Development of Virtual Reality Games for Motor Rehabilitation

G.Jin[1], K.Jiang[1] and S.Lee[2]
[1]Department of Computer Information Technology and Graphics, Purdue University Northwest, Hammond, IN, USA.
[2]Department of Business Intelligence, CHA University, Seoul, South Korea.
ge.jin@pnw.edu

***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 Livings. In this paper, we present six Virtual Reality games that we developed for 5DT data glove, 1-DOF IntelliStretch robot and Xbox Kinect to improve the accessibility of motor rehabilitation.**

***Index Terms*— Motion Capture; Rehabilitation Game; Virtual Rehabilitation.**

I. INTRODUCTION

Traditional rehabilitation relies on clinically guided, focused and repetitive physical exercises. Unassisted repetitive exercise is effective for persons with partial motor deficits, but guided-force training is required for more severely impaired patients [1]. Anisotropic weakness of muscle groups and "learned non-use phenomenon" are key reasons of substantial motor control disorder. 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 Activities of Daily Living (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 address the aforementioned limitations in motor rehabilitation and develop VR rehabilitation games that can be controlled by 5DT data glove, 1-DOF rehabilitation robot or Xbox Kinect. Furthermore, we also present a rehabilitation game that is tied with the activity of daily livings.

II. RELATED WORKS

A concerted effort has been made in the recent 20 years to develop multi-DOF rehabilitation robots to improve the motor function and control of the upper and lower limbs. Pioneering work in rehabilitation robots is the 2-DOF (degrees of freedom) MIT-Manus robot manipulator developed by Hogan et al. [2]. MIT-Manus provides a simple target matching game to practice and assist shoulder and elbow movement by constraining the patient’s hand motion in the horizontal plane. Clinical trials with MIT-Manus have shown greater gains in the upper limb motor controls compared with the traditional treatment. Assisted Rehabilitation and Measurement (ARM) Guide enforces a motorized linear constraint to actively assist the reaching movements in different directions [3]. However, the statistical significance of robot rehabilitation in assisted active movement has not been demonstrated [4]. MIME (Mirror Image Movement Enabler) uses a splint attached with PUMA 560 robot to provide force for the upper limb [5]. The 6-DOF robot allows the forearm to be placed in a large range of space. The forces and torques in unimpaired arm were measured and used to guide the robot to assist or constrain the active movement of the impaired arm. Recently, the focus of robotic rehabilitation research has shifted to multi-joints, multi-DOF exoskeleton robots for neuro-rehabilitation including 7-DOF Salford Exoskeleton [6], and 5-DOF L-Exos [7]. ARMin is a 6-DOF semi-exoskeleton robot equipped with position and force sensors to assist, enhance, evaluate, and document neurological and orthopedic rehabilitation [8]. PUPERT is a 4-DOF wearable exoskeleton robot to assist repetitive therapy for the upper extremity [9]. IntelliArm is a 10 DOF whole arm exoskeleton robot with 6 axis force sensors at shoulder, elbow, wrist joints and one torque sensor for hand open/closure [10]. MIMO (Multi-input multi-output) nonlinear modeling of multi-joint system and parameter estimation have been proposed to evaluate biomechanical changes at the shoulder, elbow and wrist during passive and voluntary upper limb movement [11]. Similar to the upper limb, LokoMat, LOPES [12] and ALEX [13] exoskeleton robots have been used for lower limb rehabilitation, and Rutgers Master II exoskeleton for hand and finger rehabilitation [14]. 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 effort was made in recent years to develop upper limb extremity VR applications for post-stroke rehabilitation [15-19]. Various methods were used to capture the motion of upper limb extremity, including Rutgers Master II [14, 19], Body-Powered-Orthosis glove [20], 5DT Dataglove, Cyberglove, Wii remote and optical motion tracker. A wide range of display devices were adopted to create immersive virtual environment. The degree of visual realism increased from 2D flat screen display [21], stereo eyeglasses [17, 22] and HMD (Head Mounted Display) [18, 23] to the fully immersive Cave Automatic Virtual Environment [16]. 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) [24]. 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 has been conducted in the area of CAVE based virtual rehabilitation. Exergaming is a new genre of video game that requires the game players to actively move their body part during the game. DDR (Dance Dance Revolution), EyeToy Kinetic and Wii Fitness games are exergames that can improve the game player’s dancing and physical fitness skills. 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, researchers need to consider appropriate game interface, rehabilitation goals, motor learning and motor control theory.

