As a kind of rehabilitation equipment based on Robot-aided Rehabilitation Therapy [1], hand rehabilitation robot uses mechanical devices to assist hand joints and fingers to do rehabilitation training [2], including flexion and extension, and realizes exercise rehabilitation strategy through control system [3]. Currently, most human-machine interactive interface for hand rehabilitation robots is developed based on PC machines or special embedded mobile devices [4], and these devices are hard to satisfy patients' demand in size, weight and price [5]. The interactive interface based on Android operating system takes the advantage of mobile devices' portability [6], which makes patients get rid of geographic restrictions [7], realizing the goal of receiving rehabilitative treatment whenever and wherever possible [8], and provides humanized interaction experience for patients through some functions [9], such as modularization and dynamic configuration [10].

Compared with other embedded systems [11], Android operating system has some incomparable excellent characteristics [12], such as openness and parallel processing [13]. We developed one human-machine interaction rehabilitation software based on Android system [14], including the user interactive layer, data access layer, virtual reality rehabilitation training layer, and individual rehabilitation layer, so that patients can get user-friendly and convenient rehabilitation experience. Moreover, a virtual reality rehabilitation exercise environment is established by means of the integration of virtual reality and system simulation [15, 16], which leads patients to participate in rehabilitation training actively and improves the effect of rehabilitation of patients. In addition, the human-machine interaction rehabilitation software is able to send patients' archives and rehabilitation data to the server, so that doctors get to know patients' healing process simultaneously, making the communication between doctors and patients more seamless [17].

In view of the growing worldwide demands for more effective and economic rehabilitation medicine equipment, This paper proposes the design of human-machine interaction rehabilitation software based on Android operating system for hand rehabilitation robot and describes the results of its experimental evaluation. The combination of virtual reality with robotics can provide new tools for creating treatments. It leads patients to participate in rehabilitation training actively and improves the effect of rehabilitation of patients. In addition, the human-machine interaction rehabilitation software is able to send patients' archives and rehabilitation data to the server, so that doctors get to know patients' healing process simultaneously, making the communication between doctors and patients more seamless.

II. THE GENERAL DESIGN

This paper designed interactive interface based on Android operating system for hand rehabilitation robot, making patients become possible to set motion parameters humanly, and establish RFCOMM pathways with Bluetooth Adapter class for the aim of sending motion parameters to the control system of hand rehabilitation robot, so that the exoskeleton can work in accordance with the requirements of patients. In the meantime, the interactive interface receives the motor data of each motion joint sent by the motion control system of hand rehabilitation robot through RFCOMM channel in real time and stores motion parameters of each finger joints solved by forward kinematics in the database. Patients can see their recovery directly with the help of chart analysis and take part in their rehabilitation treatment forwardly. Using the excellent network communication function of Android portable equipment, the interactive interface is able to send patients' recovery data to doctors, so that doctors can know patients' recovery synchronously,

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achieving seamless communication between doctors and patients [18].

As shown in Fig. 1, the overall framework of the human-machine interface is made up of three major parts, including the user interactive layer, the data access layer and the individual rehabilitation layer. The user interactive layer provides patients with humanized interactive experience; the data access layer uses communication module to realize data exchange with motion control system; the individual rehabilitation layer makes the communication between doctors and patients seamless with the help of the internet.

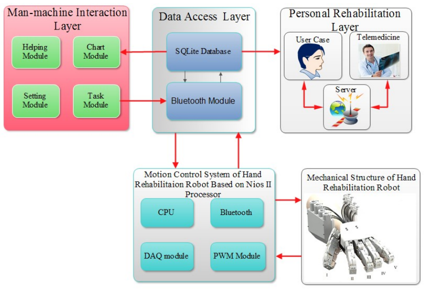


Fig. 1 The overall framework of the human-machine interface

III. The User Interactive Layer

The user interactive layer is the closest part to patients and the interactive interface, so the primary requirement for humanized interactive experience is offering users simple and practical software interfaces. The human-machine interface based on TabWidget (see Fig. 2) can ensure that patients will obtain concise and user-friendly operating experience as it is hierarchical.

TabHost is a container in TabWidget used to store multiple Tab tags, and there is a free-running layout for every Tab tag, so that developers can design corresponding layouts to meet particular mission needs according to the Tab tag. In this interactive interface, the help module, the controlling module, the chart analysis module and the setting module are embedded in TabHost, and the getTabHost function is used to get TabHost objects(see Fig. 3), moreover, the intent function is used for switching from current Activity to the target Activity.

