UPPER LIMB MOTOR REHABILITATION INTEGRATED WITH VIDEO GAMES FOCUSING ON TRAINING FINGERS’ FINE MOVEMENTS

Chong Li,* Zoltán Rusák,** Yuemin Hou,* Christopher Young,* and Linhong Ji*

Abstract

Several rehabilitation robots for upper limbs have been introduced so far, and their clinical effectiveness has been reported in many studies on recovery of motor abilities in the aged or poststroke patients. These studies, however, found little evidence of improving the functional abilities of patients. Moreover, it has been identified that the main problem of robot-assisted stroke rehabilitation is the lack of motivating and versatile robot-assisted exercises. In this article, we discuss the development of a novel upper limb rehabilitation robot integrated with video games. Our solution is operated via a novel human–computer interface, which stimulates shoulder, elbow movements, and fine finger movements. It is capable to train patients with partially recovered motor control ability. The interface enables therapists to select motivating and engaging motor training exercises represented as video games and specify rehabilitation exercises for patients using a grasping and upper limb interface. The paper presents concept of this novel interface, discusses the implementation issues and demonstrates technical and practical feasibility of our concept through a number of application examples.

Key Words

Stroke, upper limb rehabilitation, video games, human–computer interface, grasping interface

1. Introduction

Approximately 16 million people experience stroke worldwide per year, of which about two-thirds survive [1]. Eighty-five percent of stroke survivors recover partially [2], yet about 35% of them are left with a major disability [3]. Among these disabilities motor deficits, especially with the impaired upper extremity, have a large influence on patients in managing everyday activities. Due to the lack of control over arm movement, patients are not capable to perform daily living activities and regain independence [5], [6].

Recent theories of neuroscience research have shown that motor training can lead to brain plasticity [7], [8]. It has been scientifically proven that after acute brain lesion, motor training has the potential to drive brain reorganization by stimulating the nerve systems [9], [10]. From neuroscience it is known that density of mechanoreceptors in the tips of fingers is the biggest [11]; therefore, training with fingers might provide more sensory stimulation to the central nervous system (CNS). However, up to now, there are only a handful of robots that can deliver therapy to the hand and fingers, as a result previous studies with these robots showed little improvement in motion control at the wrist and fingers of the stroke patients [12].

Research in stroke rehabilitation suggests that repetition, intensity, motivation, and skilled task-oriented motor training are significant factors to a quicker progress of functional recovery and may lead to use-dependent functional reorganization [13]–[15]. Recent studies have shown that physical rehabilitation performed with robotic devices can enhance arm-movement recovery following stroke [16]. In these studies, it was found that robot-aided therapy of the proximal upper limb improves short- and long-term motor control of the paretic shoulder and elbow in sub-acute and chronic stroke patients; however, no consistent improvement on functional abilities in daily living was found after robot-assisted motor training [16].

1.1 Previous Work for Robotic Rehabilitation

Video games and virtual reality (VR) applications are being developed for robotic poststroke rehabilitation for the reason that these technologies can enhance therapy compliance through motivation and engagement [17]. They are able to simulate activities of daily living, which in the end are believed to result in better recovery of functional
abilities of stroke patients. We have studied literature to explore existing solution addressing hand and finger rehabilitation of stroke patients.

Technology assisted upper-limb poststroke rehabilitation, like VR therapy, can provide engaging and task-oriented training using feedbacks to support learning of motor skills [18]. In 2008, Alamri et al. implemented task-oriented exercises based on well established and common exercises using VR and haptic technologies [19]. However, VR-based rehabilitation has many limitations such as restricted modalities and extend of interaction that is limited by the extent of interface and display technology [20]. In addition, VR lacks the flexibility in compatibility with existing solutions, and it is also time consuming and expensive to develop a virtual environment for rehabilitation exercises. That is the main reason why it did not proliferate in clinical rehabilitation. Therefore, designing more effective, efficient, and easily learnable methods for human–machine interaction is still a challenge from a human–computer interaction perspective.