III. Material and Methods

A. User Interaction Hardware Devices

Virtual rehabilitation games were developed on various user interaction devices. The activity of daily living rehabilitation exercise was developed for CAVE virtual environment using 5DT data glove and Intersense motion tracker. 5DT data glove is a hand tracking device that can measure average flexion and abduction angle of five fingers and communicate with computer through the COM port. To accurately measure the reaching and grasping motion in the upper limb extremity, we tracked the finger flexions and abductions as well as the position and orientation of the dorsum manus (back of hand).

Figure 1: 5DT data glove for hand motion tracking

Figure 2: Intersense IS-900 position tracker

The 5DT data glove (Figure 1) has been be used to track the finger flexion/abduction, and the acoustic motion tracker (Intersense IS-900) (Figure 2) was used to track the position and orientation of the dorsum manus. The length of finger and the distance between the finger-tip and the sensor on the dorsum manus was also measured and calibrated. The hardware conflict between the data glove and the motion tracking device was resolved by rewriting VRJuggler hardware initialization code. The ultrasonic motion tracker has 3-5mm position tracking accuracy and 1 degree in yaw/pitch/roll orientation. While, the accuracy of data glove in flexion and abduction angle is 1 degree. After calibration, the motion of the hand and finger was tracked in real-time in the CAVE virtual environment.

Figure 3: IntelliStretch for elbow joint

Figure 4: IntelliStretch for ankle joint

IntelliStretch is a 1-DOF robotic rehabilitation device that can stretch the ankle or elbow joint of the patient with neurological impairment (Figure 3 and Figure 4). IntelliStretch provides passive stretching by intelligent control and voluntary movement exercise by virtual reality games. IntelliStretch motivates patients to do more active exercises. 3D VR Archery game, Stereoscopic Vehicle Driving game, and Whack a Mole game were developed for IntelliStretch 1-DOF rehabilitation robot.

Figure 5: Microsoft Kinect motion sensor

Standalone Kinect 2.0 sensor is a motion sensing input device that was produced by Microsoft for Xbox One video game consoles and Microsoft Windows PCs. Based on a wide-angle time-of-flight camera, it allows users to control and interact with game console or computer through a natural user interface using gestures. 3D dancing game and soccer game were developed for Kinect sensor using Unity3D game engine.

B. Modeling of Virtual Game Environment

The first step in rehabilitation game development is to create virtual environment and 3D models. The 3D models and game environment in our rehabilitation games were created using 3D modeling software such as 3D Max or Maya. Low polygon modeling techniques combined with texture and normal mapping have been be used to reduce the total polygon counts in the game world.

To model and rig upper limb model, three photos of right arm were taken from top, bottom and side camera views. These photos were taken as reference images to accurately reconstruct upper limb 3D model using box-modeling technique in Autodesk Maya. Subdivision proxy technique was used to create high-polygonal smoothed mesh from low-polygonal model. Figure 6 shows three reference photos taken from a right arm and Figure 7 shows the low polygon model created from the reference images.

