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Article

Design of Lumbar Rehabilitation Training System Based on Virtual Reality

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Abstract: A virtual reality-based lumbar rehabilitation training system is designed to address the increasing number of patients with low back pain (LBP) year by year. Attitude sensors are used to track lower back movement. In order to improve the effect of rehabilitation training, several virtual rehabilitation training games and assessment scenes are designed based on the Unity3D engine to complete different tasks from simple to complex. The goal is to increase patients' interest in rehabilitation training. The experimental results verify the accuracy of rehabilitation data acquisition, real-time interactive communication, and the smooth operation of rehabilitation scenes.

Keywords: virtual reality; human–computer interaction; rehabilitation training; lumbar assessment; Unity3D engine

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1. Introduction

Low back pain (LBP), one of the most severe medical and social problems globally, has affected nearly 80% of the population worldwide. From 1996 to 2016, the total cost of back pain, neck pain, and other musculoskeletal disorders was approximately USD 264 billion, resulting in significant financial burdens on both society and the families of affected individuals [1]. Although the current treatment of LBP can be divided into surgical treatment and conservative treatment, these treatment methods have the following issues. (1) One therapist can typically only oversee the care of one patient, which raises the individual cost of medical institutions. (2) Patients' compliance suffers, and their excitement for involvement is reduced by a boring training mode. (3) The use of scoring scales, which are frequently employed by therapists to evaluate the training level of patients' lumbar muscle groups, reduces the efficiency of rehabilitation training.

Virtual reality (VR), as an emerging high technology, integrates advanced technologies, such as modern computer graphics, simulation, and human–computer interaction, to build 3D environments and provide VR experiences [2]. With its unique advantages and characteristics, it has been widely used in the field of rehabilitation therapy [3]. Several studies [4–6] have shown improvements in dynamic balance, upper and lower extremity motor function, and quality of life in stroke patients after rehabilitation with VR. VR technology can enable personalized repetitive exercises for motor function in Parkinson's patients by providing more sensory feedback and stimulating both motor and cognitive functions [7,8]. Studies by Shema-Shiratzky et al. [9] and Borrego et al. [10] have also shown positive effects of VR technology on the cognitive abilities of children with cerebral palsy. Gomes et al. [11] applied the Nintendo Wii VR gaming system to 60 critically ill ICU patients and showed that 59% of patients applying VR could achieve light activity levels and 38% could achieve moderate activity levels. Sara et al. [12] applied a VR-based video game program as an adjunct tool to a conventional cardiac rehabilitation program and showed improvement in ergometry, metabolic equivalents (METS), resistance to fatigue, and health-related quality of life with excellent adherence and satisfaction perceived by patients with ischemic heart disease in phase II.

The VR interventions used in LBP experiments included games based on horse simulators [13], head-mounted displays [14], the Nintendo Wii system [15,16], Microsoft Kinect [17,18], Vicon [19], robotic devices [20], inertial measurement units [21], etc. In [13], the participants sat on a horse-shaped saddle that moved with the time of the film. In [14], the researchers adopted iPods and video glasses to show participants video clips of a person walking through a forest. In [15,16], VR research adopting the Nintendo Wii motion system made use of various gaming applications (e.g., motion programs wakeboarding, Frisbee Dog, jet ski, and canoe games). In these games, the participants must adopt a remote control with motion sensors to manage the virtual player. In [17], the researchers adopted Microsoft Kinect to implement a VR game for LBP. The game consisted of five moves: arm raises, side tilts, torso rotations, pelvis rotations, and squats. Two avatars were displayed, with a therapist avatar showing the patient how to perform the exercises and another avatar reflecting the patient's actual actions. In [18], unlike previous games that used Microsoft Kinect to visualize movement as avatars, the researchers used indirect MV to control the game where the participant must tilt the trunk left and right to control the plane. In [19], the Vicon motor system was applied in lumbar rehabilitation. In [20], a robotic device named TruST was built for trunk training in which the participants were motivated to complete a stretching task. The game consisted of a drone and a coin that needed to be collected by the drone. The drone was controlled by real hand motions. Hand movements were captured using the Vicon system, which consists of 12 cameras. In [21], the researchers adopted an inertial measurement unit (IMU) for LBP rehabilitation, which was placed on the upper back or left thigh. The participants performed four therapeutic exercises: lifting heavy objects, squats bow and arrow stretching, sitting down from a chair, and standing up. In this system, actions were represented by virtual bodies, and the target angle and task time were fed back in real time.

In summary, VR can provide a new approach to rehabilitation, offering higher compliance and better patient management in a hospital or home setting. However, few studies have provided serious play experiences and real-time evaluation feedback to LBP patients without time and venue limitations. Therefore, this paper adopts VR technology to design a rehabilitation training and evaluation system for LBP treatment. It adopts sensor technology and signal processing technology to track real-time lumbar movement and applies the motion signal as control signals to the virtual environment for training and evaluation.

2. Overall System Design

According to the current research status of the lumbar rehabilitation training and evaluation system, combined with the design requirements of the lumbar rehabilitation training and evaluation system, the main design objectives of this system are determined as follows:

(1) The use of VR technology to design rehabilitation games can build an "immersive" rehabilitation training environment for participants by means of images and music, and this "immersive" environment can increase participants' willingness to actively participate in training.
(2) Simple, rapid, and effective lumbar assessment can facilitate patients' adjustment to the rehabilitation training plan in time and assist the rehabilitation therapist in making rehabilitation training programs.

The design process is as follows. The human lumbar motion data information is collected by the attitude sensor, and the motion signal is sent to the software layer of the upper computer through Bluetooth. The upper computer accepts the motion signal to realize the change of the lumbar posture and to control the motion of the virtual object in the virtual environment. The motion signal behavior during the interaction between the human body and the virtual evaluation task is recorded for lumbar motion ability evaluation. The design flow of the lumbar rehabilitation training and evaluation system is shown in Figure 1.