Visual stimulation and feedback in video games can also improve therapy compliance by offering engaging and immersive exercises for rehabilitation training [17], in which haptic devices could be used [21]. The integration of gaming features into a rehabilitation system has been reported to enhance motivation in adult clients undergoing physical and occupational therapy following a stroke [20]. Several robots integrated with video games have been developed. Among them, InMotion2 (Interactive Motion Technologies, Inc., Cambridge, MA), is a commercial version of a robot developed specifically for upper limb neurorehabilitation [22], [23]. InMotion2 provides training sessions consisting of goal-oriented video games focused on exercising the shoulder and elbow. It also involves palm movement, such as power grasping of a handle bar, but it lacks fine finger movement exercises.

Acosta et al. [24] has compared traditional task-oriented robot training with trainings by video games. They have concluded that almost all patients unanimously choose motor training integrated with video games over traditional training due to more engaging and interesting exercises. However, they also found that the reaching distances and the motion envelop of patients achieved by the traditional reaching tasks are larger than those covered with the video games.

1.2 Our Work

In this paper, a new upper limb rehabilitation robot integrated with video games, which is operated via an easy set-up interface, is presented. The motor training requires patients to move a robotic arm to complete several tasks of engaging video games, during which patients can use several grasping postures to manipulate the robot. This new interface forces the patients to use fine finger movements in combination of large movement of the arm. The grasping interface maps its input to mouse movements and events thereby enabling the control of any type of video games that can be controlled by a computer mouse. Online and offline games simulating daily living activities, such as cooking, can be easily linked to our rehabilitation interface. By selecting appropriate games as training exercises therapist can engage patients in a playful yet useful manner. In the current implementation of our interface, the focus of the tasks of motor training is on movement coordination of the whole arm rather than strengthening of one certain muscle, with the purpose of improving the patients' functional abilities of shoulder and elbow and the fine finger movements. Moreover, it facilitates the use of various types of grasping postures to complete different tasks. The difficulties of the video games can be increased by the interface program according to the performance of the patients enabling further development of the motoric ability of patients. The goal is to achieve function recovery, independence, and early reintegration of social and domestic life for subjects with hemiplegia. In the rest of the paper, first we summarize our earlier research work, in which we have found that parallel robotic arms can provide the mechanical structure dexterity so that patients are able to manipulate the robotic arms precisely. Then, we present the design of a novel interface and its integration with video games. We also discuss a number of representative examples demonstrating the feasibility and capability of the developed technology. Finally, we present perspectives about the future work including set-up of clinical tests which aims to achieve an all-embracing assessment of the developed system.

2. Upper Limb Rehabilitation Robot Design

2.1 Upper Limb Rehabilitation System

The robot system (Fig. 1) consists of one platform, one parallel robotic arm, one computer, two servo motors (MAXON RE50, with encoder HEDL 5540, 500CPT), two controllers, and three screens. Parallel robotic arms are fixed on the platform, in which a screen is embedded. The embedded screen and the screen on the platform give visual feedback to the patients, and the other screen is for the physical therapist to control the system. Two motors, fixed under the platform, drive the robotic arm in the passive manner. In the current implementation of our interface, the focus of the tasks of motor training is on movement coordination of the whole arm rather than strengthening of one certain muscle, with the purpose of improving the patients' functional abilities of shoulder and elbow and the fine finger movements. Moreover, it facilitates the use of various types of grasping postures to complete different tasks. The difficulties of the video games can be increased by the interface program according to the performance of the patients enabling further development of the motoric ability of patients. The goal is to achieve function recovery, independence, and early reintegration of social and domestic life for subjects with hemiplegia. In the rest of the paper, first we summarize our earlier research work, in which we have found that parallel robotic arms can provide the mechanical structure dexterity so that patients are able to manipulate the robotic arms precisely. Then, we present the design of a novel interface and its integration with video games. We also discuss a number of representative examples demonstrating the feasibility and capability of the developed technology. Finally, we present perspectives about the future work including set-up of clinical tests which aims to achieve an all-embracing assessment of the developed system.