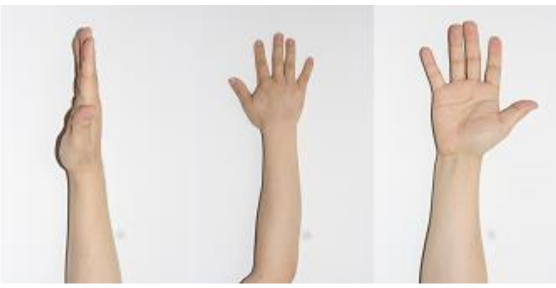

Figure 6: Reference photos for 3D upper limb modeling

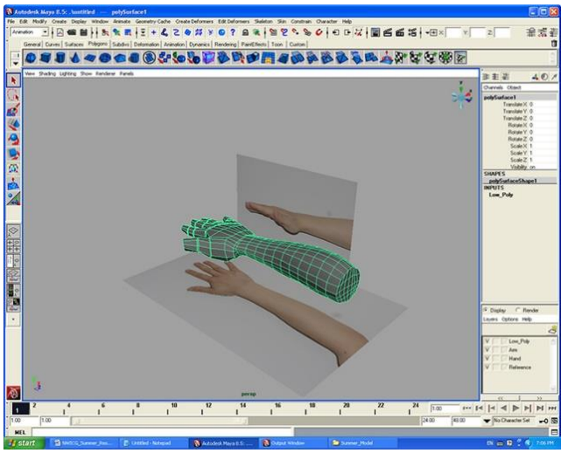

Figure 7: Low-polygon modeling of upper limb

To create photorealistic hand model, the 3D model from the previous stage was unwrapped in UV texture coordinate to map the texture from photos. The UVW Unwrap tool in 3D Studio Max was used to unwrap the polygons to match with the real photos. A skeletal bone structure was created inside the 3D arm model using 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 (Figure 8). For the interactive VR applications, the vertex weight maps were exported as a texture map for each bone. Open Scene Graph (OSG) SDK can read these vertex weight maps and apply weight to each vertex influenced by the bone structure (Figure 9).

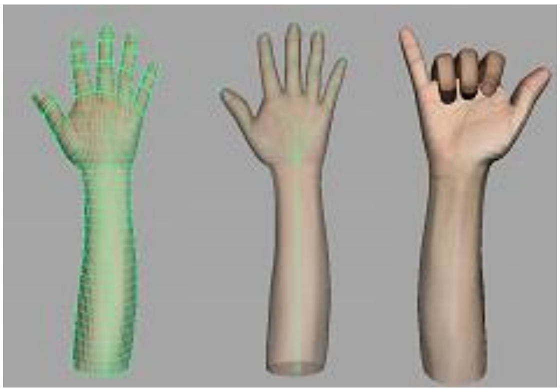

Figure 8: 3D upper limb model with skeleton structure

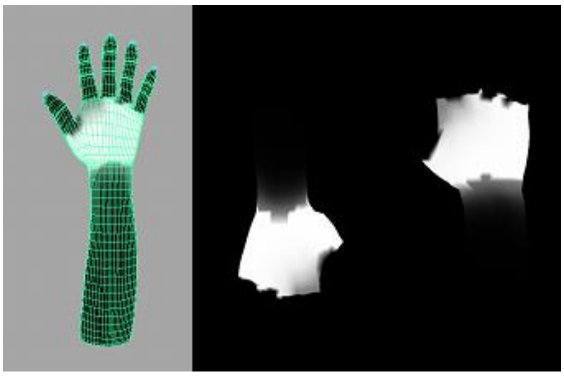

Figure 9: Vertex weight and exported vertex weight map

Figure 10 is a screen capture of environment and character modeling for the 3D archery game. Archery game was preferred over the shooting game, because some patients are still under the age of 18. To create daily living environment, a typical kitchen area was created from low polygonal models and real-world images (Figure 11). The oven, refrigerator and dishwasher models were created with polygonal shaped box and the Pringles chip was created with simple cylindrical shapes.

