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Feature Evaluation of Upper Limb Exercise Rehabilitation Interactive System Based on Kinect

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ABSTRACT The virtual rehabilitation system combining virtual rehabilitation environment and upper limb rehabilitation technology is interactive and interesting, which can improve the enthusiasm and initiative of patients for rehabilitation training, improve the efficiency of rehabilitation training and improve the effect of rehabilitation treatment. This paper firstly conducts in-depth research and analysis on the research progress of the upper limb rehabilitation robot system, and deeply studies the principle and rehabilitation principle of the stroke caused by hemiplegic dyskinesia, and summarizes the goals and methods of the upper limb rehabilitation system design. Secondly, the hand motion tracking is realized by Kinect's bone tracking, and the optimal tracking distance is determined experimentally, which verifies the stability and robustness of the tracking. Static gesture recognition adopts two gesture recognition schemes based on Kinect depth image and color space model respectively. Finally, using the rehabilitation robot and Kinect sensor as the hardware platform, the virtual rehabilitation training system experimental platform is constructed, and the horizontal rehabilitation exercise and the three-dimensional space rehabilitation exercise are respectively studied experimentally, and the exercise data obtained by using healthy subjects as the experimental object is analyzed. Based on this, the validity and feasibility of the Kinect-based upper limb exercise rehabilitation interactive system were verified.

INDEX TERMS Kinect, virtual rehabilitation environment, three-dimensional space rehabilitation exercise, gesture recognition.

I. INTRODUCTION

Stroke-induced limb dyskinesia is currently a more effective method for rapid rehabilitation after treatment. A large number of rehabilitation training can re-establish the connection between human limb motor function and central nervous system. Repetitive rehabilitation exercises can be performed. Effectively repair damaged nerves in the brain to achieve the purpose of treating hemiplegia. Due to the complexity and fineness of the movement of the upper limbs of the human body, the central nervous system of the movement is also more complicated. Therefore, the recovery period of the upper limb motor function is far beyond the lower limbs, so the rehabilitation training of the upper limbs of the human body is more important.

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Based on Kinect's upper limb exercise rehabilitation technology, it is a new technology developed in recent years that does not require any control equipment, can directly use limb movements to interact with digital devices and virtual environments, and solves the need in the existing virtual interaction process. The Kinect somatosensory device produced by Microsoft Corporation is a 3D somatosensory camera. It also includes real-time dynamic capture, image recognition, microphone input, speech recognition, and community interaction [1]–[3]. The patient does not need to wear any sensor on the body. Kinect can realize the interaction with the computer by capturing the movement of the patient in the three-dimensional space by the camera. Combining the human-computer interaction technology with the Kinect somatosensory device to perform the exercise rehabilitation training provides the patient with a novel Rehabilitation environment [4]–[6]. A large number of clinical experiments have proved that patients are more inclined to be close to the living environment in the virtual rehabilitation environment, and can quickly adapt to the rehabilitation environment, thereby helping to improve the patient's self-care ability and speed up the recovery of the affected side. During the rehabilitation training process, the patient can acquire various facial features such as vision and hearing in real-time through the virtual rehabilitation environment and obtain feedback information of the corresponding sports, thereby generating a realistic sense of presence and immersion. It can be seen that the virtual reality environment is combined with the rehabilitation robot. The rehabilitation system has the advantages of repeatability, interactivity, and real-time [7]–[9]. Based on accelerometers and gyroscopes, a method of upper limb motion tracking is obtained [10]–[12]. The two kinds of sensors are used to detect the motion information of the human body, and the human body information is remodeled, and the upper limb motion model is constructed to realize the control of each set. The method is relatively simple and the cost is low. The current Kinect-based upper limb exercise rehabilitation interactive system has existed, but there is no specific application for the robot-assisted rehabilitation training system. Therefore, the Kinect upper limb exercise rehabilitation interaction technology is applied to the robot-assisted exercise rehabilitation training, and the Kinect-based somatosensory interaction is carried out. The robot assisted rehabilitation training method and system research will further improve and improve the technical level of human-machine cooperative rehabilitation training, which has important academic significance and clinical application value [13]–[15]. However, due to the imperfect limb movement function of the patient, it is impossible to carry out rehabilitation training independently. The traditional Kinect-based upper limb rehabilitation interaction requires the doctor to perform one-to-one repetitive rehabilitation training for the patient, and stimulate the brain motor nerve repair through a large number of limb movements. Although traditional rehabilitation methods have certain therapeutic effects on the rehabilitation of patients, there are still many shortcomings. Based on Kinect's upper limb rehabilitation interaction, the patient's exercise support obtained by three-dimensional coordinate transformation quantifies the joint motion angle and becomes a quantitative evaluation of rehabilitation. The important basis is to intuitively evaluate the patient's rehabilitation effect, and to carry out high-efficiency remote decision-making in a targeted manner, which can be distinguished by horizontal rehabilitation training and three-dimensional space rehabilitation training methods. Using the Unity3D 3D engine to import 3D models and scenes onto the software simulation platform [4], [14], [16], [17], a virtual game designed for balanced rehabilitation training for patients with hemiplegia due to traumatic brain injury and spinal injury was designed. During the rehabilitation game, the patients participating in the balance rehabilitation training will display the patient's morphological movement and motion state as virtual creatures while the Kinect sensor is tracking the patient image in real time. The patient can perform the phase based on the feedback motion information. The overall balance of the shoulder, elbow and wrist adjusts itself to complete the real-time interaction between the virtual person and the patient, thereby training the patient's body's balance perception ability, and finally achieving the goal of comprehensive rehabilitation training.

In this paper, Kinect upper limb exercise rehabilitation technology combined with virtual rehabilitation environment, the Kinect system is re-developed, through the research of key technologies such as the recognition and tracking of upper limb movements, a set of exercise rehabilitation interactive system suitable for patient rehabilitation can be designed. The patient provides a virtual environment of daily life behavior with highly realistic visual effects, and obtains real-time and accurate feedback to the patient, so that the patient can obtain sufficient immersion and realism from the patient, and stimulate the enthusiasm of the patient to participate in the treatment. Treatment improves the effectiveness of rehabilitation training. Firstly, the research progress of the research on the upper limb rehabilitation robot system has been deeply studied and analyzed. The principle and rehabilitation principle of the stroke caused by hemiplegic movement disorder is deeply studied, the goals, methods, and methods of upper limb rehabilitation system design are summarized. Secondly, the hand motion tracking is realized by Kinect's bone tracking, and the optimal tracking distance is determined experimentally, which verifies the stability and robustness of the tracking. Static gesture recognition adopts two gesture recognition schemes based on Kinect depth image and color space model respectively. Finally, using the rehabilitation robot and Kinect sensor as the hardware platform, the virtual rehabilitation training system experimental platform is constructed, and the horizontal rehabilitation exercise and the three-dimensional space rehabilitation exercise are respectively studied experimentally, and the exercise data obtained by using healthy subjects as the experimental object is analyzed. The Kinect-based upper limb exercise rehabilitation interaction provides patients with a more natural way of human-computer interaction, making the rehabilitation process more intelligent and user-friendly. In addition, gesture recognition can also be used as the research basis for future hand rehabilitation training, which is of great significance for the construction of a complete rehabilitation system. Based on this, the validity and feasibility of the Kinect-based upper limb exercise rehabilitation interactive system were verified. The rest of this paper is organized as follows. Section 2 discusses Upper body rehabilitation interaction design based on Kinect, Section 3 shows the simulation experimental results, and Section 4 concludes the paper with summary and future research directions.