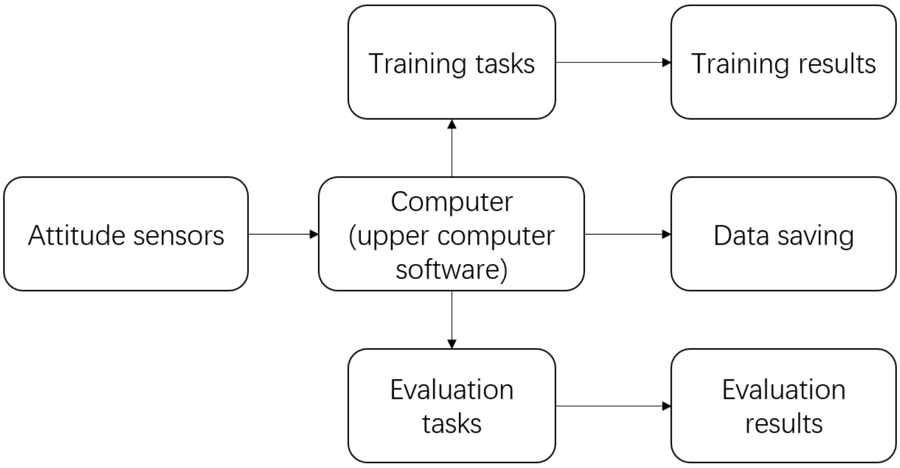


Figure 1. Flowchart of the overall design of the lumbar rehabilitation training and evaluation system.

According to the function division, the system can be divided into a hardware layer, a software layer, and an application layer, as shown in Figure 2. The hardware system is responsible for collecting human motion signals and sending them to the software layer through Bluetooth communication; therefore, the hardware layer must have basic components, such as a computer, an attitude sensor, a Bluetooth module, etc. The software layer should have certain functions, such as information processing, human–computer interaction, a result display, lumbar training, lumbar evaluation, and information storage. The application layer indicates that the system should have the functions of lumbar evaluation and lumbar training.

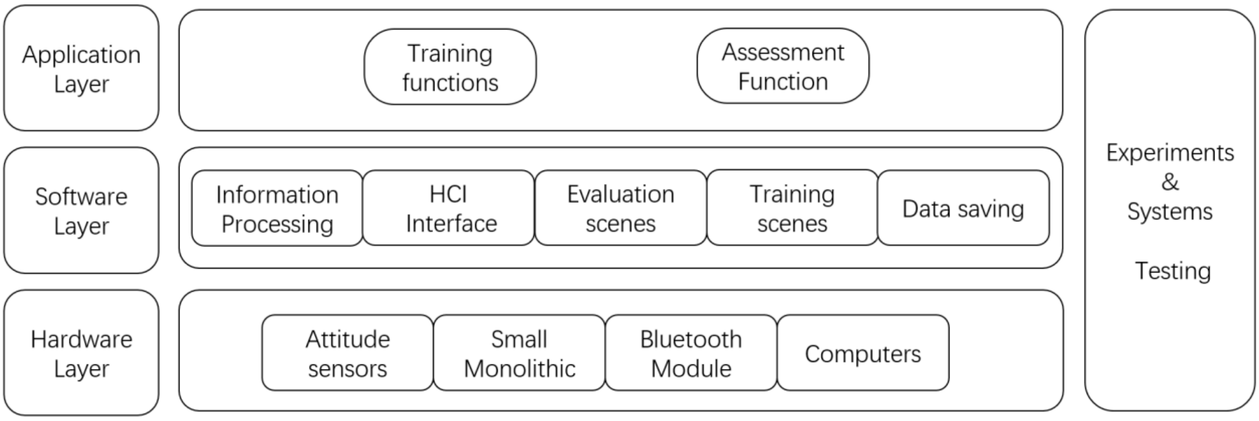


Figure 2. Overall framework of the lumbar rehabilitation training and evaluation system.

The lumbar rehabilitation system based on VR is shown in Figure 3. The attitude sensor is paired with the computer through Bluetooth, and the system software system is installed in the computer. The participant, wearing an attitude sensor, stands on the flat ground and completes the training and evaluation of the lumbar through the prompting of the software system in real time. The attitude sensor should be attached to non-deforming clothing and works best when attached directly to the skin of the middle of thoracic vertebrae.

Figure 3. Overview of lumbar rehabilitation system based on virtual reality.

3. Hardware Layer Design

3.1. Attitude Sensor

The attitude sensor is a high-performance 3D motion attitude measurement system based on MEMS technology. It contains a three-axis gyroscope, a three-axis accelerometer, a three-axis electronic compass, a power supply, and a Bluetooth module. By integrating various high-performance sensors and the core algorithm engine of attitude dynamics, combined with a dynamic Kalman filter fusion algorithm, it provides high-precision, highly dynamic, real-time compensated three-axis attitude angle. The attitude measurement accuracy is 0.2°, and the stability is extremely high. The performance is even better than some professional inclinometers.

The player has to perform four movements to move the cat in the virtual environment. The movements are detected by the attitude sensor. The gyroscope measures the rotation angle around the three-axis X, Y, and Z (roll, pitch, and yaw, respectively). Unit quaternions are a representation of the orientation of the fused data from the gyroscope, accelerometer, and magnetometer. It is one mathematical representation for the orientation of the device. Euler Angles and rotation can also be used to represent the orientation. Quaternions can be represented in Equation (1), where q_0 is the angle of rotation and q_1, q_2, and q_3 are the vectors x, y, and z of the 3-dimensional space.

$$\mathrm{Q} = (q_0, q_1, q_2, q_3) \tag{1}$$

The rotation around the x-axis (roll), y-axis (pitch), and z-axis (yaw) can be calculated from quaternions using Equations (2)–(4), respectively [22].

$$Roll = \arctan\frac{2(q_0q_1 + q_2q_3)}{1 - 2(q_1q_1 + q_2q_2)} \tag{2}$$

$$\text{Pitch} = \text{arctan2}(q_0q_2 - q_3q_1) \tag{3}$$

$$Yaw = \arctan\frac{2(q_0q_3 + q_1q_2)}{1 - 2(q_2q_2 + q_3q_3)} \tag{4}$$

These three rotation angles were used to control the game avatar. If the roll is greater than or equal to a threshold, the cat will bend forward. If the roll is less than or equal to a threshold, the cat will stretch back. The pitch angle is used to move the cat to the left or the right.