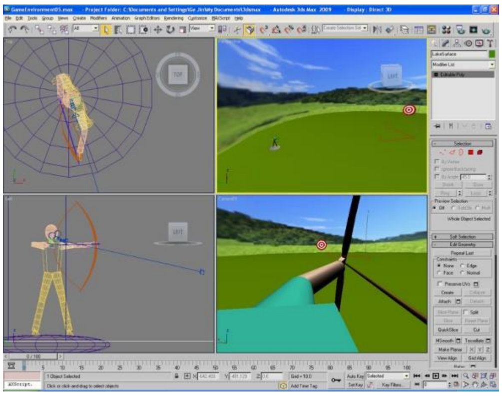

Figure 10: Environment and character modeling of 3D archery game

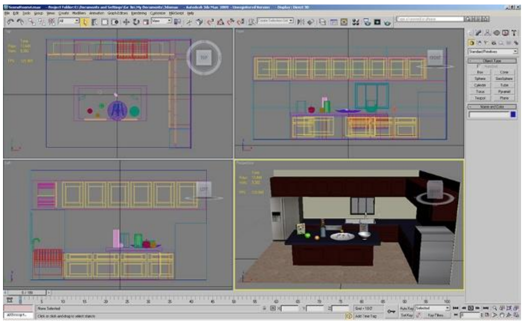

Figure 11: Low-polygon modeling of kitchen area

The 3D character for the soccer game was created from Adobe Fuse software (Figure 12). Instead of modeling a 3D character from scratch, Adobe Fuse allows a user to assemble a 3D character from more than 20 base characters and further customize it into a unique character with different weight, height, skin tones, and texture. The 3D character from Adobe Fuse was transferred seamlessly into Adobe Mixamo software. Mixamo will automatically rig the 3D character and export the 3D character into Unity3D game engine. The soccer goal post and the stadium were modeled using 3D Max software and imported into the Unity3D game engine.

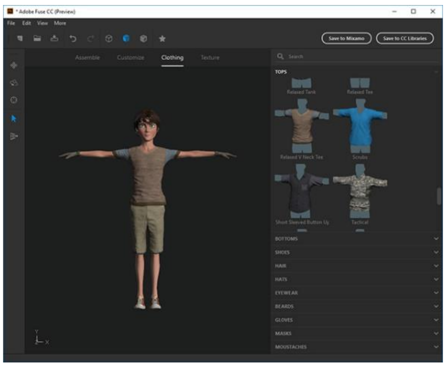

Figure 12: 3D character modeling and customization in Adobe Fuse

C. Virtual Reality Rehabilitation Game Development

The VR games designed for the rehabilitation purpose should consider the suitability for patients. Patients with motor dysfunction present different level of disability in range of motions, speed, force and cross-coupling of joints. We designed three types of VR games: ADL games with 5DT data glove, coordinate control games with 1-DOF rehabilitation robot, and 3D dancing and sport games with Xbox Kinect.

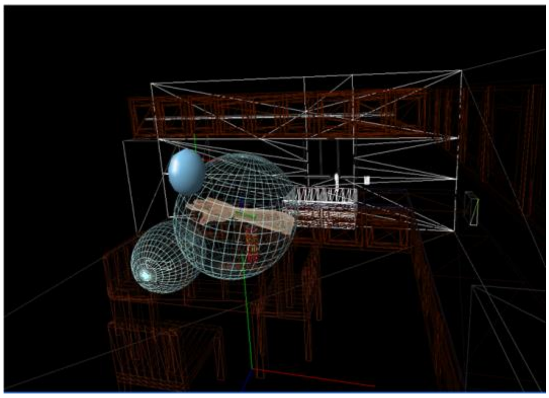

Figure 13: Collision detection with bounding spheres

To allow the user freely interacts with 3D objects in the virtual environment, the collision between the fingers/hand and the virtual 3D object needs to be detected and resolved. We have applied hierarchical collision detection approach by combining bounding sphere (Figure 13) and oriented bounding box (OBB). Collision detection with bounding sphere is the first step to check if the hand and virtual object are in the close range. If the bounding spheres are intersecting with each other, we checked the OBB of each finger joint. The OBB was defined as four planes bounded by the normal vector and a 3D point on the plane. We ignored the bounding planes between two joints, since those planes will not collide with 3D object. We did not perform triangle-to-triangle collision, since the OBB based collision detection is sufficient for non-haptic VR applications.

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 were 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 will be 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 and the collision detection method were combined to allow users to move a virtual 3D object to a new location. 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 14: 3D upper limb rehabilitation game for ADL

The 1-DOF coordinate control games were designed to move game items to a specific coordinate using the upper limb or ankle. Archery game was developed as a fun alternative to repetitive therapy exercises for recovering foot or ankle surgery patients. The game was controlled by 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. If it was hit, the target would vanish and reappear at a new location in three-dimensional space. Figure 15 is the anaglyphic rendering of the archery game.

Figure 15: Anaglyphic 3D virtual reality archery game

Dynamic 1-DOF robotic games were designed to train the patient with certain speed and force. The game speed and the required force were adjusted based on the patient's level of injury. The first game is the driving game, where the patients need to move the vehicle to avoid the incoming traffic (Figure 16). The speed of vehicle will change based on the patient's ability of movement. The second game is the "whack a mole" game, where the patient needs to hit the up-rising moles using a hammer (Figure 17). This game requires the coordinate control, speed, and force to hit the target.