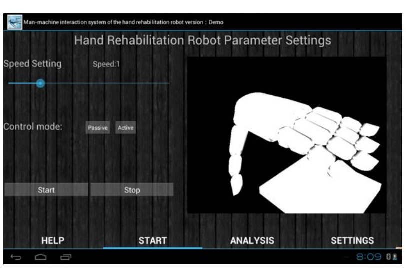


Fig. 2 The human-machine interface based on TabWidget

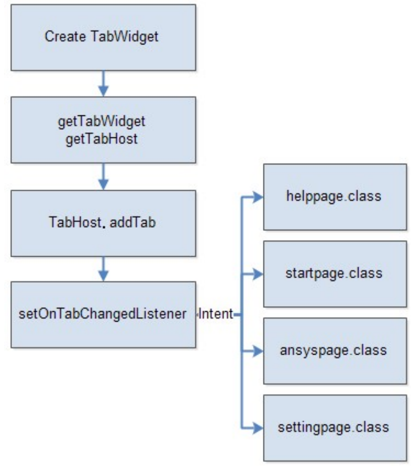


Fig. 3 The detailed modules of TabWidget

IV. The Data Access Layer

The data access layer sends speed and angle information of motors collected by motion control system to the interactive interface through RFCOMM channel. And the motion information of each finger joints solved by forward kinematics will be stored in the motion information database which is developed based on SQLite open-source database.

As Fig. 4 shows, the PIP joint and DIP joint of hand rehabilitation robot's open kinetic chain belong to two closed chain mechanisms with single degree of freedom respectively [19]. And the PIP joint has the same structure as the DIP joint; therefore, the two one-degree-of-freedom closed-loop mechanisms have the same structure, consisting of a one-degree-of freedom symmetric pinion-and-rack parallel sliding mechanism and two adjacent knuckles, which can drive the joint.

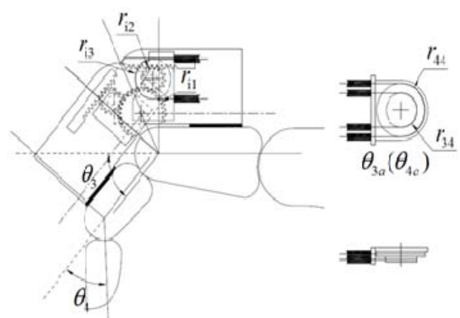


Fig. 4 The schematic diagram of single-degree-of freedom symmetric pinion-and-rack parallel sliding mechanism

According to the structure characteristics of the symmetric pinion-and-rack parallel sliding mechanism, the structure equation model of the closed chain mechanism is solved as follows.

$$\theta_{ia} = \frac{r_{i1}}{r_{i2}} \cdot \frac{r_{i3}}{r_{i4}} \cdot \theta_i (i = 3, 4) . \quad (1)$$

The PIP joint and DIP joint are driven independently, and the coupling ratio is adjusted by the radius of line wheels connected to the motor shaft, therefore, the structure equation model of the coupling structure can be written as shown below.

$$\begin{bmatrix}\theta_{3a}\\ \theta_{4a}\end{bmatrix}=\begin{bmatrix} r_{31}/r_{32}\cdot r_{33}/r_{34} & 0\\ 0 & r_{41}/r_{42}\cdot r_{43}/r_{44}\end{bmatrix}\cdot\begin{bmatrix}\theta_{3}\\ \theta_{4}\end{bmatrix}=\begin{bmatrix}\theta_{3a}\\ \theta_{3a}\end{bmatrix}. \quad (2)$$

Besides, the data stored in the database will be transmitted to the chart analysis module through the Intent communication mode in order to put the analysis of rehabilitation manipulator' motion deeper, which contributes to provide patients with more rich and intuitive recovery data and improve the initiative and participation of patients during the rehabilitation training.

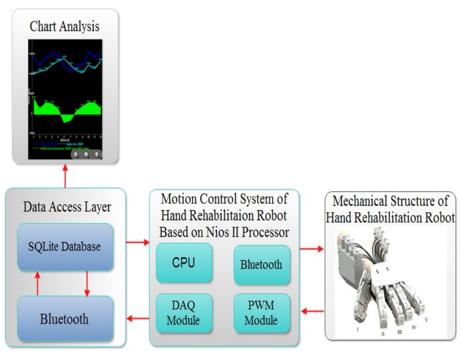


Fig. 5 The structure diagram of the data access layer

As a communication bridge between the interactive interface and the motion control system of the hand rehabilitation robot, the Bluetooth communication module can make real time communication with motion control system once connected to the motion control system. In android, there are some classes and interfaces in Android. Bluetooth package, which offers a Bluetooth adapter, Bluetooth device class, a Bluetooth connection etc, and this Bluetooth API allow applications to establish the RFCOMM protocol and connected to other specified devices. The control process of the Bluetooth communication module is showing as follows in Fig. 6.

