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Development of Virtual Reality Games for Motor Rehabilitation

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Abstract

Motor rehabilitation is a long term, labor intensive and patient-specific process that requires one-on-one care from skilled clinicians and physiotherapists. Virtual rehabilitation is an alternative rehabilitation technology that can provide intensive motor training with minimal supervision from physiotherapists. However, virtual rehabilitation exercises lack of realism and less connected with Activities of Daily Living (ADLs). In this paper, we combine the virtual reality (VR) technologies and rehabilitation games to improve the effectiveness of motor rehabilitation.

***Keywords*:** Rehabilitation Game, Virtual Rehabilitation, Motion Capture

1. Introduction

Traditional rehabilitation relies on clinically-guided, focused and repetitive physical exercises. Virtual rehabilitation could provide assistive and controlled motor training to focus and intensify patient effort and attention. However, virtual rehabilitation exercises lack of visual realism and could not immerse the subject to the virtual environment. In addition, the ADL skills have not been integrated into the rehabilitation exercises. Virtual reality (VR) technology provides interactive, enjoyable, and real-life motor retraining exercises in virtual environment. In this paper, we will address the aforementioned limitations in motor rehabilitation and develop VR rehabilitation games that can be controlled by 1DOF rehabilitation devices. Furthermore, we also present a rehabilitation game that tie with the activity of daily living.

2. Related Works

A concerted effort has been made for the recent 10 years to develop multi-DOF rehabilitation robots to improve the motor function and control of upper and lower limbs after stroke. Pioneering work in rehabilitation robots is the 2-DOF (degrees of freedom) MIT-Manus robot manipulator developed by Hogan et al. [1]. MIT-Manus provides a simple target matching game to practice and assist shoulder and elbow movement. Clinical trials with MIT-Manus have shown greater gains in upper limb motor controls compared with traditional treatment. Assisted Rehabilitation and Measurement (ARM) Guide enforces a motorized linear constraint to actively assist reaching movements in different directions [2]. MIME (Mirror Image Movement Enabler) uses a splint attached with PUMA 560 robot to provide force for the upper limb [3]. The 6-DOF robot allows forearm to be placed in large range of space. The forces and torques in unimpaired

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arm are measured by a six axis sensor to guide the robot to assist or constrain the active movement of impaired arm. Recently, robotic rehabilitation research focus has evolved to multi-joints, multi-DOF exoskeleton robots for neuro-rehabilitation including, ARMin [4] and IntelliArm [5]. The exoskeleton robots provide guided external force for neuro-recovery, allowing for a more consistent training regimen and tracking of patient's progress from quantitative feedback.

Enormous efforts have been made in recent years to develop upper limb extremity VR applications for post-stroke rehabilitation [6, 7, 8, 9, 10]. A wide range of display devices have been used to create immersive virtual environment. The degree of visual realism increased from 2D flat screen display [11], stereo eyeglasses [5, 8] and HMD (Head Mounted Display) [9, 12] to the fully immersive Cave Automatic Virtual Environment [7]. 2D flat screen VR applications, such as IREX and Eye-Toy use a video camera and chroma-key technology to extract the foreground (the patient) from the background. The major limitation of IREX and Eye-Toy systems is that the captured upper limb motion is limited to two dimensions. The Head Mounted Display provides 3D immersion by projecting stereo images to the left and right display panels. Since the HMD has a narrow field of view, the stroke patient needs to move his head to look around the virtual environment. Stroke patients are inclined to move their neck and body together, and the weight of HMD imposes an additional burden to the patient. As a result, the patients are reluctant to move their head during the VR rehabilitation with Head Mounted Display [9]. In addition, 60% of subjects wearing HMD complained about Virtual Reality Induced Symptoms and Effects (VRISE) [13]. CAVE based virtual rehabilitation provides full immersion to the virtual environment and allows the patients to move freely inside the CAVE. A limited number of research efforts have been done in the area of CAVE based virtual rehabilitation. Game technologies developed for entertainment purpose have been adapted to educational, training and healthcare purpose. Serious games have drawn great interest from physicians and healthcare providers in patient treatment. However, in order to use the off-the-shelf games for rehabilitation purpose, clinicians must carefully select the most appropriate games for each patient based upon the patient's ability. To apply computer game technologies and theories for rehabilitation, appropriate game interface, rehabilitation goals, motor learning and motor control theory need to be considered.