Figure 1. Upper limb rehabilitation robot based on parallel robotic arms.
mode of the robot. While in the active mode, the two motors only record the position. There are two slide rails, two sliders, and one rod (fixed with one of the sliders) in each arm (Fig. 2). The redundant degrees of freedom provide the structure with flexibility. This mechanical structure help the patients move the handle grip precisely according to their will in the active mode.

We have implemented both passive and active mode for upper limb rehabilitation robot. In passive mode, the movements of patients are achieved by the electric motors of the robotic arms, which enables rehabilitation of acute or sub-acute stroke patients whose motor control ability of the shoulder and elbow in the impaired limb need active robotic assistance. To provide static support for the impaired arm, a tray for the elbow is used in the passive mode as it is illustrated by Fig. 3. In active mode, stroke patients, who already have fairly good motor control ability at the shoulder and elbow, move voluntarily and the electric motors of the rehabilitation robot only record the position of the handle grip. Active mode enables the patients to interact with a video game that is displayed in the screens in front of them by moving the handle grip with their impaired limb to certain points and triggering mouse events by different grasping postures as required by the task of the game. This paper presents the concept of this rehabilitation interface in active mode.

2.2 Principle of the User Interface

To integrate motor training with video games, the key is to build an effective, efficient, and easily learnable human–computer interface, which enables the patient to play video games. Three challenges of the stroke patient rehabilitation user interface development were addressed.

1. The first challenge was to develop a hardware interface that enables the users to perform different types of grasping tasks.
2. The second challenge was to build a software interface that supports natural human–machine interaction so that system is able to understand which part of the hardware interface is engaged in a particular exercise.
3. Finally, the third challenge was to provide a method that facilitates physical therapists in creating training exercises, in which different types of grasping postures and grasping forces are prescribed.

The principles of the solutions to the challenges are as follows:

1. The goal of the interface is to involve training fine finger movements. Therefore, what exactly are these fine movements have to be defined first. Cutkosky et al. [25] distinguished power grasping and precision grasping as means of manipulating objects in daily activities. Humans are typically making a decision on the actual type of grasping based on the combination of task-oriented and geometric considerations play of the task at hand. If the object must be clamped, then some basic geometric considerations and the purposes are the most important factors to determine the posture of grasping. Our concept implements five different types of rehabilitation exercises as illustrated by Table 1. These five grasping postures enable the users to execute meaningful rehabilitation exercises in realistic daily life circumstances. A list of possible video games is listed in the second column of Table 1 facilitating the practice of specific grasping postures in realistic context. The fourth column illustrates how the pressure sensors are placed on the grasping interface to be able to detect the posture and strength of grasping. We use Force Sensing Resistors (FlexiForce A401, force range: 0–110 N, thickness: 0.208 mm, sensing area: 25.4 mm diameter), which can be attached to different parts of the handle grip flexibly, for the detecting contact and measure the contact forces between the hand of the user and the handle grip.

2. The second challenge is to develop software for enabling natural human–machine interaction for rehabilitation exercises. To integrate the hardware interface with video games, we have to map the detected signals of the pressure sensors of the handle grip and angle sensors of the robotic arms onto mouse movements and events. The algorithm of the software is represented by the flow chart in Fig. 4. In the first step, the cursor of the system is supposed to move as the handle grip moves. This means that the system has to track the position of the handle grip and compute the X and Y coordinate of the cursor based on the actual position of the handle grip. The tracking of the position of handle
Table 1
Different Types of Training Exercises with Fingers