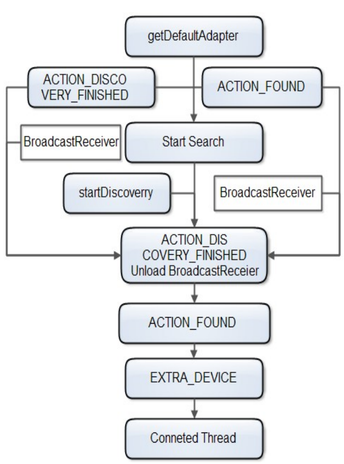


Fig. 6 The flow chart of the Bluetooth communication module

V. THE VIRTUAL REALITY LAYER

In virtual reality rehabilitation training layer, patients' hand motions are displayed on the interactive interface with the help of virtual reality technology, so that patients become conscious of their hands movement through the interface directly. Through the call to OpenGL relevant packages, the virtual reality rehabilitation training layer can realize various functions, including display, motion and collision detection of 3D model.

TABLE I
KEY WORDS IN .OBJ FILES

Key words	Information
v	Geometry vertexes
vt	Map coordinates
vn	Vertex normal
f	Surface index

In view of the complexity of modeling in OpenGL, the 3D model used in the virtual reality layer is imported from external 3D modeling workers. The 3D model constructed is stored in the OBJ file format, then, the program is able to identify the model through the key word appearing on the top of the data line in the obj file, the list of related key words is as follows [20]. At the first step, the program links each point through surface indexing method, constructs a plurality of triangle planes, and build the basic 3D model. Then the program calculates the model' color, determines the light conditions and texture mapping method. Finally, the program transfers mathematical description and color information of the model to user interactive layer through rasterization, and Fig. 7 shows the overall process.

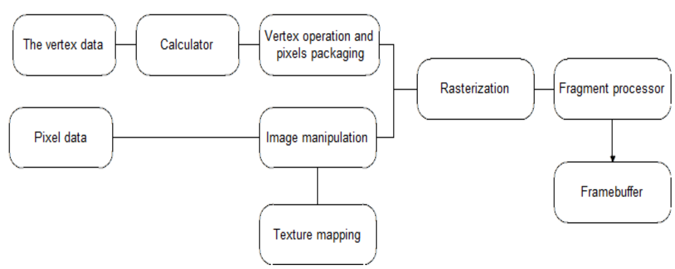
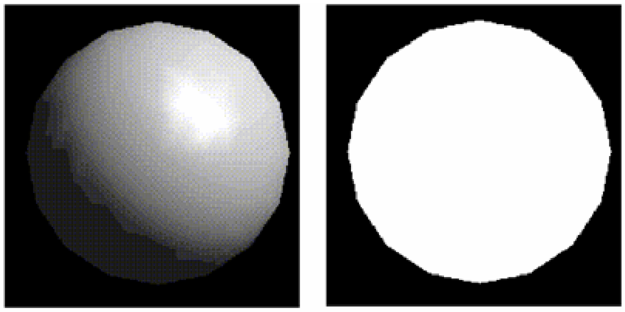


Fig. 7 The flow chart of 3D model construction

In order to make the constructed graph seem to have third dimension, shaded pixel points should be eliminated by calculating the depth information of graphics. Before rendering each new pixel, OpenGL will compare the depth value of the new pixel with the depth value of the pixel stored in the depth buffer in order to recognize pixels display by calling the command starting the depth buffer. As a result, the pixel that is near the viewer will be shown while the pixel that is far away from the viewer will be hidden.

Besides, light condition is also an indispensable part of model display (see Fig. 8).



(a)A sphere exposed to light (b) A sphere in the darkness
Fig. 8 The flow chart of 3D model construction

Considering the display of 3D model, two types of white light source, ambient light and diffusion light, are combined in the system.

The model needs to change its stance with hand's motion. In OpenGL, model transformation is to vary vertex elements of the model and recompose these varied vertex elements in fact. Like the forward kinematics, homogeneous coordinate transformation is used to transform models with column vectors representing homogeneous vertexes in OpenGL.