3.2. Data Communication

The three-dimensional attitude sensor mainly adopts the RS485 serial port for reading and writing, and its serial port read and write operation inherits the idea of file operation.

The basic process is shown in Figure 4. When the program is running, the system instantiates the serial port through the SerialPort class to configure the serial port parameters, and then it opens the serial port using the open method. After the serial port is successfully opened, the hexadecimal function command representing the sensor address is stored in an array, and the write function is used to write the function command string to the send buffer. When the buffer detects that a character has been written, the character is automatically sent to the sensor linked to the serial port. After the connection to the device is established, characters are written into the receive buffer. In this case, the system automatically triggers the data-receiving event and completes data acceptance when the number of characters in the data acceptance buffer is greater than the specified value of the serial port property. Serial port communication requires the communication parties to set the data frame protocol. The attitude sensor sends the data frame according to the agreed protocol content, and the upper computer receives the data frame according to the agreed protocol content. The frame header of the attitude sensor protocol is two consecutive hexadecimal 0X55, the identifier bit is 0X51, the following 3–10 bits are data bits, and the last bit is the SUM check bit. The specific meanings are shown in Table 1. In the virtual scene of Unity3D, the pose parameter of the script-receiving attitude sensor needs to be attached.

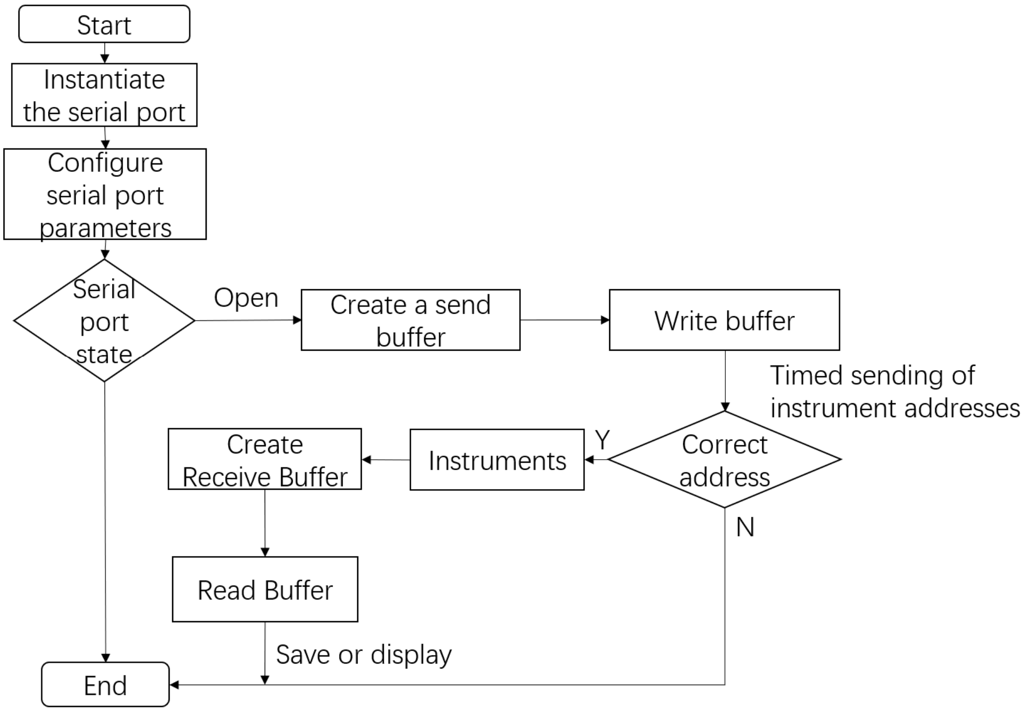


Figure 4. Serial port read and write operation flowchart.

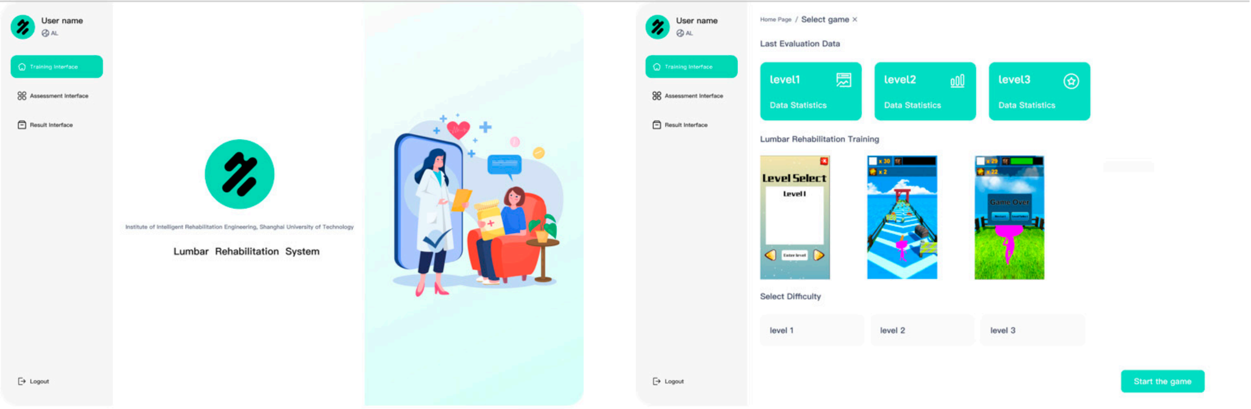
Table 1. Serial port communication protocol format.