Figure 16: Stereoscopic view of vehicle driving game

Figure 17: 3D Whack-a-Mole game

The 3D environment of Kinect game was modeled using Autodesk 3D Max and Maya software. Several loyalty-free 3D assets that are related with Kinect avatar control was acquired from Unity Marketplace. Figure 18 shows the Kinect soccer rehabilitation game in Unity3D game engine environment and Figure 19 shows the Kinect dancing rehabilitation game in Unity3D game engine environment.

Figure 18: Modeling of soccer game in Unity3D game engine

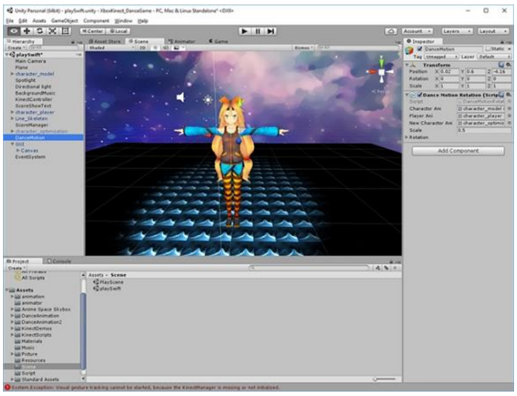

Figure 19: Kinect dancing rehabilitation game in Unity3D game engine

The Kinect Dancing game and Soccer game were created on top of the Microsoft Kinect for Windows SDK. Unity3D game engine provides free scripts such as KinectManager and AvatarController (Figure 20). Scripts from Unity3D Asset store were used to control and animate the 3D characters in Dancing and Soccer games. The behaviors of the Kinect game characters and other dynamic objects were implemented by programming Unity C# script for each 3D character and dynamic assets in the game environment.

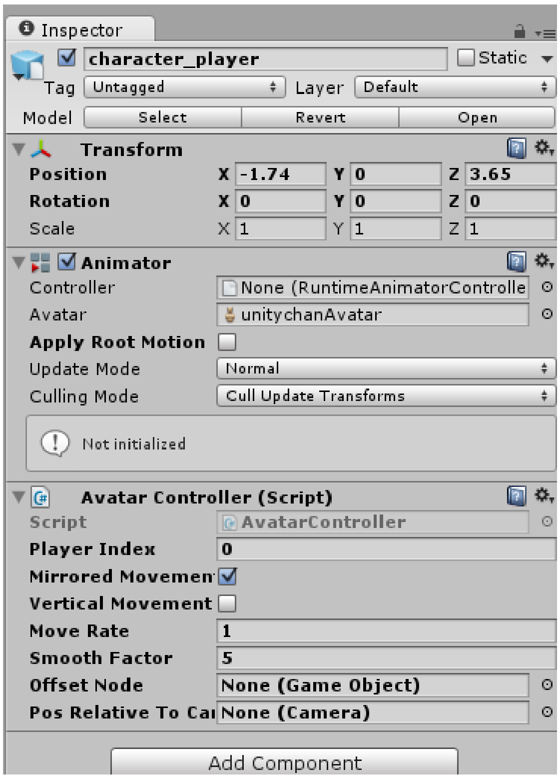

Figure 20: Unity3D avatar controller script

IV. RESULTS

In this section, we will present and compare the development results of the aforementioned rehabilitation games.

Figure 21 shows the real-time hand deformation and collision detection results of ADL rehabilitation game, and Figure 22 shows the VR rehabilitation game for upper limb motor rehabilitation in the CAVE Virtual Environment.