To realize model transformation, we are expected to call relevant instructions because transformation matrix is packaged in OpenGL [21]. Among these instructions, glTranstlatef(x, y, z) is used to realize models' translation transformation by calling the transformation matrix

$$T=\begin{bmatrix}1&0&0&x\\0&1&0&y\\0&0&1&z\\0&0&0&1\end{bmatrix}. \quad (3)$$

glScalef(x, y, z) can realize the discretionary zoom of models with the help of the transformation matrix

$$S=\begin{bmatrix}x&0&0&0\\0&y&0&0\\0&0&z&0\\0&0&0&1\end{bmatrix}. \quad (4)$$

Models' rotation transformation depend on glRotatef(a, x, y, z) for help and rotation transformation is broken to a number of axial rotation transformations.

Rotation transformation which is around the X axis is shown as below.

$$glRotatef(\theta,1,0,0)=\begin{bmatrix}1&0&0&0\\0&\cos\theta&-\sin\theta&0\\0&\sin\theta&\cos\theta&0\\0&0&0&1\end{bmatrix}. \quad (5)$$

Rotation transformation which is around the Y axis is shown as below.

$$glRotatef(\varphi,0,1,0)=\begin{bmatrix}\cos\varphi&0&\sin\varphi&0\\0&1&0&0\\-\sin\varphi&0&\cos\varphi&0\\0&0&0&1\end{bmatrix}. \quad (6)$$

Rotation transformation which is around the Z axis is shown as below.

$$glRotatef(\psi,0,0,1)=\begin{bmatrix}\cos\psi&-\sin\psi&0&0\\\sin\psi&\cos\psi&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}. \quad (7)$$

In order to make different constituents of the model move separately, a line of code should be added before each model block in the .Obj file. OpenGL stores all knuckles of the model as different objects by identifying the line of code while reading the .Obj file, which will be drawn as separate model. Parameters of the model transformation matrix should be set while transforming the model, so that the transformed model is going to be rebuilt at the time when the system calling related functions again. Because the rotation center is ordinate origin by default, the model should be translated to ordinate origin before rotating the model and come back to its original location after finishing the rotation.

In virtual environment, collision-detection model is supposed to be established in order to detect whether the collision between finger model and virtual plate happens. The plate can be simplified to a cuboid model placed perpendicular to the Z axis and the distal phalanx model required to do collision detection is based on AABB Bounding Volume for the sake of precision requirement and simplicity principle.

To ascertain the AABB model of a given model, only the maximum value and the minimum value in 3D coordinates of each vertex need to be considered. It is a plate placed perpendicular to the Z axis that may collide with the distal phalanx model and can be stored as a AABB model directly, so what need to considered during collision detection is the minimum value of Z coordinates. In this way, the whole AABB model can be projected on Z and the collision detection problem can be recognized as a numerical comparison problem in one dimensional coordinate system, as shown in Fig. 9.

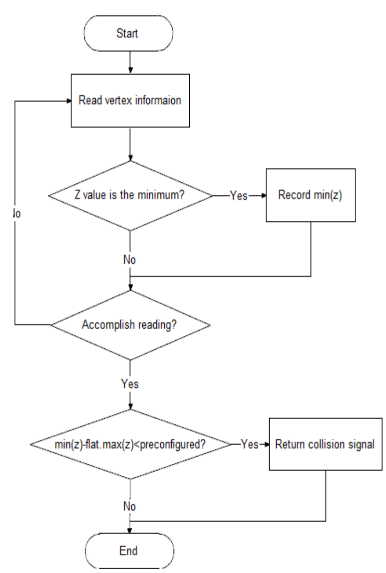


Fig. 9 The flow chart of collision detection

V. The Individual Rehabilitation Layer

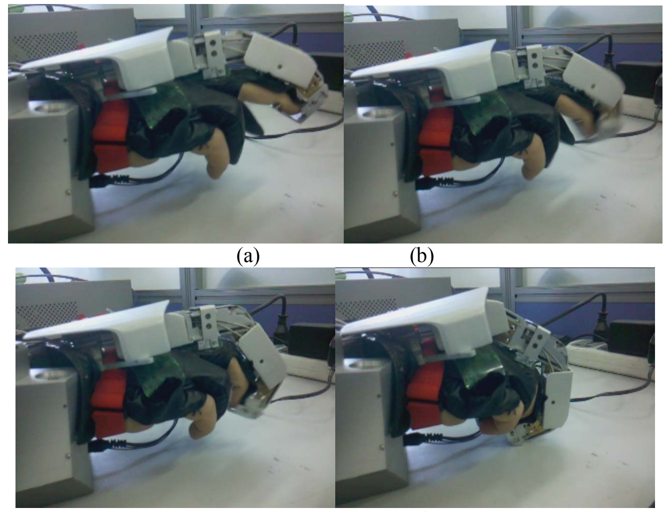
The individual rehabilitation layer is the important part of rehabilitation, which provides important guarantee for effective rehabilitation. By the help of android devices' superior network communication ability, patients are allowed to record their archives information, such as name and medical record number, into a database. Besides, patients' recovery data is saved to the database with rehabilitation going, so that patient profile is established on the server through wireless internet. In order to stay up to date with patients' recovery, doctors should view patients' recovery data by enabling the client on PC machine to connect to a server. Moreover, doctors can send their treatment recommendations to patients through the internet for the sake of patients' improvement in health.