<table>
<thead>
<tr>
<th>Rehabilitation Exercise</th>
<th>Video Game</th>
<th>Grasping Posture</th>
<th>Sensor Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object pick-up</td>
<td>Picking up small ingredients</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Grip strengthening</td>
<td>Grasping an apple, throwing a ball</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Finger extension</td>
<td>Quiz button (pushing down a large red button)</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>Wrist flexion</td>
<td>Gear shift in a car</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>Using a knife</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>
grip is achieved by using angular position sensors of the electric motor of the robotic arm. In the second step, the system also has to recognize which part of the handle grip is engaged for a particular rehabilitation exercise. For instance, when the task is to grasp a knife, part of the handle grip that is designed for lateral pinching is supposed to be engaged. To detect that the user is using the appropriate part of the interface and applies to proper grasping posture a mapping algorithm has been developed that recognizes grasping postures based on pressure sensors’ signals. Table 2 summarizes the principle of this mapping algorithm. The algorithm reads the analog input of all force sensors, and if signals indicate the right combination with the expected grasping posture it proceeds to the next step. To implement this mapping, we have adapted the principle of grasping posture recognition proposed by Rusak et al. [26]. In their paper, they proposed a new principle to control contact forces and to determine the grasping posture during human–virtual object interaction in VR environments. They use the penetration of a virtual hand into a virtual object as virtual sensor data to determine the applied grasping posture based on the distribution of contact patches on the hand. We have adapted this principle to a real environment by replacing the virtual sensors data by real sensor data.

In the last step, the algorithm processes the signals of pressure sensors to compute the magnitude of the grasping forces. A threshold of each force sensor is set in the program in advance. If the force exerted by the patients is higher than this threshold value, which means the finger movement has met the demand, the system triggers a mouse event expected by the video game.

3. The third challenge is to offer means for the therapist to transform their rehabilitation program into video game-based exercises. In the first implementation, an interface has been developed that enables rehabilitation therapists to select online and offline games for exercising a specific rehabilitation tasks, set the magnitude of the contact forces for the handle grip according to the patients’ recovery condition. In our future research, we want to realize a system that could detect the shape and weight of the object used in the games and the recovery level of patients, and automatically set the type of required grasping posture and magnitude of forces. Specifically, the system is supposed to set which part of the interface is engaged and the threshold value of the force sensors according to the shape and weight of the object displayed in the game. For instance, if the object in the game is long and thin, like a pencil, then a small force is required to exert on the lateral pinching part. The system is also supposed to monitor how the patients perform in the training exercise and record their training parameters, such as the magnitude of the force that the patient exerts, the speed and distance that the patient moves, and the time that the patient completes the tasks. Then the system can automatically analyze the gathered data and evaluate the performance of the patient. If the patient finishes the tasks smoothly, the system is expected to make the video game harder to develop the patient’s potentials.

<table>
<thead>
<tr>
<th>Posture/sensor</th>
<th>Sphere top</th>
<th>Sphere left</th>
<th>Sphere right</th>
<th>Cylinder left</th>
<th>Cylinder right</th>
<th>Flat left</th>
<th>Flat right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object pick up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressed</td>
<td>Pressed</td>
</tr>
<tr>
<td>Heavy grasping</td>
<td>Pressed</td>
<td>Pressed</td>
<td>Pressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gripping</td>
<td></td>
<td></td>
<td></td>
<td>Pressed</td>
<td>Pressed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finger extension</td>
<td>Pressed</td>
<td>Touched–released</td>
<td>Touched–released</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral pinching small</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressed</td>
<td>Pressed</td>
</tr>
<tr>
<td>Lateral pinching large</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressed</td>
<td>Pressed</td>
</tr>
</tbody>
</table>
2.3 Implementation of the User Interface

2.3.1 Handle Grip Design

For different game tasks, patients are required to use different ways of grasping to mimic activities of daily living. For instance, in an online cooking game shown in Fig. 5, the users are supposed to grasp and move several ingredients and a knife in the screen. Players have to put the correct ingredients in the right order into a bowl to complete the game task. For grasping the onions, the patients are required to grasp the sphere of the handle grip and exert the proper level of force to pick up and hold the onion and move it to the cutting board. To chop the onion they have to pick up the knife using the lateral pinching part of the interface of the handle grip. The design of the universal handle is shown in Fig. 6, which is rotatable to the robotic arm. For the haptic interface, we use the force sensing resistor (Fig. 7) as the force sensor, and use Arduino (Mega 2560) (Fig. 7) to read the analog input of the sensors.