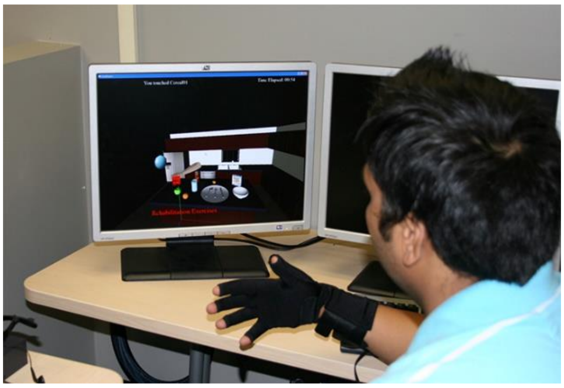

Figure 21: Real-time hand deformation using 5DT data glove

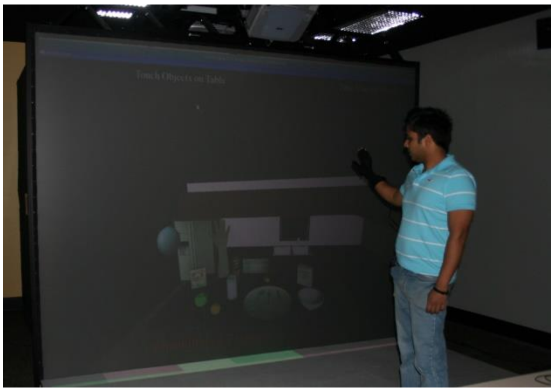

Figure 22: Upper limb motor rehabilitation game in CAVE virtual environment

Figure 23 shows the compiled game screen of Kinect dancing rehabilitation game, and Figure 24 shows the configuration of Kinect motion sensor and game laptop during the rehabilitation game play.

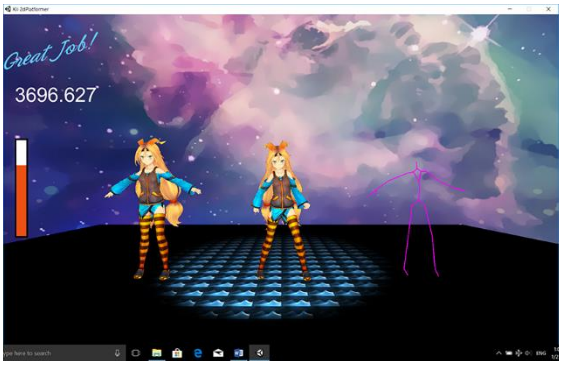

Figure 23: Kinect dancing rehabilitation game

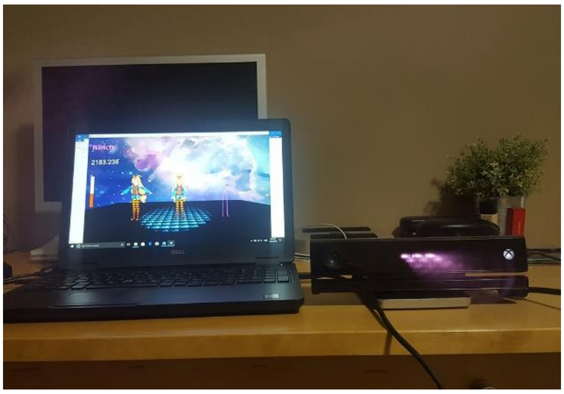

Figure 24: Configuration of Kinect sensor and laptop in dancing game

Figure 25: Kinect soccer rehabilitation game

Figure 25 shows the compiled game screen of Kinect soccer rehabilitation game, and Figure 26 shows the configuration of Kinect motion sensor and game laptop during the soccer rehabilitation gameplay.

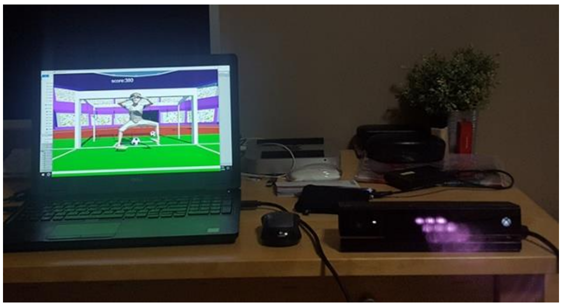

Figure 26: Configuration of Kinect sensor and laptop in soccer game

Table 1 compares three types of VR rehabilitation games developed in this paper. The rehabilitation games were compared based on graphical display devices, game development engine, degrees of freedom of motion, motion-tracking devices, force feedback capability, and connectivity to Activity of Daily Livings.