II. KINECT-BASED INTERACTIVE DESIGN FRAMEWORK FOR UPPER LIMB REHABILITATION

A. SPORTS REHABILITATION MEDICAL THEORY

The theory of motor re-learning requires patients to be able to perceive depth in each movement during the entire

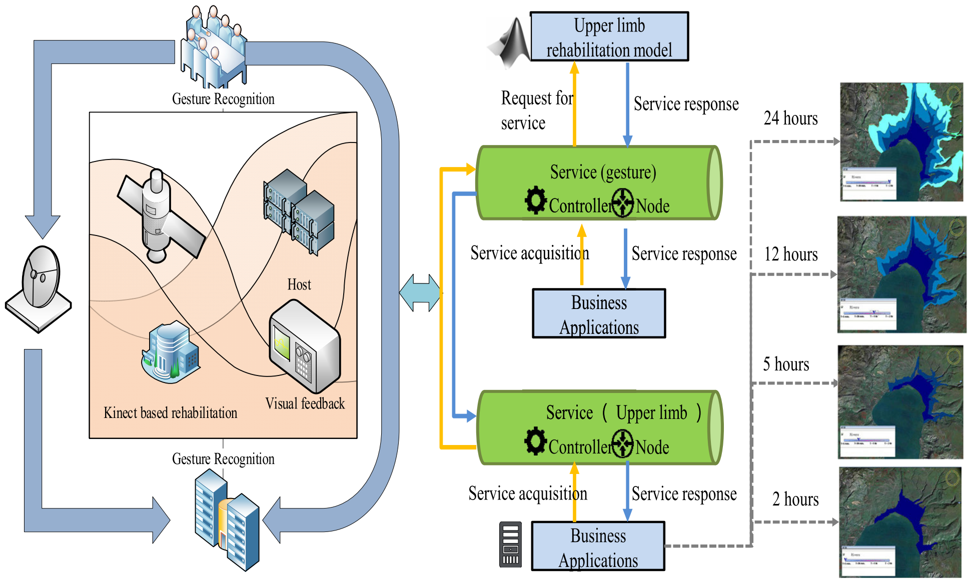


FIGURE 1. Theoretical framework of sports rehabilitation medical system.

rehabilitation process, and these actions use the higher precision muscle strength and joint angle. In the process of repeated training in sufficient time, slowly learn to control the speed, direction and amplitude of limb movement [18]–[20]. Therefore, this topic proposes to combine Kinect somatosensory technology, virtual reality technology and robot-assisted rehabilitation training system. It can achieve the purpose of sports re-learning by repeating multiple trainings under various rehabilitation training modes, and promote patients from passive training to active training. The theoretical framework of the sports rehabilitation medical system is:

As shown in Figure 1, upper limb service shows that the rehabilitation methods for the central nervous system of the human brain are based on the theory of brain plasticity and functional recombination, that is, which refers to the coordinated exercise of movements in rehabilitation training. Service gesture responds adaptively and can self-repair according to the environment. Functional recombination refers to the change of brain function to the plastic region of the brain [21]. Currently, there are several methods for upper limb rehabilitation:

1) NEUROMUSCULAR DEVELOPMENT PROMOTING TECHNOLOGY [22]

It mainly uses the human nerve central system as a therapeutic rehabilitation object, and refers to the basic principles and rules of neurodevelopment, neurophysiology and neuroelectricity to the rehabilitation treatment of dyskinesia caused by brain function damage. The technology of dim sum includes PNF CProprioceptive Neuromuscular Facilitation) technology, Rood technology, Bobath technology and Brunnstrom technology. Combine rehabilitation therapy with people's daily life behaviors to establish common sports training tasks, and integrate visual, tactile, linguistic and other sensory stimuli. Patients can enhance the coordination and control of joint movement by repeatedly strengthening the training of multi-joint complex exercises.

2) MANDATORY USE OF EXERCISE THERAPY [23]

Correcting permanent acquisitional disuse is the most common mandatory exercise therapy. It is mainly for those patients who are unable to move their own limbs due to damage to the central nervous system. Rehabilitation physicians use their limbs to bind them.

3) EXERCISE RE-LEARNING THERAPY [24]

Exercise re-learning therapy is to restore the patient's motor function to the ultimate goal after the damage of the central nervous system of the human brain. It is based on the brain plasticity and functional recombination, and then based on the aspects of neurodevelopment, neurophysiology, and neuroelectrics. The sufficient condition for realizing the reorganization of patients' functions is a targeted, repetitive, re-study and retraining process that advocates multiple feedbacks to enhance repetitive training. For example, when training the upper limb motor function, the module training of the abduction and extension of the shoulder joint and the flexion and extension of the elbow joint are integrated to carry out exercise training.

Based on the above analysis, based on the theoretical medical basis of the upper limb rehabilitation process and the basic characteristics of the patient, we summarize the basic objectives of upper limb rehabilitation: (1) Correct the abnormal movement pattern of the upper limbs and enhance the coordination of the joint movements of the upper limbs. (2) Strengthen the specific range and ability of each joint of the patient and increase the strength of the muscle tissue. (3) Improve patient confidence and help them return to normal life.

TABLE 1. Range of motion of ULERD and human upper limbs.

Body movements	Human joint range of motion (degrees)	Equipment joint range of motion (degrees)
Elbow flexion/extension	140/0	180/0
Forearm internal rotation / external rotation	85/70	85/75
Wrist flexion and extension	73/70	70/65

B. RESEARCH ON MOVING TARGET TRACKING BASED ON KINECT

The upper limb rehabilitation robot has three parts: the hand, the forearm and the upper arm. The upper arm has a length of 18 cm, a width of 9.5 cm, a height of 4.5 cm, a forearm length of 10 cm, and a width of 10.4 cm. Both the upper arm and the forearm can be fixed on the affected limb of the patient by a medical bandage. The hand has a hollow circular position for the patient's affected side arm, and the diameter of the hollow circular placement space is 7.5cm. The robot's driving method selects a smooth pulley line drive, which satisfies the smoothness and flexibility of the patient. In order to accommodate different patients with hemiplegia, we designed the plate between the hand and the forearm to be of a length controllable form. The range of motion of ULERD and human upper limbs is shown in Table 1.

Depth measurement technology, also known as Light Coding, was first developed by PrimeSense and later used by Kinect somatosensory devices and became one of the core technologies. He uses an infrared laser transmitter to transmit, an infrared camera to receive, and the depth information of the illumination space is obtained through corresponding techniques. The principle of this technology is to illuminate the three-dimensional space by random light source, and then to reflect the light at different positions of different objects in the space, so as to calibrate the three-dimensional space and obtain the specific structure of the whole space [25], [26].