2.3.2 Control Design

As the handle grip moves above one of the displays of the rehabilitation device, it offers a platform for almost direct interaction with virtual objects. To track the position of the handle grip on the display, we use the motor encoders to read the angles the motors rotate, $\theta_1$ and $\theta_2$, as shown in Fig. 8. We compute the coordinates of the handle grip based on (1).

$$\begin{align*}
    x &= \frac{800}{\sin(\theta_1 + \theta_2)} \times \sin \theta_2 \times \cos \theta_1 - 50 \\
    y &= 400 - \left( \frac{800}{\sin(\theta_1 + \theta_2)} \times \sin \theta_2 \times \sin \theta_1 - 225 \right)
\end{align*}$$

(1)
3. Rehabilitation with Video Games

This section presents some illustrative examples that enable users to complete their rehabilitation program by playing video games (Fig. 9). In the first step, physical therapist has to set the game settings for the patient. First, the physical therapist selects a proper game for the patient, and analyzes the type of objects to be grasped in the game and selects in the system the order of grasping, then sets the expected threshold values for grasping. Next, the physical therapist helps the patient sit in the chair and grasps the handle grip, which is supposed to fix the upper body of the patient because the patient should not move his or her body to complete the task. After these preparatory steps, the physical therapist can run the program and patient can start the motor training exercises. The stroke patients should use their fingers to press the right combination of the force sensors according to the task instructed by the physical therapist.

Any online and offline games, that can be controlled by a computer mouse, can be used for rehabilitation exercise. Table 3 presents some relevant examples representing daily life activities designed for children to be played on the Internet. As illustrated in Fig. 5, a cooking game requires the patients to manipulate ingredients and kitchen ware in a virtual environment. As a result, the patients have to apply many kinds of arm movements, such as humeral adduction, internal rotation, elbow flexion, forearm pronation, and wrist and finger flexion, all of which also needed in the activities of daily life. While playing the games, the patients’ functional abilities are trained.

The difficulty of the rehabilitation system integrated with video games can be easily increased to develop the patients’ potential. For example, if the pictures of the game on the screen become larger, patients need to move the handle grip to reach further on the screen. Another method is that the threshold value of the force sensor can be increased according to the performance of the patient, so that it will demand larger force from the hand. Thus the potentials of the patients can be developed.

As we discussed in the second part, users can use different grasping postures to manipulate the robot. For instance, they may grasp the cylinder or the ball on the top of the handle grip using two or three fingers. Different grasping posture will exercise different muscles of the hand, wrist, and the forearm. Consequently, several ways of grasping in the daily life can be simulated by playing the video games, in which the functional abilities of the patients will be retrained.

4. Future Work

4.1 Validation

In our future research, design of the universal handle grip design will be validated in a clinical experiment. Participants of the experiment will be required to use this prototype and the traditional method to train their hand and fingers’ movements, respectively. A structured questionnaire will be designed to compare these two solutions. Questions, such as how many points you give to each solution, or score the engagement level or motivation level when you conduct the motor training using the two methods, will be answered. Then the data collected from the experiments will be analyzed to evaluate the stimulating effects and training effectiveness of the prototype.

4.2 Quantitative Assessment System

Quantitative assessments are essential for advancing clinical rehabilitation. Correct evaluation helps prioritize treatment interventions based on specific identifiable motor and sensory deficits, and it creates appropriate short- and long-term goals for treatment based on the outcome of the scores, professional expertise, and the desires of the patient.