Data Name	Data Description	Notation
RollL	Roll Angle X-Low 8 bits	X = ((RollH << 8) ǀ RollL)/32,768 × 180(°)
RollH	Roll Angle X-High 8 bits	
PitchL	Pitch Angle Y-Low 8 bits	Y = ((PitchH << 8) ǀ PitchL)/32,768 × 180(°)
PitchH	Pitch Angle Y-High 8 bits	
YawL	Yaw Angle Z-Low 8 bits	Z = ((YawH << 8) ǀ YawL)/32,768 × 180(°)
YawH	Yaw Angle Z-High 8 bits	
VL	Version number-Low 8 bits	Version number = (VH << 8) ǀ VL
VH	Version number-High 8 bits	
SUM	Checksum	SUM = 0 × 55 + 0 × 53 + RollH + RollL + PitchH + PitchL + YawH + YawL + VH + VL

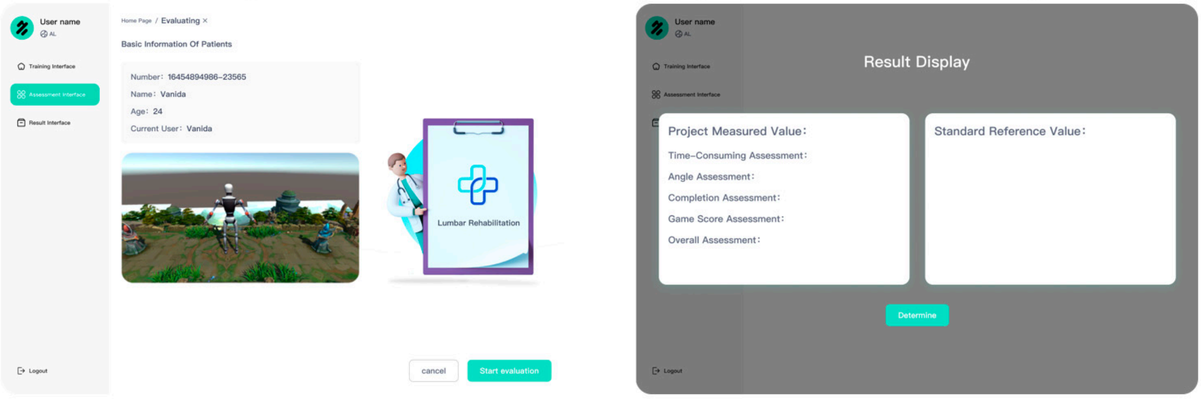
4. Software Layer Design

The software layer is mainly the design of the human–computer interaction interface. The interface for human–computer interaction is written in the C# programming language, and the Visual Studio2019 16.11.6 tool is used to write a WinForm form application program. Meanwhile, the Unity3D software is used to create the VR setting for system evaluation and training. The open link of the executable file of the created VR scene is embedded into the corresponding button of the WinForm form application program to make participants' operation easier. This allows the participants to open the corresponding evaluation or training interface through the button in the interactive interface.

Figure 5 shows the human–computer interaction interface of the system software layer.



（a） Main system interface （b） Lumbar rehabilitation training HCI interface



Number：16454894986-23565
Name：Vanida
Age：24
Current User：Vanida

（c） Lumbar rehabilitation assessment HCI interface （d） Assessment results display interface

Figure 5. Human–computer interaction interface.

(a) The system's main interface

The main interface of the system mainly provides patients with jumping buttons for various function selection interfaces. At the top of the main interface, there are function selection buttons, including the "Login" button, "Training" button, "Evaluation" button, and "Result" button.

(b) Human–computer interaction interface for lumbar rehabilitation training

The training interface mainly helps patients select lumbar rehabilitation training tasks, conveniently open the corresponding training scenes, and complete lumbar rehabilitation training. There are several lumbar training tasks in the drop-down menu, and the training tasks are conducted in the form of virtual games with human–computer interaction.

(c) Human–computer interaction interface of the lumbar rehabilitation assessment

The evaluation interface is mainly used to record patients' personal information. Patients open the VR scene for evaluation, and then the system records real-time human movement data during the completion of the evaluation task.

(d) Evaluation result display interface

In the main interface of the system, the system enters the assessment result display interface after clicking "Assessment Interface", which is mainly used to display the patient's lumbar assessment results. On the left side of the interface, the patient's corresponding movement time, tilt angle, completion degree, and game score are given. On the right side, the reference values of each characteristic parameter of the patient are given, and the lumbar level of each assessment item of the patient is displayed intuitively.

5. Rehabilitation Scene Planning and Construction

5.1. Lumbar Rehabilitation Training Model

5.1.1. Requirements Gathering

We interviewed a physical therapist about the game requirements. We talked about the typical traits of LBP sufferers, the typical physiotherapy treatment, and their thoughts on integrating VR and serious games into the rehabilitation program. Depending on the causes of the pain, different physiotherapy techniques are used to treat LBP. Exercises are the typical treatment for Non-Specific LBP. The treatment of exercise mainly includes two stages: flexibility training and strength training. Four popular flexibility exercises—forward flexion, backward extension, and left and right lateral flexion—were taken into consideration in a long list of flexibility exercises. For the serious game to be "personalized", it is crucial to include three levels for varying degrees of pain or stiffness.

5.1.2. Scene Planning

In order to meet the movement track requirements of lumbar rehabilitation training, the scene of the game maps the left and right angles of the lumbar to the moving range of the cat's position according to a certain proportion. As shown in Figure 6, in the virtual scene, the patient realizes simultaneous movement of the patient and the virtual game object by controlling the cat to move left, right, forward, and back on the street. The game has three levels based on pain and stiffness, and the settings of obstacles and running speed are specified according to the patient's current back degree. When the game is running, the cat will run according to the speed specified by the level, while hurdles, treasure chests, gold coins, and cakes will appear randomly on the path. When the cat eats the treasure box, gold coins, and cakes or hits the hurdles, the Unity3D system will trigger the scoring logic and automatically add or subtract points.

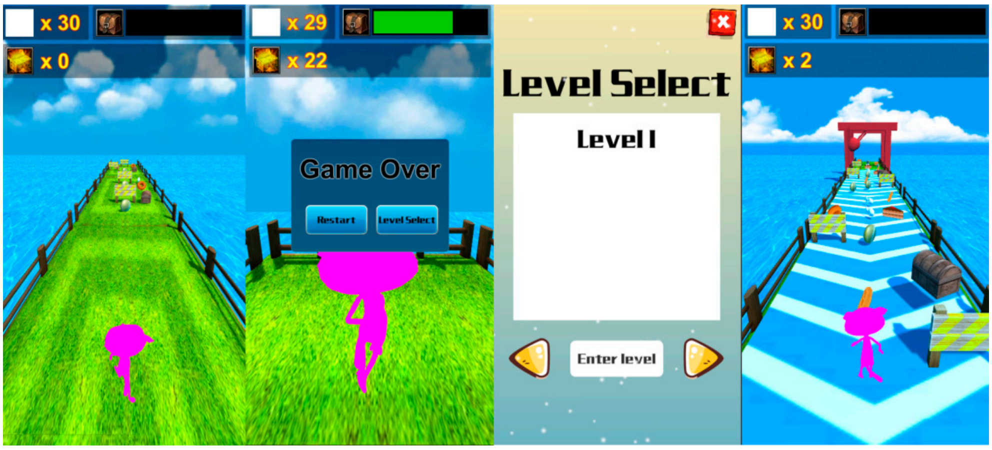


Figure 6. Lumbar rehabilitation training mode.