As shown in Figure 2, after obtaining the depth information of the three-dimensional space, it is also necessary to determine the light source of the Kinect. Take a fixed separation distance, divide the space into a number of reference planes, and store the image of the laser speckle on each plane. For example, in a space of 2m-3m, take a reference plane with a distance of 1 cm, then you will get 1015 laser speckle patterns. By comparing the captured image with the previously stored image and the cross-correlation operation, a cross-correlation image representing the spatial position of the object can be obtained. The obtained depth information is encoded according to the gray value of the image, and the gray value is positively correlated with the distance between the object and the Kinect. The higher the gray value, the larger the distance between the object and the Kinect; otherwise, the smaller is the distance.

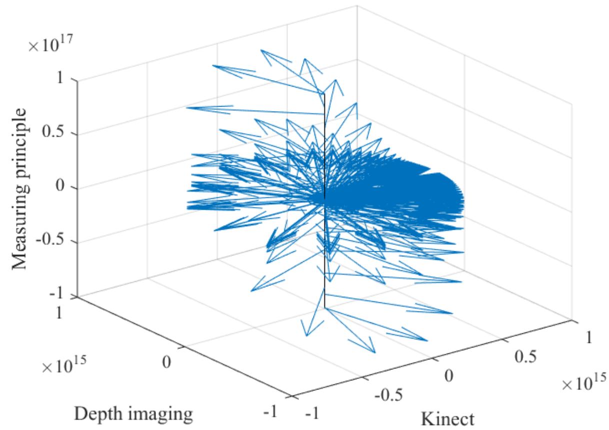


FIGURE 2. Kinect-based depth imaging measurement verification.

Kinect's infrared sensor acquires depth information for each point in the field of view, solves the position of the space object. The judgment of this infrared sensor on the external environment depends on the black and white spectrum. Black is used to represent the farthest distance and white is the closest distance. The gray between black and white represents the different position and distance information of objects in the field of view. He encodes the obtained depth information, converts it into a depth image representing the surrounding environment, generates an image stream at a rate of 30 frames/s, and reproduces the surrounding environment in real time in 3D. The human body can stand or sit in the Kinect field of view, and the human bone joint points captured in the sitting position are 10, and in both cases, the two bones can be tracked at most, and up to six users in the field of view are detected. In the human bone tracking data development kit provided by Kinect, we can control the number of human body tracking. Although it supports tracking of up to six users, only the complete bone information of two of them can be obtained. The other four users can only get their location. Here, through the secondary development of Kinect, we are able to track the situation of multiple users in the case of two users we are interested in. Through Kinect bone tracking, we can get the following data:

(1) Tracking status of related bones, including only position data in passive mode, and active mode including complete bone data (spatial position information of user joint points); (2) A unique bone tracking ID for assigning to each user in the field of view; (3) User centroid position, this value is only available in passive mode.

C. LIMB MOTION TRACKING BASED ON KINECT BONE TRACKING

The purpose of motion tracking in this paper is to control the target point in the rehabilitation game by acquiring the real-time position information of the upper limb and the hand, and realize more natural human-computer interaction between the patient and the rehabilitation game. Considering that during the rehabilitation process, in addition to patients,

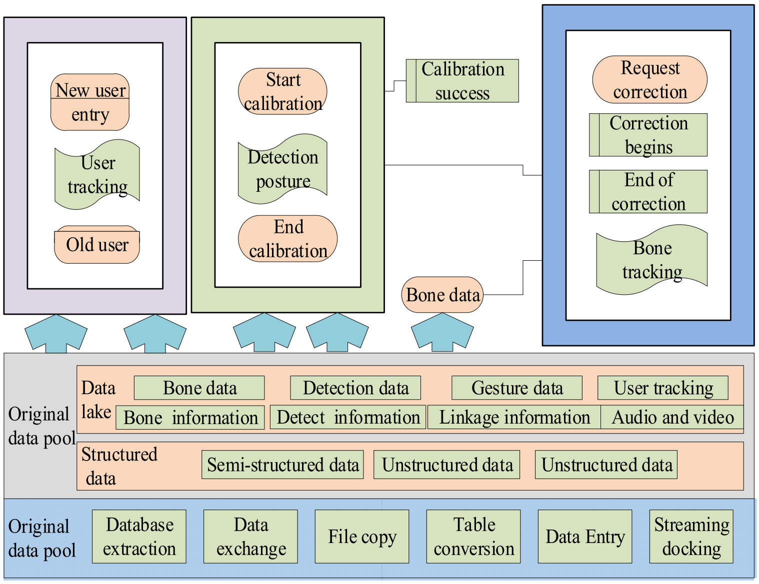


FIGURE 3. Upper limb bone tracking flowchart.

their families and physicians may also appear in Kinect's field of vision. Therefore, it is necessary to distinguish between different people appearing in the field of using different IDs to analyze each group of bone data. During the rehabilitation process, the patient can intuitively obtain the real-time tracking image obtained by Kinect, which is obtained by real-time rendering of the depth image information in a specific area of the interface, and can directly obtain the visual feedback information of the bone tracking.

Taking the right hand as an example, the bone point is first projected onto the depth image to obtain the point on the depth image corresponding to the bone point, and the point P(dx, dy) on the corresponding depth image is defined. Sw, Sh and dw, dh respectively represent the width of the bone data stream. The width and height of the high and deep data stream, and the location of the deep data stream is Dx, Dy. It can be converted by the following formula:

$$X = d_x/S_w \times d_w \quad (1)$$

$$Y = d_h/S_w \times d_h \quad (2)$$

$$x = D_x + X \quad (3)$$

$$y = D_y + Y \quad (4)$$

By using the above coordinate transformation relationship, the spatial coordinates of the individual bone points of the human body can be converted into image coordinates, and the two-dimensional bones and joint point maps are drawn on the corresponding positions of the screen.

In order to achieve natural human-computer interaction and virtual rehabilitation training between patients, real-time data of the upper limbs and hands of the human body are needed to simulate rehabilitation training. These real-time data are obtained by tracking the bone movement through the Kinect sensor. During the rehabilitation training, the patient can directly see the image interface of Kinect real-time tracking, in which the image is drawn in real time by the depth image information on the interface, thereby visually obtaining the visual feedback of the bone tracking. The development of the Kinect application is basically developed under the Windows system, mainly using the Kinect SDK as a software toolkit for application development, and also can choose to use the OpenNI open source library. OpenNI is a multi-language, cross-platform development kit that supports the Windo ws system and has many development limitations. Because this topic is developed under the Linux system, the development tool Qt combines C++ to develop Kinect bone tracking. Based on the advantages of OpenNI application open source, the human bone tracking algorithm provided by OpenNI open source library can achieve the desired effect and meet the application development requirements.

As shown in Figure 3, since Kinect tracks multiple users, more than one user can be detected in the visible range of the sensor, and the Kinect tracking system will do this in order to accurately capture the motion data of the user who needs to be trained. The method for the user to identify the identity, the calibration time is 2-3 seconds, the system will determine that the user is the trainer. When the entire program is turned on, the Kinect sensor detects the user in the visible range, and the skeleton is displayed according to the entire process. In the human bone tracking data development kit provided by Kinect, we can control the number of human body tracking. Although it supports tracking of up to six users, only the complete bone information of two of them can be obtained. The other four users can only get their location.

Kinect's infrared sensor acquires depth information for each point in the field of view, solves the position of the space object. The judgment of this infrared sensor on the external environment depends on the black and white spectrum. Black is used to represent the farthest distance and white is the closest distance. The gray between black and white represents the different position and distance information of objects in the field of view. He encodes the depth information he gets and converts it into a depth image that represents the surrounding environment.