An evaluation system can be established based on the performance in the game process. The system can be used as a rehabilitation tool, and to quantitatively measure the patient’s progress of recovery. Quantitative evaluation could be made pre- and post-rehabilitation periods where standardized measures of motor impairment and functional ability are assessed (e.g., Fugl-Meyer Assessment, Action Research Arm Test, and Wolf Motor Function Test).
<table>
<thead>
<tr>
<th>Games</th>
<th>Game Task</th>
<th>Arm and Finger Movements</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="http://spele.nl/kebab-maken-spel/" alt="kебап 2" /></td>
<td>Grasp the objects and use the knife to slice them.</td>
<td>Shoulder and elbow movement; grip strengthening; lateral pinch.</td>
</tr>
<tr>
<td><img src="http://spele.nl/cook-show-buffalo-spel/" alt="烤火 2" /></td>
<td>Keep pressing the force sensor and move the handle grip to track the task path.</td>
<td>Shoulder and elbow movement; wrist flexion; Grip the handle cylinder to simulate stirring materials.</td>
</tr>
<tr>
<td><img src="http://spele.nl/poffertjes-spel/" alt="煎饼 2" /></td>
<td>Put the raw material on the oven, after the cake is done, move it to the plate.</td>
<td>Shoulder and elbow movement; object picking up.</td>
</tr>
<tr>
<td><img src="http://spele.nl/snooker-2-spel/" alt="斯诺克 2" /></td>
<td>Select the proper ball and make it into the bag.</td>
<td>Shoulder and elbow movement; finger extension (press the force sensor to use the proper force to hit the ball.)</td>
</tr>
</tbody>
</table>
Studies with stroke patients are still needed to verify and can be reliably controlled through this interface offering videogames. We have shown that the rehabilitation tasks demonstrated by connecting several rehabilitation tasks to ing the patients' functional abilities of the impaired arm. The focus of the tasks of motor training is on movement the patients so that it can develop the patients' potentials. by the interface program according to the performance of forces. The difficulty of the video games can be increased different types grasping postures and magnitude of grasping activities (e.g., cooking) stimulates the patients to apply different types grasping postures and magnitude of grasping forces. The difficulty of the video games can be increased by the interface program according to the performance of the patients so that it can develop the patients' potentials. The focus of the tasks of motor training is on movement coordination of the whole arm rather than muscle strengthening of one certain muscle, with the purpose of improving the patients' functional abilities of the impaired arm. The functionality and feasibility of our device has been demonstrated by connecting several rehabilitation tasks to videogames. We have shown that the rehabilitation tasks can be reliably controlled through this interface offering natural interaction with virtual objects. Further clinical studies with stroke patients are still needed to verify and validate the effectiveness of this system in rehabilitation of stroke patients.

4.3 Clinical Test
Rehabilitation of stroke patients distinguishes passive and active mode for the upper limb rehabilitation robot. Physical therapists identify the robotic rehabilitation mode for a patients based on their degree of recovery and motor ability. In the early stage post-stroke, patients are in the flaccid paralysis period, in which the passive mode is used. Currently, in real clinical environment the upper limb rehabilitation robots are used successfully mainly in early stages of rehabilitation when the passive mode is used. However, passive movement is insufficient to alter motor recovery [27]. Active engagement and movement attempts are considered to be more important than passive movement [27]. Therefore, active mode is required to deliver therapies to patients whose motor function ability of shoulder and elbow and the fine movement abilities of the fingers still needed to be improved. To validate the effectiveness of this system integrated with video games, clinical tests will be conducted with stroke patients. Furthermore, as passive mode is also implemented in this system, tests with stroke patients at the early stage of rehabilitation will also be conducted.

5. Conclusion
This article presents a novel upper limb rehabilitation robot integrated with video games, which is operated via a novel human–computer interface presented. The motor training requires patients to move the robotic arms to complete several tasks of the games, focusing on fine movement of the fingers, during which patients can use several ways of grasping to virtual objects in the games. The robotic interface has been developed in such a way that it is compatible with any type of video games that can be played with a computer mouse. The designed haptic interface together with games mimicking everyday life activities (e.g., cooking) stimulates the patients to apply different types grasping postures and magnitude of grasping forces. The difficulty of the video games can be increased by the interface program according to the performance of the patients so that it can develop the patients' potentials. The focus of the tasks of motor training is on movement coordination of the whole arm rather than muscle strengthening of one certain muscle, with the purpose of improving the patients' functional abilities of the impaired arm. The functionality and feasibility of our device has been demonstrated by connecting several rehabilitation tasks to videogames. We have shown that the rehabilitation tasks can be reliably controlled through this interface offering natural interaction with virtual objects. Further clinical studies with stroke patients are still needed to verify and validate the effectiveness of this system in rehabilitation of stroke patients.

References

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