5.1.3. Scene Building

Firstly, the background, prepared in advance, the cat's prefabricated body, etc. are imported into the Unity3D game engine, and their relative positions are adjusted to design the initialized state of the scene. Then, the main feature of obstacles appearing randomly is implemented functionally, and the cat is allowed to run on the road continuously before reaching the end. Therefore, Unity3D needs to continuously cycle through the map generation, and Unity3D needs to destroy the road sections that the cat passes to improve the running processing efficiency. The specific logic flowchart of this part is shown in Figure 7. After the game starts, the Unity3D system will automatically generate roads and obstacles, and as the game character moves, the system will perform collision detection in real time. When the game character reaches the road birth point, the system automatically generates a new road and randomly generates obstacle prefabs through the Random function, which in turn instantiates obstacles.

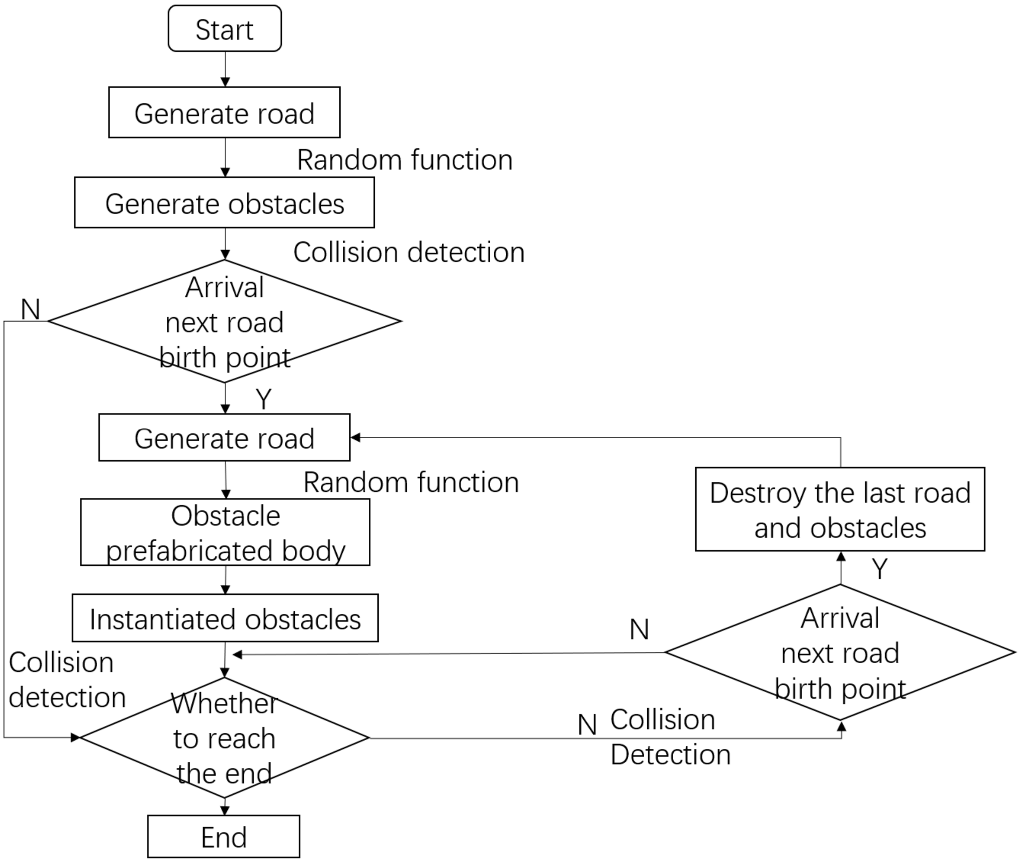


Figure 7. Logic diagram of random obstacle generation.

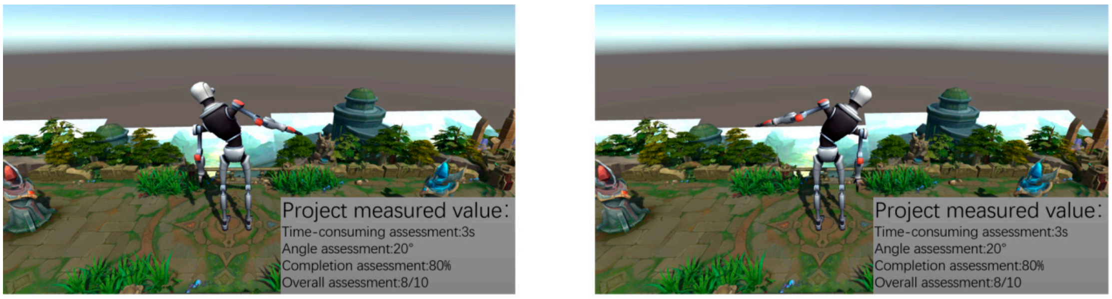
Secondly, as the game character continues to move, it detects in real time whether to reach the next road birth point. When the next road birth point is reached, the system will destroy the previous road and obstacles, while generating new roads and obstacles. When the cat touches gold coins, treasure chests, and cakes in the game, Unity3D will automatically call the OnCollisionEnter event method as a way to obtain the collision information of the game object and then realize the plus or minus score effect. When the cat is colliding with the hurdle object, Unity3D automatically calls the OnCollisionEnter event method and the Destroy method to realize the colliding effect.