D. KINECT-BASED UPPER LIMB REHABILITATION INTERACTIVE SYSTEM GESTURE SEGMENTATION

Gesture segmentation is to extract hand information from a complex background, and the most important feature of human hand and background is its color-one skin color. Skin color does not change significantly due to changes in hand position or size, and its robustness is better. Therefore, segmentation using hand-features of skin color features is a classic method in the field of gesture recognition. However, skin color based features are still subject to a number of external factors. For example, the change of illumination, the different skin colors of different users, and even the resolution of the images obtained by shooting, will have a certain degree of influence on the result of gesture segmentation. Therefore, it is necessary to find a stable color space model to depict the skin color features of the human hand, and to match the hardware requirements, thereby segmenting a good hand image. As a preprocessing stage for gesture recognition, there are many common methods for gesture segmentation. There are mainly methods based on increasing background constraints, methods based on threshold setting algorithms, methods based on hand contour shapes, and gesture segmentation methods based on color space. With the release of the Kinect somatosensory device, the hand image can be obtained by segmenting the gesture by setting the depth image and setting the distance threshold.

According to the principle of three primary colors, the amount of light is expressed in units of primary color light. In the RGB color space, any color Q can be mixed and mixed with different components of R, G, and B. The formula is:

$$Q = r[R] + g[G] + b[B] \tag{5}$$

The three color variables in the HSV (Hue, Saturation, Value) model are hue (H), purity (S), and lightness (V), which are common color space models. The HSV color space model is a nonlinear color model space. The model space is transformed from the RGB color space model. The parameter H represents the specific position information in the color light. The H parameter is expressed as an angle, and the three components of red, green, and blue are separated by 1200. Purity S is a proportional value ranging from 0 to 1, which represents the ratio between the purity of the selected color and the maximum purity of the color. When S=0, there is only a gray value. V indicates the brightness of the color, ranging from 0 to 1, and the formula for converting RGB to HSV is as follows:

$$V = \frac{1}{3}(R+G+B) \tag{6}$$

$$S = 1 - 3 \times \frac{Min\{R, G, B\}}{R+G+B} \tag{7}$$

$$TempH = \arccos\{\frac{(R-G)+(R-B)}{2 \times \sqrt{(R-G)^2+(R-B) \times (G-B)}} \tag{8}$$

The YUV color space model, also known as the YCbCr color space model, is also transformed from the RGB model. Where Y represents brightness, Cb represents the red portion of the light source, and Cr represents the blue portion of the light source. The formula for converting RGB to YCbCr is as follows (RGB ranges from 0 to 255):

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299, 0.587, 0.114 \\ -0.1678, -0.3313, 0.5 \\ 0.5, -0.4187, -0.0813 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 0.5 \\ 0.5 \end{bmatrix} \tag{9}$$

Although the RGB color space plays an important role in many fields, the three components of red, green and blue in the RGB color space are highly correlated, which makes the clustering of the skin color very inconspicuous. These three color components are also very different for the brightness of the light. In addition, the object used by RGB is a machine, so it is almost impossible to perform digital adjustment. In the field of skin color detection and segmentation, the color model after RGB is generally selected. The depth data information provided by Kinect is recorded in pixels. When performing gesture recognition, it is necessary to determine the distance according to the actual distance. The depth value returned by Kinect is not the actual distance, but a relative data. Therefore, the first step of gesture segmentation is to perform three-dimensional coordinate transformation to convert the position in the Kinect coordinate system into actual spatial position information.

Assuming that the Kinect sensor acquires an object whose depth value in the field of view is d, it can be calibrated and converted to obtain the corresponding depth value in real distance. Threshold setting we take a two-fold approach. The minimum value of the first threshold setting depth value is a fixed value of threshold because we default to the gesture when the user is in the position closest to Kinect. The second threshold is to add a variable threshold to adapt to the slight jitter of different users when making gestures, this jitter will cause changes in depth values. Finally, the two thresholds are merged to obtain the overall threshold of the gesture segmentation.

The "cleaning table" virtual rehabilitation environment only targets the rehabilitation exercise of the patient in the horizontal movement direction, and the virtual rehabilitation environment of putting and putting the apple can realize the movement of the upper limbs of the human body from the bottom to the top. The original intention is to intuitively In real time, the patient can be promoted in the process of rehabilitation training to achieve higher degree of freedom of training, not only can train the ability of the patient to exercise a single limb, but also use the daily movements as a training action to improve the coordination of the patient's compound rehabilitation exercise. And the "take the apple" rehabilitation environment is a complex task, designed to improve the range of motion of the upper limb flexion and extension. This rehabilitation environment provides a detailed three-dimensional motion analysis of taking apples for rehabilitation tasks, which includes several different exercises, including picking up apples, moving apples, and laying down apples, thus identifying three consecutive stages: reaching the apple position, moving the apple and placing it in the designated position, the motion analysis of these stages can give a movement with a higher logic and observable action state.

In the rehabilitation scene of taking apples, the corresponding relationship between the movement of the upper limbs and the apples in hand is one-to-one. The movement of the apple can be realized by the Kinect sensor gesture recognition. For patients who need only the rehabilitation of the affected limb alone, they can be autonomous. Control the handling of apples in the rehabilitation scene. When the hand is close to the apple, the apple is automatically grabbed, and then the virtual hand moves to the position of the fruit plate in the virtual scene, and the apple is placed in the fruit bowl. The combined movement of the upper limbs of the patient in the horizontal and vertical directions will cause the apple in the scene to rotate clockwise and then into the fruit bowl. During the rehabilitation training, the computer screen will display the hand movement data information of the patient during the rehabilitation training in real time, and provide visual feedback to the patient and the rehabilitation physician.

During the training process, the trajectory of motion, the speed of motion and the smoothness of motion are used as important indicators to evaluate the patient's athletic ability. The smoothness of the trajectory can be calculated and analyzed as follows:

$$NJS=\sqrt{\frac{1}{2}\int\left(\left(\frac{d^2x}{dt^2}\right)^2+\left(\frac{d^2y}{dt^2}\right)^2+\left(\frac{d^3z}{dt^2}\right)^2dt\right)\left(\frac{t^5}{s^2}\right)} \tag{10}$$

In the formula, NJS is the numerical representation of the smoothness of the motion trajectory, where x, y, and z represent the three-dimensional coordinates of the joint node captured by the Kinect sensor, t is the motion time of the affected limb, and s is the motion distance. It can be seen from the above formula that the smoother the motion trajectory and the shorter the motion time, the smaller the NJS value indicating the smoothness of the motion trajectory, and the better the patient's ability to control and coordinate the limb.