3. Methodology of Rehabilitation Game Development

3.1 Modeling of 3D Virtual Environment

The first step in rehabilitation game development is creating virtual 3D environment and models. The 3D models and game environment in our rehabilitation games were created by the 3D modeling software (3D Max or Maya). Low polygon modeling techniques combined with texture and normal mapping will be used to reduce the total polygon counts in the game world. Figure 1 is the environment and character modeling for the archery game (Fig. 1). Archery game is preferred over the shooting game, because some patients are still under age 18. To create daily living environment, typical kitchen area is created from low polygonal models and real-world images (Fig. 2). The oven, refrigerator and dish washer models were created with 6 polygons and the Pringles chip was created with simple cylindrical shapes.

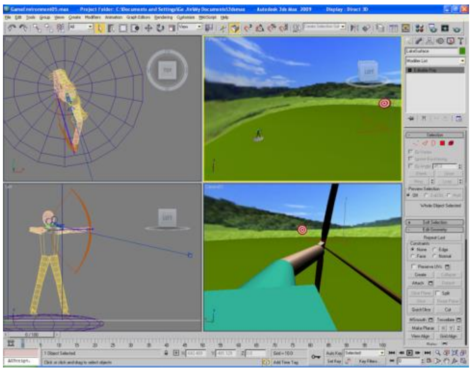

Fig. 1. Environment and character modeling

The upper limb was modeled by Maya 3D modeling tools and the vertex weight map was exported as texture image to be used by graphics programming languages. A skeletal bone structure was created inside the 3D arm model in Autodesk Maya, and the vertex weight painting was applied to the vertices influenced by the bones. With rigging and vertex weight painting, the 3D arm model can be animated by rotating the bone structures (Fig. 3).

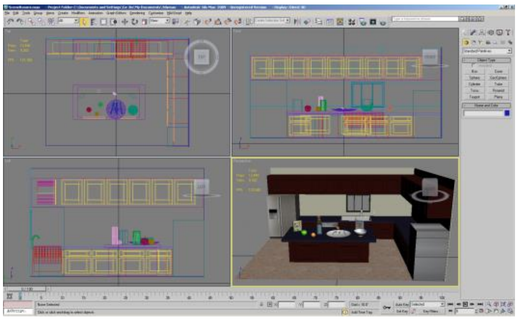

Fig. 2. Low polygonal modeling of kitchen area

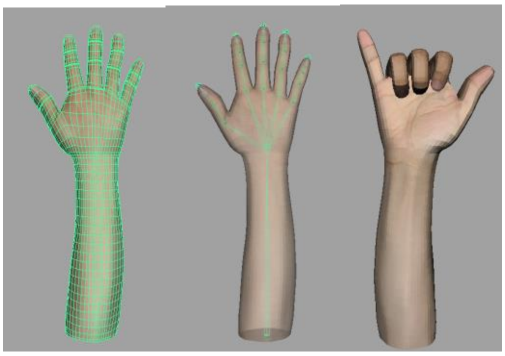

Fig. 3. 3D Arm model with skeleton structure

3.2 Collision Detection

The 3D environment and the game models (character, arm, car and etc) were imported into the graphics rendering engine. 3D objects in virtual environment are uniquely named so that the game models can interact with the virtual environment. To allow the user freely interact with 3D objects visualized in the virtual environment, the collision between the virtual 3D objects needs to be detected and resolved. We have applied hierarchical collision detection approach by combining bounding sphere and oriented bounding box (OBB). Collision detection with bounding sphere is the first step to check if the virtual objects are in the close range. If the bounding spheres are intersecting with each other, we checked the OBB of each sub-objects. The OBB is defined as 6 planes defined by the normal vector and a 3D point on the plane. We did not perform triangle-to-triangle collision, since the OBB based collision is sufficient for VR rehabilitation games.

3.3 Modeling of 3D Virtual Environment

The VR exercises that are designed for the rehabilitation purpose should consider the suitability for patients. Patients with motor dysfunction present different level disability in range of motions, speed, force and cross-coupling of joints. We designed three types of VR exercises: the coordinate control game, the dynamic game that both the coordinate control and speed and ADL exercises that aims for training activity of daily living skills.
The coordinate control games are designed to move game items to a specific coordinate using the upper limb or ankle. Archery game is developed as a fun alternative to repetitive therapy exercises for recovering foot or ankle surgery patients. The game would be controlled with a single foot/arm-activated, pressure-sensitive button or lever. The 3D archery game provides a limited supply of arrows to the player to hit a specified number of targets. Upon being struck, the target would vanish and reappear in a different location in three-dimensional space. Figure 5 is the anaglyphic rendering of the archery game.