VI. INTERACTION EXPERIMENTS

Fig. 10 shows human-machine interaction integrated experiment platform, Fig. 11 demonstrates hand rehabilitation robot's movement controlled by interactive software and the interactive interface, including user interactive interface, rehabilitation interface, personal parameter setting interface and data analysis interface, is shown in Fig. 12. During the experiment, patients can set their desired movement models through the interactive interface. The interactive interface controls the rehabilitation manipulator's motion and reveals the affected hand's motion information received from motion control system by Bluetooth communication module. Experiments have suggested that the interactive interface has the ability to control rehabilitation manipulator safely and reliably and acquire its motion parameters in real time.

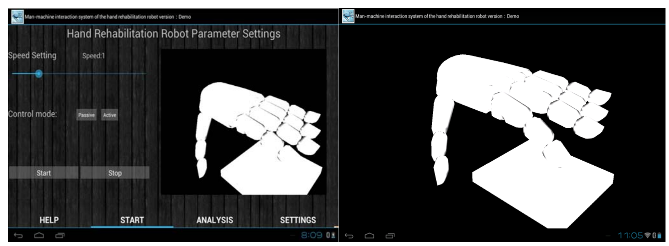
Fig. 10 Human-machine interaction integrated experiment platform

The interactive interface based on Android system is capable of offering patients with convenient and humanized interactive experience, which has been proved to be feasible. The hand rehabilitation robot can in time respond to control instructions and return motion parameters of the affected hand in real time. Moreover, seamless communication between doctors and patients can be realized by portable equipment's excellent network performance, which is of great significance for the development of telemedicine.

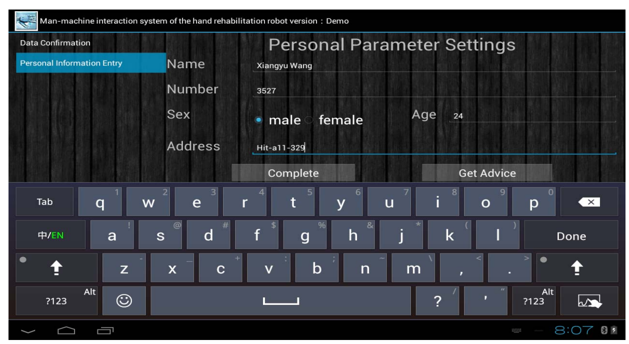


(a) (b) (c) (d)

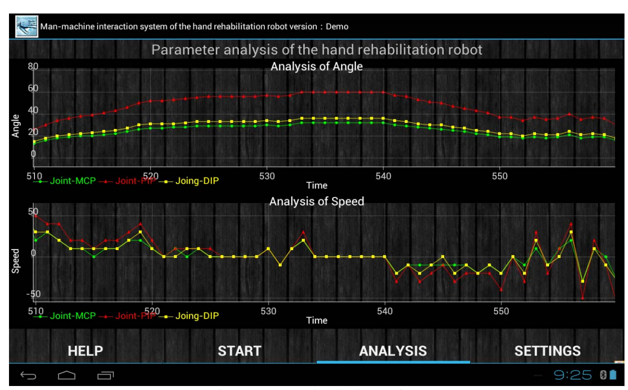
Fig. 11 Process of robot's movement



(a) User interactive interface (b) Rehabilitation interface



(c) Personal parameter setting interface



(d) Data analysis interface

Fig. 12 Human-machine interface

VII. CONCLUSIONS

This paper develops the design of human-machine interaction rehabilitation software based on Android operating system for hand rehabilitation robot and describes the results of its experimental evaluation. The combination of virtual reality with robotics can provide new tools for creating treatments. It leads patients to participate in rehabilitation training actively and improves the effect of rehabilitation of patients. In addition, the human-machine interaction rehabilitation software is able to send patients' archives and rehabilitation data to the server, so that doctors get to know patients' healing process simultaneously, making the communication between doctors and patients more seamless. Based on the results of initial human-machine interaction experiment, further improvements in the system can be expected.

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