III. RESULTS AND DISCUSSION

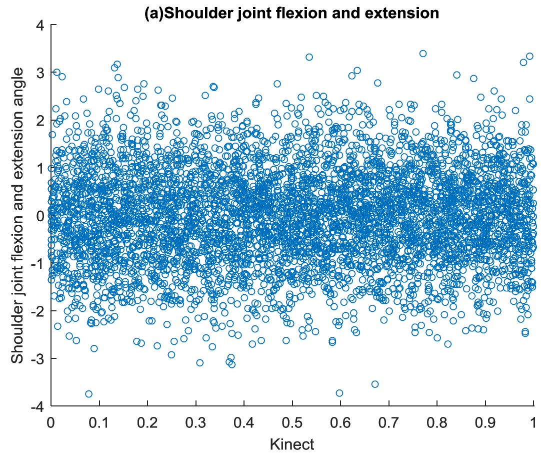
A. KINECT-BASED UPPER LIMB REHABILITATION INTERACTION

The ''wiping table'' virtual rehabilitation environment is primarily designed for repetitive horizontal movements on the same plane of the patient. The data for the exercise rehabilitation interactive data collection unit is comprehensively analyzed; the exercise rehabilitation program unit is generated; the exercise rehabilitation program generated by the exercise rehabilitation program generation unit is fed back and the exercise rehabilitation program execution unit is fed back to the execution result, thereby supervising the evaluation rule set. In the ''wipe table'' virtual rehabilitation environment, the black point stain is erased by the Kinect sensor gesture recognition controlling the square inside the virtual scene. The movement of the stain and the recovery of the upper limb of the patient is a one-to-one relationship. When the patient wipes the stain in the table environment, the stains appear randomly at different positions on the table plane. The effectiveness of the level rehabilitation training is an important indicator for the rehabilitation training of the system. It can be compared with the standard movement angle and the actual movement angle of the corresponding horizontal plane assisted by the rehabilitation robot. If the difference between the two is small, designing horizontal rehabilitation training is reasonable and feasible.

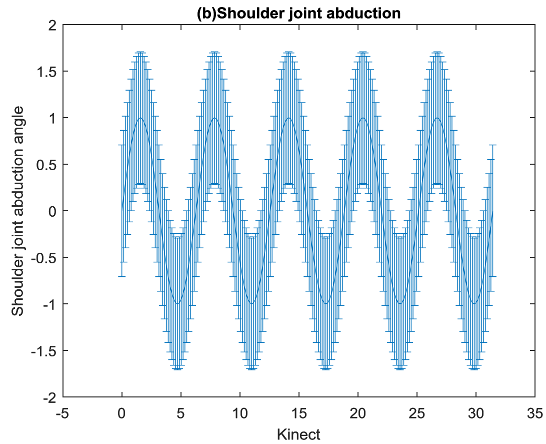
Due to the fragility of the affected limbs of patients with dyskinesia, the safety of the subject is based on the experiments conducted by the health personnel. In the experiment, the healthy subject was facing the Kinect sensor and displayed a ''cleaning table'' virtual rehabilitation environment on the computer while standing in the field of 1.5-2m. During the experiment, the rehabilitation physician first designed a set of virtual rehabilitation environment actions, obtained the standard motion angle through Kinect sensor and inverse kinematics analysis method, and then imported the exercise data into the WAMTM robotic arm control program. Then, the healthy subjects were Kinect stands within the visible range, and the right limb holds the end of the WAMTM robotic arm for active rehabilitation. When the healthy subject has excessive error at a certain moment in the rehabilitation exercise and the standard movement angle, the robot control program is triggered to perform certain exercise assistance on the subject, thereby ensuring that the subject can complete the virtual rehabilitation task.

In order to more clearly verify the effect of the level rehabilitation training, the subject's right upper limb completes four sets of movements, and the control program obtains the actual movement angle corresponding to each joint of the subject in real time, wherein the right upper limb joint coordinates acquired by the Kinect sensor The data are based on the premise of active movement consciousness, and the actual movement angle can be calculated by inverse kinematics analysis; and the reference movement angle is the standard movement angle of the rehabilitation physician. Since the normal adult brain's motor response time is between 100-200 milliseconds, the overall tracking time is delayed by I50 milliseconds to meet the actual application needs. The two motion data are plotted as shown in Figure 4. Figure (a) shows shoulder joint flexion and extension, Figure (b) shoulder joint abduction, Figure (c) shoulder joint internal rotation, and Figure (d) elbow flexion and extension, Figure (e) shows monthly joint flexion and extension.

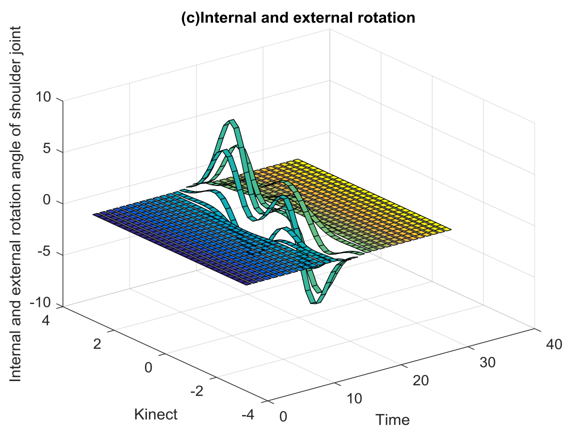
Through graph analysis, it can be seen that compared with the reference exercise data, it can be seen that the movement angles of the first two degrees of freedom of the upper limb



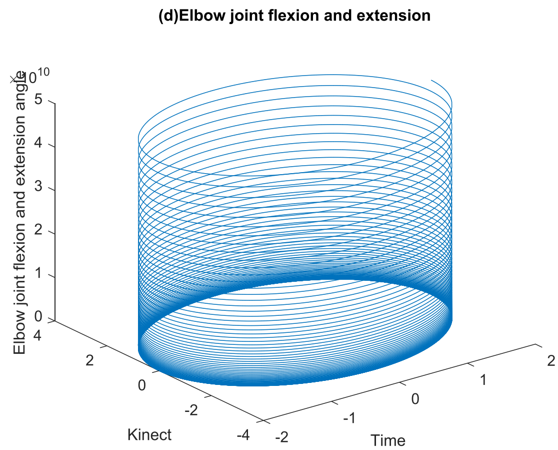
(a) Shoulder flexion and extension



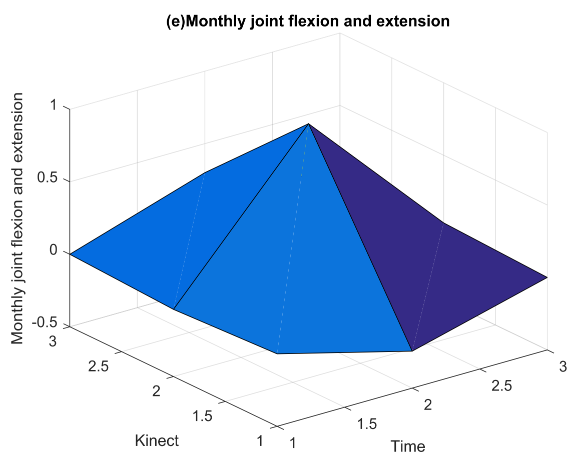
(b) Shoulder joint abduction



(c) Internal and external rotation of the shoulder joint



(d) Elbow flexion and extension



(e) Monthly joint flexion and extension

FIGURE 4. **Upper limb movement angle curve.**

of the subject are relatively close, especially the shoulder joint flexion and extension and shoulder abduction adduction, while the other two degrees of freedom are A small amount of angular error may be due to the fact that healthy subjects did not maintain other degrees of freedom during the experiment and caused some deviation in motion. Therefore, based on the

TABLE 2. Upper limb joint motion range.