Fig. 4. 3D Archery Game

Dynamic games are designed to train the patient with certain speed and force. The game speed and the required force will be adjusted based on the patient's level of injury. The first game is driving game, where the patient needs to move the vehicle to avoid the incoming traffic (Figure 6). The speed of vehicle is changed based on the patient's ability of movement. The second game is "whack a mole" game, where the patient needs to hit the up-rising mole using hammer (Figure 7). This game requires the coordinate control, speed, and force to hit the target.

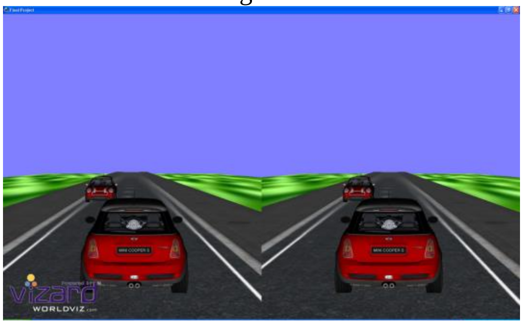

Fig. 5. Vehicle driving game

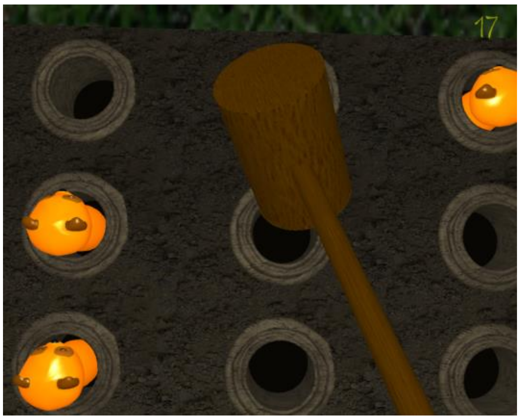

Fig. 6. Whack a mole game

One of the main objectives of rehabilitation is to improve the Activities of Daily Living (ADL). The ADL includes basic activities such as bathing, dressing, doing light housework and preparing meals. We created virtual daily living environment, where the user can reach and grasp virtual objects such as glasses, dishes, cereal boxes, and fruits with data glove. The reaching and touching tasks are created by directly applying collision detection method from the previous section. We have placed virtual 3D objects in the range of reaching and touching. The user can touch these objects one by one with the data glove. After completion of the rehabilitation exercise, the total time used for the rehabilitation exercises is displayed on the screen. The second level of rehabilitation exercise is to grasp and move virtual objects. This level of task requires the user to perform grasping motions and move the virtual object from its original position to the target position indicated by the system. The hand gesture from the data glove has been combined with collision detection method. After hand-object contact such as grasping and holding, we enforced threshold to compensate the noise signal from the data glove. The hand and object were considered as one object during the elbow and wrist movement. Figure 8 show the VR rehabilitation exercise in immersive virtual environment and Figure 9 is the screen capture of virtual reality rehabilitation exercise.

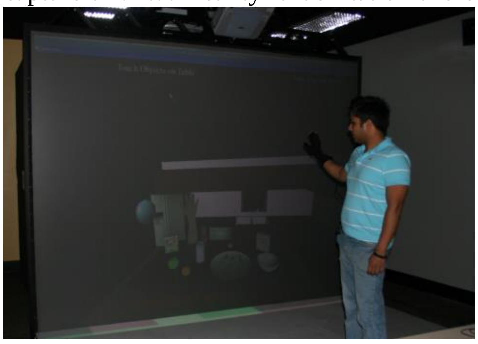

Fig. 7. Hand rehabilitation in CAVE

Fig. 8. Hand rehabilitation in CAVE

4. Conclusions and Future Works

In this paper, we have demonstrated our work of combining the VR technologies and rehabilitation games to improve the effectiveness of motor rehabilitation. We explored clinically related game development for robotic rehabilitation in a real-life context. This clinically relevant approach will ensure that the technical developments are not only based upon the engineering foundation, but also applicable to the improvement of the quality of our life. The VR based rehabilitation system developed in this paper will provide more practical alternative opportunities for the patients to take rehabilitation therapy. The increased immersion in virtual environment and enhanced visual realism will motivate the users to perform rehabilitation tasks. Although, the proposed research has been focused on 1DOF rehabilitation devices, the generality of the research can be applied to the multi-DOF rehabilitation devices. For the future work, we want to identify the key elements that stimulate the motor function recovery in rehabilitation using virtual reality based robotic rehabilitation. The proposed VR rehabilitation games could also be applied to the home based tele-rehabilitation.

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