Thirdly, for the sake of development convenience, simplification of the program code, and later update and maintenance, the main parameters of the game are visualized and can be changed directly by dragging and dropping the parameters with the mouse. In order to make the whole game resemble the physical world at the same time, the Rigidbody and

Collider components are added to the game object, which can simulate the state of external force in the real world more realistically.

5.2. Lumbar Rehabilitation Assessment Model

The lumbar rehabilitation evaluation subsystem guides patients to complete training actions unconsciously by creating a relaxing, pleasant, comfortable, operation-friendly game scene. Feedback and encouragement are given promptly during the training process, which generates active and positive emotions in patients and alleviates tedious feelings during the lumbar rehabilitation training process, as shown in Figure 8.

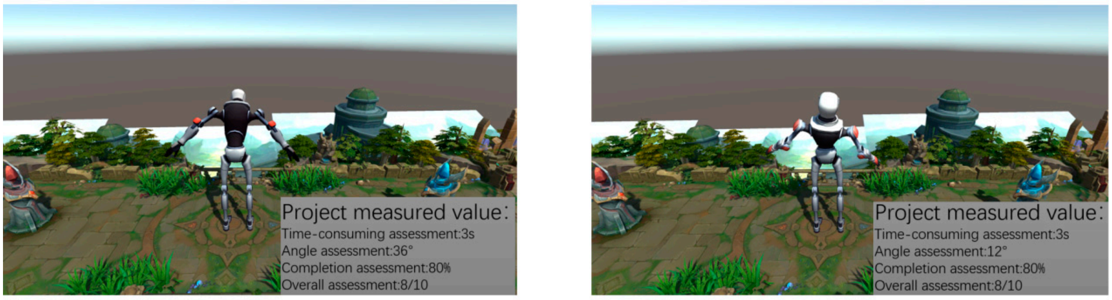


Project measured value:
Time-consuming assessment:3s
Angle assessment:20°
Completion assessment:80%
Overall assessment:8/10

Project measured value:
Time-consuming assessment:3s
Angle assessment:20°
Completion assessment:80%
Overall assessment:8/10

(a) Left lateral flexion

(b) Right lateral flexion



Project measured value:
Time-consuming assessment:3s
Angle assessment:36°
Completion assessment:80%
Overall assessment:8/10

Project measured value:
Time-consuming assessment:3s
Angle assessment:12°
Completion assessment:80%
Overall assessment:8/10

(c) Forward flexion

(d) Backward extension

Figure 8. Low back rehabilitation assessment model.

(1) There is feedback on the accuracy of the action at the top of the screen. The screen will be briefly red with the accuracy of the action above 90% being PERFECT, above 80% being GREAT, and above 70% not passing the feedback. Continuous feedback of 70% or more accuracy will appear as a continuous hit effect.
(2) After the patient leaves the detection range, the system will pop up a window and perform a 10 s countdown, prompting the patient to return to the current training, and return to the 3 s countdown to continue the training.
(3) If the patient does not return within 10 s after leaving the test, the system will automatically exit. If the patient has completed 20% of the total movements of the training, the system will save the data for settlement by default. If the number of the total movements completed is less than 20%, the system will not save the data.
(4) Settlement stage

After the training is completed, the overall training data of the current training will be generated. For detail of the data, the patient will need to contact the rehabilitation therapist to inquire in the hospital customization subsystem.

(5) Training restart phase

After confirming the data in the settlement interface, an interface will prompt the patient to restart training again and click to return to the login interface.

6. System Testing

6.1. Attitude Sensor Function Test

This section focuses on measuring the three-dimensional plane angles of participants wearing the sensor system in the right and left lateral flexion posture, forward flexion posture, and back extension posture. The angular data were collected from 4 healthy college students (mean age 24.9 ± 2.69 years, mean height 176.3 ± 9.6 cm, weight 76.5 ± 10.6 kg) with no spinal degenerative disease, LBP, or other symptoms. The participants were informed of the experimental steps and mastered the basic procedures and precautions of the experiment before data collection. Before the experiment, the skin of the middle of the thoracic vertebrae to be measured was wiped clean with alcohol, and the attitude sensor was pasted. The experimental environment should avoid electromagnetic interference, and the participants needs to remain relaxed and complete the appropriate movements. Participants were required to perform each posture twenty times. After an action was performed, the body was in a relaxed state. MATLAB R2023a was used to fit the experimental data, and joint motion angles under different states were obtained, as shown in Figure 9.

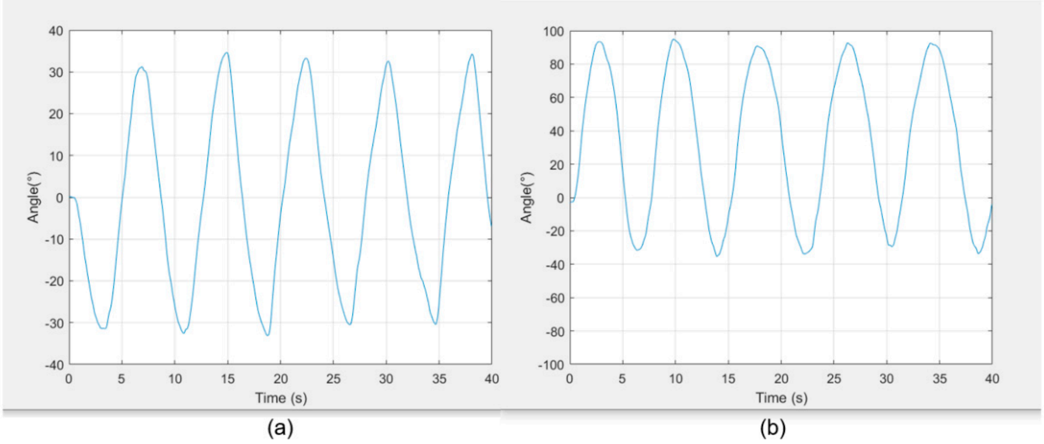


Figure 9. (**a**) Movement angle curves for left and right lateral flexion. (**b**) Movement angle curves for forward flexion and backward extension.