Upper limb joint	Range of motion
Shoulder flexion and extension	-150~+300
Shoulder abduction	-50~180
Internal and external rotation of the shoulder joint	-90~ +15
Monthly joint flexion and extension	0—150

comparison of the range of upper limb joint motion in Table 2, the effect of upper limb motion tracking based on Kinect sensor can be seen.

B. COMPARATIVE EXPERIMENTAL ANALYSIS

We installed the Mtx inertial sensor on the elbow where the subject did not wear ULERD, on the one hand for bilateral control of the rehabilitation device, and on the other hand for measuring the change in the elbow joint angle when the ULERD side limb was not worn, and obtained the elbow Joint angle change diagram, inertial sensor, the inertial sensor mass is 0.03kg, very light and portable, can be directly attached to the wrist joint of the subject, thereby obtaining the movement information of the contralateral limb, and realizing the rehabilitation robot control. He is able to obtain information on the angular changes of the joints of the limbs, and the collected motion data information can be communicated with the computer in real time.

$$\omega(t) = \int_0^t \alpha(t) d_t \tag{11}$$

$\alpha(t)$ is the rotational acceleration at any time, $\omega(t)$ is the rotational speed at any time.

$$\theta(t) = \int_0^t \omega(t) d_t \tag{12}$$

$\theta(t)$ is the Euler angle at any time.

For the limbs wearing the ULERD rehabilitation robot side, Kinect itself can provide RGB-D ordinary color images. We use Kinect SDK for windows to model the joint points of the human body, so that it is convenient to get the coordinates of the joint points in the corresponding depth image, and then By performing three-dimensional coordinate transformation, a more stable and reliable real space coordinate can be obtained, and the joint angle can be obtained. Figure 5 is a schematic diagram of the joint angle quantization based on Kinect.

Each experimenter can get the corresponding elbow joint angle curve by doing a game. The experiment has obtained a total of 300 joint angle curves. Among them, 300 joint angle curves based on Mtx sensors are based on 300 pieces of Kinect. We fit the joint angle curve of all subjects and obtain a tracking curve of the two.

In the Figure 6, the solid line is the movement of the healthy side of the patient who is not wearing the ULERD table, and the movement of the affected side of the patient.

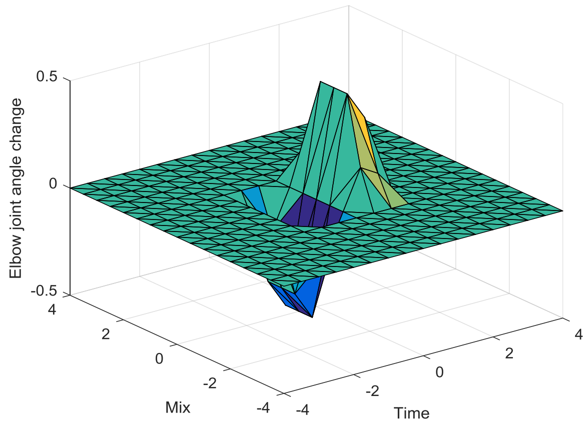


FIGURE 5. Mtx-based elbow joint angle change verification.

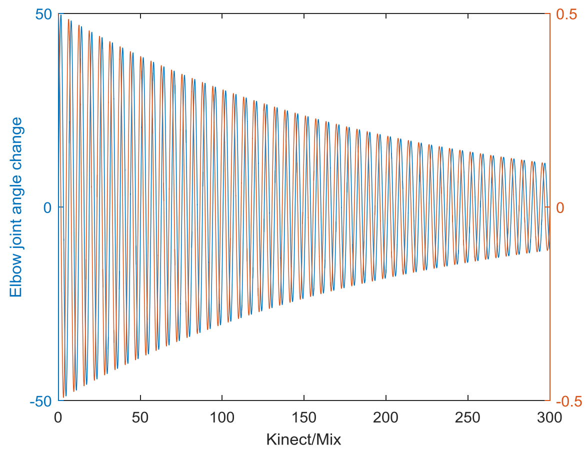


FIGURE 6. Comparison of angle curve of elbow joint based on Kinect.

The curve is the change of the joint angle when the ULERD side limb is moving, and the joint angle change when the side limb is moving. From the experimental data, the Kinect-based limb motion tracking effect is good overall, but there are still some unstable situations. When the elbow joint flexion and extension angle is large (within the range of 80-95), data jitter occurs on the curve, and the jitter range is still within the error tolerance. The overall tracking time delay is within 100 milliseconds. Considering that the normal adult's motion response time through the brain is in the range of 100-200 milliseconds, the delay time is sufficient for practical applications.

It is most common to use two-dimensional motion curves on different planes in current clinical practice, and three-dimensional joint space motion is a novel concept in clinical medicine. In order to make the rehabilitation exercise design more acceptable to clinicians, this topic has drawn three-dimensional qualitative analysis of the trajectories of the shoulders, elbows and wrists. Figure 7 to Figure 10 are three-dimensional motion trajectories of three joint nodes, and three-dimensional motion trajectories of the shoulder joint, the elbow joint and the wrist joint are separately displayed.

As shown in Figure 7, Figure 8, Figure 9 and Figure 10, the graph shows the movement trajectory of the shoulder

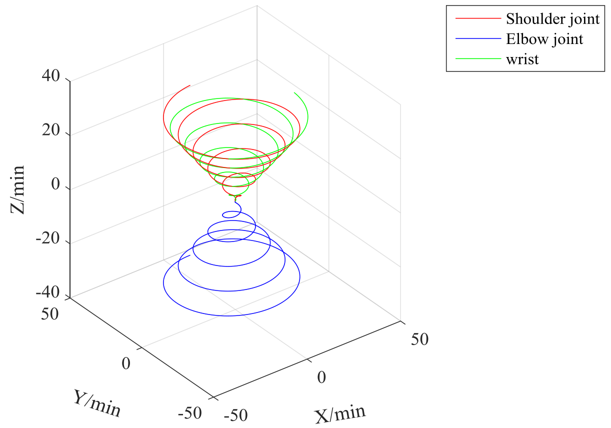


FIGURE 7. Three-dimensional three-dimension motion trajectory.

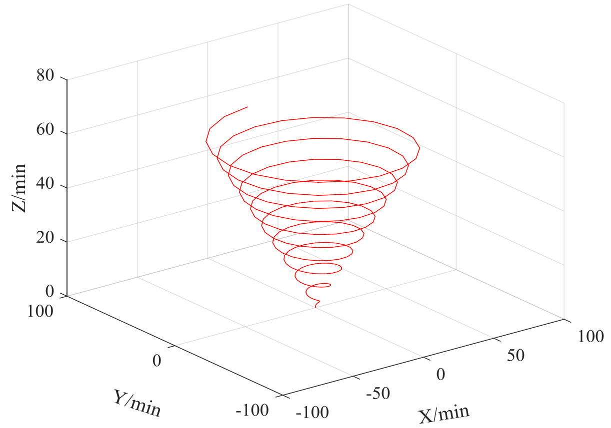


FIGURE 8. Shoulder joint movement track.

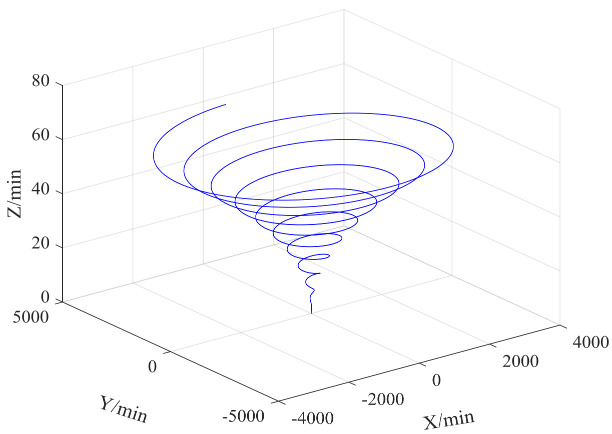


FIGURE 9. Elbow joint movement track.

joint, the elbow joint and the wrist joint with the trunk as the reference coordinate system, which can represent the movement of healthy subjects, and the three-dimensional motion trajectory from three joints. In view, the movements of the shoulders, elbows and wrists are basically the same when completing a complete cycle of exercise. Observed from the trajectory of the shoulder joint, elbow joint and wrist joint, as the upper limb gradually rises, the shoulder joint reaches a certain height first, so the shoulder and other joint movements have a smaller range of motion; when the rear arm reaches a certain level When the height of the front arm is slowly raised, the range of motion of the elbow joint becomes larger, indicating that the movement trend is gradually accelerated; the wrist joint is moving all the way until the end of the virtual rehabilitation training, in which a small part of the change occurs, and a complete motion verification curve is exercised. The range is getting larger and larger, indicating that the subject has a significant rotation when the apple is lowered in the third stage. The exercise rate and the smoothness of the trajectory were used as the evaluation indexes. Since the movement trend of the elbow joint and the wrist joint was the most obvious, the exercise data of the wrist joint of the subject was evaluated, and Table 3 is the quantitative result of the wrist and joint evaluation data of the elbow joint.

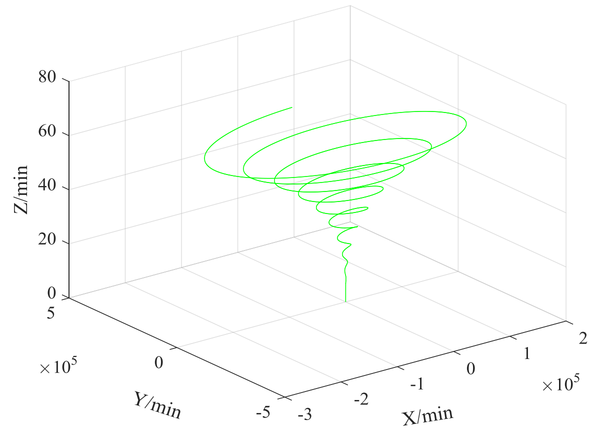


FIGURE 10. Wrist movement track.

TABLE 3. Quantification results of training evaluation data.

	Movement rate (m/s)	Smoothness of motion
Elbow joint	0.015-0.03	25.761
Wrist	0.015-0.028	119.743

The experimental results show that the participants in the experimental exercise have a stable rate of motion, and the smoothness of the trajectory of the elbow joint and the wrist joint is small, especially the elbow joint indicates that the limb's control ability and coordination are good, combined with the three joint motion three-dimensional motion trajectory, based on The tracking effect of Kinect's three-dimensional space rehabilitation exercise is good overall, reflecting the movement function of the upper limb to a certain extent, and it is helpful to carry out virtual rehabilitation training for patients in the later stage.

According to the comprehensive recovery of the patient's middle and late rehabilitation and upper limb motor function, comprehensive reinforcement training is carried out on the coordination of the shoulder, elbow and wrist of the patient, aiming at the effect from the horizontal rehabilitation exercise and the three-dimensional space rehabilitation exercise. The therapeutic effects of the virtual rehabilitation training carried out were evaluated from the ''wiping table'' movement angle and the ''take apple'' movement track respectively. Finally, the motion analysis of the two experiments shows that the two virtual rehabilitation training environments designed are feasible.

IV. CONCLUSION

This paper presents a rehabilitation assist system based on Kinect. The system consists of a rehabilitation training subsystem and a rehabilitation evaluation subsystem. The patient can complete the treatment during the rehabilitation game and give the patient and the doctor an intuitive feedback on the rehabilitation exercise, which not only enhances the patient's willingness to actively recover, but also maximizes the rehabilitation effect. It can also be a powerful basis for the evaluation of rehabilitation effects, allowing doctors to propose rehabilitation strategies to improve rehabilitation efficiency and cost. The Kinect-based moving target tracking is realized, and the tracking result can be input as a rehabilitation game platform. The method is based on the HSV color space model and the method based on the Kinect depth image setting threshold to segment the extraction gesture. Based on the hardware system and the research content of this paper, the exoskeleton upper limb rehabilitation system based on somatosensory technology is constructed. According to the basic principles of rehabilitation game design, Kinect's motion tracking technology was designed to realize the ''connection'' rehabilitation puzzle game, which was studied from three aspects: game interface design, hand movement trajectory drawing and game rule logic realization. Finally, the rehabilitation system was integrated and applied, and the bilateral rehabilitation process based on Kinect was realized. The feasibility of the interactive system was verified by comparative experiments. In the future, multiple gesture commands can be developed into the control port of rehabilitation exercise, which makes the rehabilitation process diversified and the rehabilitation training mode interesting. These play an important role in enhancing the sensory experience of the patient's rehabilitation process. The application of motion tracking and gesture recognition technology can also be studied in depth.

Due to time and objective conditions, experimental studies are healthy subjects and the sample size is small, which may affect the evaluation of the rehabilitation training system. In the future, a large number of random samples are needed for controlled experimental studies to further validate the Kinect upper limb movement interaction. The feasibility of performance evaluation of rehabilitation system, and can be combined with the assistance of rehabilitation robots to further explore the impact of applying Kinect somatosensory technology to the field of upper limb rehabilitation. The key technology research of the interactive system is not subject to the interference of illumination, background color and other factors. It has good robustness and provides a good technical basis for subsequent gesture recognition, but the application of dynamic tracking and gesture recognition technology is also In-depth research is possible. In the future, it is applied to the hand rehabilitation training in the future, and obtains more comprehensive information of patients through somatosensory equipment, etc., and becomes one of the indicators of rehabilitation evaluation, providing a more intuitive quantitative rehabilitation effect for doctor patients. we establishing a complete rehabilitation system.

REFERENCES

[1] B. Bonnechère, V. Sholukha, L. Omelina, S. Van Sint Jan, and B. Jansen, ''3D analysis of upper limbs motion during rehabilitation exercises using the kinect sensor: Development, laboratory validation and clinical application,'' *Sensors*, vol. 18, no. 7, p. 2216, 2018.

[2] K. Voon, I. Silberstein, A. Eranki, M. Phillips, F. M. Wood, and D. W. Edgar, ''Xbox Kinect based rehabilitation as a feasible adjunct for minor upper limb burns rehabilitation: A pilot RCT,'' *Burns*, vol. 42, no. 8, pp. 1797–1804, 2016.