Then, the angles of motion of the human lumbar spine in each posture in different states were shown as average values, as shown in (5):

$$d_{\mathrm{m}} = \frac{\sum_{j=1}^{N} D_{max}}{N} \tag{5}$$

d_m is the average of the maximum values of all sample sizes, D_{max} denotes the maximum value of the movement angle for each participant, and N denotes the number of participants. The experimental results showed that the movement angles d_m under the four movements of left lateral flexion posture and right lateral flexion posture, forward flexion posture, and back extension posture were 30.8°, 30.7°, 91.3°, and 31.0° respectively. As shown in Figure 10, in these four states, the angles are consistent with the angles set in Table 2, which verifies the rationality of the system designed in this paper. Finally, Table 3 provides detailed data on the four postures of volunteers.

Table 2. The range of motion of the human lumbar under various modes of motion.

Movement Posture	Rotary Axis	Training Range (°)	Assessment Range (°)
Left and right lateral flexion	Sagittal axis (y)	−25~25	−30~30
Forward flexion and backward extension	Coronal axis (x)	−15~45	−30~90

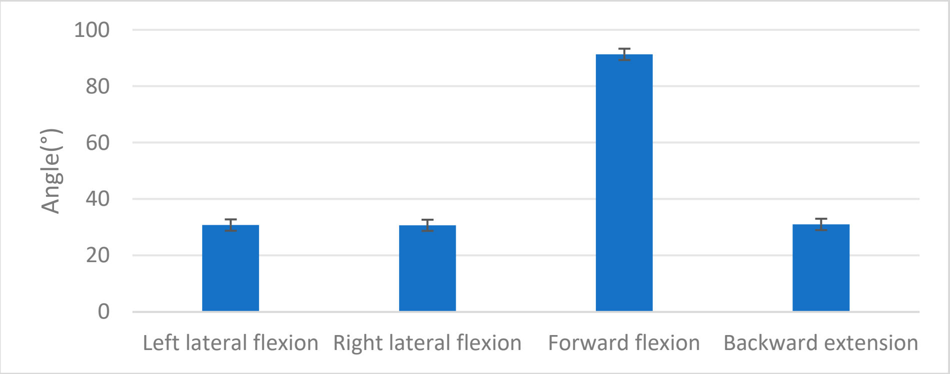


Figure 10. Angle of lumbar spine motion in different postures.

Table 3. Detailed data on the four postures of volunteers.

Volunteer	Age	Sex	Left Lateral Flexion	Right Lateral Flexion	Forward Flexion	Backward Extension
1	22.5	Male	−30.16 ± 1.58	29.52 ± 1.81	91.55 ± 1.39	−30.66 ± 1.83
2	27.3	Female	−31.38 ± 1.23	31.40 ± 0.93	92.34 ± 2.23	−31.03 ± 1.98
3	27.8	Male	−31.30 ± 1.61	30.85 ± 1.53	89.85 ± 2.80	−31.08 ± 1.97
4	21.9	Male	−30.53 ± 1.98	30.89 ± 1.48	91.32 ± 2.46	−31.12 ± 1.66

During the experiment, it can be seen that the stability and accuracy of training data collection are relatively high in rehabilitation training. In addition, virtual rehabilitation scenes can accurately prompt the actions of participants, and the game action process is continuous and smooth. The subjects focus their attention on the virtual scene and task mode, effectively improving their interest in rehabilitation and training initiative, thus verifying the effectiveness of virtual scene design for rehabilitation training.

6.2. Lumbar sEMG Test

The lumbar surface electromyographic (sEMG) signal data were obtained from four graduate students who had an average age of 25.1 ± 1.4 years, an average height of 175.0 ± 6.2 cm, an average weight of 69.1 ± 14.1 kg, and no spinal degenerative disease, LBP, or other symptoms. The control group in this experiment did not receive prompts for lumbar exercise from the lumbar rehabilitation training system, while the experimental group received prompts for exercise from the lumbar rehabilitation training system. The changes in the sEMG signals of the lower back of the same subject during two exercises were compared. The subjects completed three sets of movements in two different movements, with one group completing forward and backward bending and left and right lateral bending movements within 24 s. This test selects RMS features for analysis, which can represent the effective value of sEMG and represent the contribution of muscle groups during the action process. In the process of extracting the features of the lumbar sEMG signal, a 50 ms sliding window was selected to calculate the average RMS of the lumbar sEMG signal. At the same time, the average power frequency MPF features were also selected for analysis. An experimental diagram was used for measuring the lumbar erector spinalis and thoracic erector spinalis muscles, as shown in Figure 11a. The experimental data show that the sEMG signal of the lumbar erector spinalis is obvious, as shown in Figure 11b. Therefore, subsequent experiments will mainly analyze the lumbar erector spinalis. As shown in Figure 11c, the MATLAB processing diagram of the sEMG signal of the lumbar erector spinalis muscle of one of the volunteers is presented.

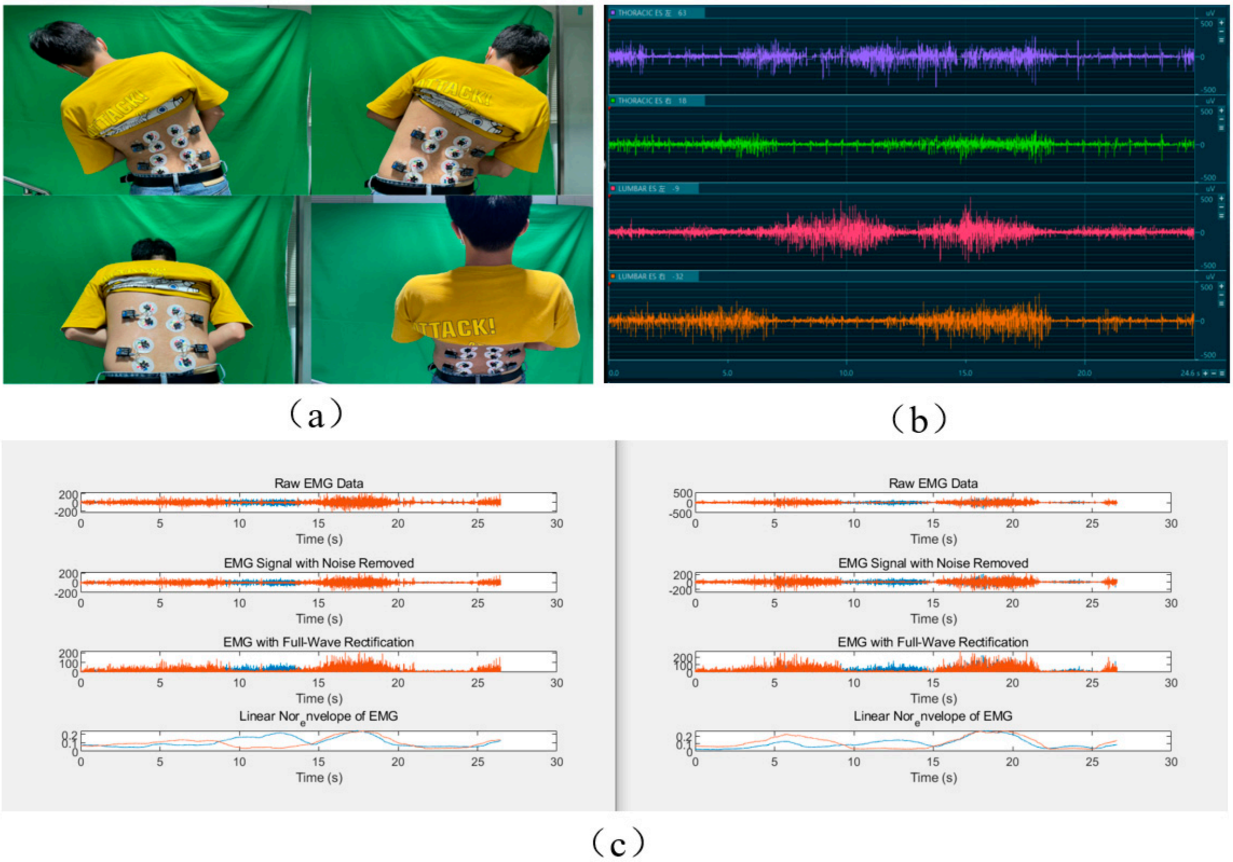


Figure 11. Lumbar sEMG test procedure diagram. (**a**) Volunteer experiment diagram. (**b**) sEMG of the volunteer's lumbar erector spinalis with pink and yellow and thoracic erector spinalis muscles with purple and green. (**c**) Changes in sEMG of the lumbar erector spinalis muscle of one volunteer (Red and blue represent the left and right channels).

As shown in Table 4, the sEMG signals of the volunteers were slightly different, but the RMS values of the four volunteers without indications from the lumbar rehabilitation training system were lower than those with indications from the lumbar rehabilitation training system. The larger the RMS, the greater the contribution made by the muscles [23–25]. This indicates that the use of virtual reality lumbar rehabilitation training games could effectively improve patient engagement. However, the MPF value decreased after being prompted by the lumbar rehabilitation training system, as shown in Table 5, so, based on this, we analyzed whether the extreme angle indicated by the lumbar rehabilitation training system was too large and whether the duration was too long, leading to lumbar fatigue.

Table 4. RMS data with and without prompts for lumbar sEMG signals.

Volunteer	Age	Sex	Without Prompts RMS Value	With Prompts RMS Value
1	23.6	Male	0.063267	0.087950
2	23.9	Male	0.105767	0.105967
3	27.2	Male	0.112767	0.114150
4	25.5	Male	0.080533	0.090700

Table 5. MPF data with and without prompts for lumbar sEMG signals.

Volunteer	Age	Sex	Without Prompts MPF Value	With Prompts MPF Value
1	23.6	Male	123.3954	105.4824
2	23.9	Male	101.5361	99.2009
3	27.2	Male	105.8396	101.896
4	25.5	Male	112.9738	102.6586

7. Discussion

7.1. Main Research Results

The main goal of rehabilitation is to improve the individual's independence in daily activities. VR promotes motor learning and improves motor function by providing customized training, repetitive intensity, multimodal feedback, and motivation [26]. VR-based games promote entertainment, improve exercise compliance, ref. [27] and divert attention from pain, thereby allowing patients to perform repetitive motor exercises [28]. It is more important that the use of a VR system can reduce rehabilitation costs and evaluate the accuracy of rehabilitation participants' movement [20]. The preliminary results of this study show that the system has the following advantages. (1) Using a high-precision attitude sensor for data acquisition can effectively improve the reliability of data information. (2) Through a large amount of literature reading combined with VR technology, we designed a simple, fast, and effective evaluation experiment, and the system can quickly and accurately evaluate the lumbar ability. (3) The evaluation and training environment built using computer and VR technology makes participants feel more natural and greatly enhances the immersion and interest in evaluation and rehabilitation training. Moreover, the training mode of VR games can fully mobilize participants' initiative to participate in training and focus compared with the traditional lumbar training mode. (4) With the advantage of VR technology, the designed lumbar rehabilitation evaluation and training system can finally save costs and break through the limitations of time and space, and participants can independently complete the lumbar evaluation and training at home, greatly improving the flexibility of the system.

7.2. Limitations and Future Work

Many different tests, experiments, and improvements are left for the future. Randomized controlled trials with assessment experts could be conducted in patients with LBP to assess the effectiveness of this intervention in reducing pain and improving motor function.

Virtual games for rehabilitation basically meet the expected requirements of demand analysis and design, but the game content is not rich enough. The game currently has no multiplayer and only allows one patient to perform rehabilitation training in a virtual setting. In addition, virtual rehabilitation games need to allow patients to interact more during rehabilitation training, and more social features can be added to the games, such as in-game chat systems. In addition, the game can also add hold time adjustment, reminders, practice learning, and correction features.

8. Conclusions

This study adopts VR technology to design a lumbar rehabilitation training and evaluation system. It allows participants to conduct proper rehabilitation or exercise regularly at home, thus reducing the possibility of injury. Specifically, the sensor technology and signal processing technology are used to track the real-time lumbar movement, and the movement signal is applied to the virtual environment of evaluation and training as a control signal. Through human–computer interaction in the virtual environment, with accuracy and interest, lumbar rehabilitation training and evaluation can be realized.

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