[3] W.-W. Liao, S. M. Waller, and J. Whitall, ''Kinect-based individualized upper extremity rehabilitation is effective and feasible for individuals with stroke using a transition from clinic to home protocol,'' *Cogent Med.*, vol. 5, no. 1, 2018, Art. no. 1428038.

[4] H. Tran, P. N. Pathirana, M. Horne, L. Power, and D. J. Szmulewicz, ''Quantitative evaluation of cerebellar ataxia through automated assessment of upper limb movements,'' *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 27, no. 5, pp. 1081–1091, May 2019.

[5] H. Tannous, D. Istrate, M. C. H. B. Tho, and T. T. Dao, ''Feasibility study of a serious game based on Kinect system for functional rehabilitation of the lower limbs,'' *Eur. Res. Telemed.*, vol. 5, no. 3, pp. 97–104, 2016.

[6] C. Qin, A. Song, and C. Wu, ''Scenario interaction system of rehabilitation training robot based on Unity3D and Kinect,'' *Chin. J. Sci. Instrum.*, vol. 38, no. 3, pp. 530–536, 2017.

[7] B. Oskarsson, N. C. Joyce, and E. De Bie, ''Upper extremity 3-dimensional reachable workspace assessment in amyotrophic lateral sclerosis by Kinect sensor,'' *Muscle Nerve*, vol. 53, no. 2, pp. 234–241, 2016.

[8] N. Arman, E. Tarakci, and D. Tarakci, ''Effects of video games–based task-oriented activity training (Xbox 360 Kinect) on activity performance and participation in patients with juvenile idiopathic arthritis,'' *Amer. J. Phys. Med. Rehabil.*, vol. 98, no. 3, pp. 174–181, 2019.

[9] E. Knippenberg, J. Verbrugghe, I. Lamers, S. Palmaers, A. Timmermans, and A. Spooren, ''Markerless motion capture systems as training device in neurological rehabilitation: A systematic review of their use, application, target population and efficacy,'' *J. Neuroeng. Rehabil.*, vol. 14, no. 1, pp. 61–72, 2017.

[10] S. Cho, W.-S. Kim, N.-J. Paik, and H. Bang, ''Upper-limb function assessment using VBBTs for stroke patients,'' *IEEE Comput. Graph. Appl.*, vol. 36, no. 1, pp. 70–78, Jan. 2016.

[11] A. Rastegarpanah, M. Saadat, and A. Borboni, ''Parallel robot for lower limb rehabilitation exercises,'' *Appl. Bionics Biomech.*, vol. 2016, Apr. 2016, Art. no. 8584735.

[12] K. S. Lee, J. H. Park, and J. Beom, ''Design and evaluation of passive shoulder joint tracking module for upper-limb rehabilitation robots,'' *Frontiers Neurorobot.*, vol. 12, pp. 38–47, Jul. 2018.

[13] C. H. Su and C. H. Cheng, ''Developing and evaluating creativity gamification rehabilitation system: The application of PCA-ANFIS based emotions model,'' *EURASIA J. Math., Sci. Technol. Educ.*, vol. 12, no. 5, pp. 1443–1468, 2016.

[14] W. L. Ding, Y. Z. Zheng, and Y. P. Su, ''Kinect-based virtual rehabilitation and evaluation system for upper limb disorders: A case study,'' *J. Back Musculoskeletal Rehabil.*, vol. 31, no. 4, pp. 611–621, 2018.

[15] D. Eizicovits, Y. Edan, and I. Tabak, ''Robotic gaming prototype for upper limb exercise: Effects of age and embodiment on user preferences and movement,'' *Restorative Neurol. Neurosci.*, vol. 36, no. 2, pp. 261–274, 2018.

[16] W.-S. Kim, S. Cho, S. H. Park, J.-Y. Lee, S. Kwon, and N.-J. Paik, ''A low cost kinect-based virtual rehabilitation system for inpatient rehabilitation of the upper limb in patients with subacute stroke: A randomized, double-blind, sham-controlled pilot trial,'' *Medicine*, vol. 97, no. 25, 2018, Art. no. e11173.

[17] A.-T. Chiang, Q. Chen, Y. Wang, and M. R. Fu, "Kinect-based in-home exercise system for lymphatic health and lymphedema intervention," *IEEE J. Transl. Eng. Health Med.*, vol. 6, 2018, Art. no. 4100313.

[18] W.-S. Kim, S. Cho, S. H. Park, J.-Y. Lee, S. Kwon, and N.-J. Paik, "A low cost kinect-based virtual rehabilitation system for inpatient rehabilitation of the upper limb in patients with subacute stroke: A randomized, double-blind, sham-controlled pilot trial," *Medicine*, vol. 97, no. 25, 2018, Art. no. e11173.

[19] E. de Bie, B. Oskarsson, and N. C. Joyce, "Longitudinal evaluation of upper extremity reachable workspace in ALS by Kinect sensor," *Amyotrophic Lateral Sclerosis Frontotemporal Degeneration*, vol. 18, nos. 1–2, pp. 17–23, 2017.

[20] S. S. Esfahlani, B. Muresan, A. Sanaei, and G. Wilson, "Validity of the Kinect and Myo armband in a serious game for assessing upper limb movement," *Entertainment Comput.*, vol. 27, pp. 150–156, Aug. 2018.

[21] Y. C. Du, C. B. Shih, and S. C. Fan, "An IMU-compensated skeletal tracking system using Kinect for the upper limb," *Microsyst. Technol.*, vol. 24, no. 10, pp. 4317–4327, 2018.

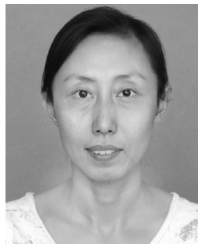
[22] B. Dehbandi, A. Barachant, D. Harary, J. D. Long, K. Z. Tsagaris, S. J. Bumanlag, V. He, and D. Putrino, "Using data from the Microsoft Kinect 2 to quantify upper limb behavior: A feasibility study," *IEEE J. Biomed. Health Inform.*, vol. 21, no. 5, pp. 1386–1392, Sep. 2017.

[23] C. K. Hun and W. K. Song, "Feedback training using a non-motorized device for long-term upper extremity impairment after stroke: A single group study," *J. Phys. Therapy Sci.*, vol. 28, no. 2, pp. 495–499, 2016.

[24] M. van den Berg, C. Sherrington, M. Killington, S. Smith, B. Bongers, L. Hassett, and M. Crotty, "Video and computer-based interactive exercises are safe and improve task-specific balance in geriatric and neurological rehabilitation: A randomised trial," *J. Physiotherapy*, vol. 62, no. 1, pp. 20–28, 2016.

[25] G. Shi, Y. He, B. Li, L. Zuo, B. Yin, W. Zeng, and F. Ali, "Analysis and modeling of wireless channel characteristics for Internet of Things scene based on geometric features," *Future Gener. Comput. Syst.*, vol. 101, pp. 492–501, Dec. 2019.

[26] D. Simonsen, M. B. Popovic, E. G. Spaich, and O. K. Andersen, "Design and test of a Microsoft Kinect-based system for delivering adaptive visual feedback to stroke patients during training of upper limb movement," *Med. Biol. Eng. Comput.*, vol. 55, no. 11, pp. 1927–1935, 2017.



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