Table 1
Comparisons of Developed VR Rehabilitation Games

	Upper Limb Rehab Game	1-DOF Robot Games	Kinect Games
Display	CAVE	Desktop monitor	Desktop monitor
Game Engine	Open scene graph	Open scene graph	Unity
Degree of Freedom	6-DOF with hand motion	1-DOF	6-DOF with multiple bone joints
Tracking	Intersense-900	Intelli-Stretch	Kinect
Activity of Daily Living	Yes	No	No
Force Feedback	No	Yes	No

V. 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 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 focused on 5DT data glove, 1-DOF rehabilitation devices, and Kinect motion sensor, the generality of the research can be applied to various 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 be applied to the home based tele-rehabilitation.

ACKNOWLEDGMENT

Authors want to thank GeYang Xie, Guoheng Chen, Jerry Dekker, Site Guo and David Helton in developing game contents. This work was supported in part by Northwest Indiana Computational Grid Project from the US Department of Energy.

REFERENCES

[1] P. S. Lum, C. G. Burgar, P. C. Shor, M. Majmundar, and M. Van der Loos, "Robot-Assisted Movement Training Compared with Conventional Therapy Techniques for the Rehabilitation of Upper-limb Motor Function after Stroke", Arch Phys Med Rehabil, Vol. 83, No. 7, 2002, pp. 952-959.

[2] N. Hogan, H. I. Krebs, J. Charnnarong, P. Srikrishna, and A. Sharon, "MIT-MANUS: a Workstation for Manual Therapy and Training I", in Proceedings IEEE International Workshop on Robot and Human Communication, Tokyo, 1992, pp. 161-165.

[3] D. J. Reinkensmeyer, L. E. Kahn, M. Averbuch, A. McKenna-Cole, B. D. Schmit, and W. Z. Rymer, "Understanding and Treating Arm Movement Impairment after Chronic Brain Injury: Progress with the ARM Guide", J Rehabil Res Dev, Vol. 37, No. 6, 200, pp. 653-662.

[4] G. Kwakkel, B. J. Kollen, and H. I. Krebs, "Effects of Robot-Assisted Therapy on Upper Limb Recovery after Stroke: a Systematic Review", Neurorehabil Neural Repair, Vol. 22, No. 2, 2008, pp. 111-121.

[5] R. Riener, T. Nef, and G. Colombo, "Robot-Aided Neurorehabilitation of the Upper Extremities", Med Biol Eng Comput, Vol. 43, No. 1, 2005, pp. 2-10.

[6] N. G. Tsagarakis and G. C. Darwin, "Development and Control of a "Soft-Actuated" Exoskeleton for Use in Physiotherapy and Training", Autonomous Robots, Vol. 15, No. 1, 2003, pp. 21-33.

[7] A. Montagner, A. Frisoli, L. Borelli, C. Procopio, M. Bergamasco, M. C. Carboncini, and B. Rossi, "A Pilot Clinical Study on Robotic Assisted Rehabilitation in VR with an Arm Exoskeleton Device", in IEEE International Conference on Virtual Rehabilitation, Venice, Italy, 2007, pp. 57-64.

[8] T. Nef, M. Mihelj, and R. Riener, "ARMin: a Robot for Patient-Cooperative Arm Therapy", Med Biol Eng Comput, Vol. 45, No. 9, 2007, pp. 887-900.

[9] M. Balasubramanian, B. Shepard, E. Koeneman, J. Koeneman, and J. He, "RUPERT: An Exoskeleton Robot for Assisting Rehabilitation of Arm Functions", in IEEE Virtual Rehabilitation, Vancouver, BC, Canada, 2008, pp. 163-167.

[10] H. S. Park, Y. P. Ren, and L. Q. Zhang, "IntelliArm: An Exoskeleton for Diagnosis and Treatment of Patients with Neurological Impairments", in 2nd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics, Scottsdale, AZ, USA, 2009, pp. 109-114.

[11] L.Q. Zhang, H. S. Park, and Y. P. Ren, "Shoulder, Elbow and Wrist Stiffness in Passive Movement and Their Independent Control in Voluntary Movement Post Stroke", in IEEE International Conference on Rehabilitation Robotics (ICORR 2009), Kyoto, Japan, 2009, pp. 805-811.

[12] R. Ekkelenkamp, J. Veneman, and H. van der Kooij, "LOPES: A Lower Extremity Powered Exoskeleton", in 2007 IEEE International Conference on Robotics and Automation, Roma, Italy, 2007, pp. 3132-3133.

[13] S. K. Banala, S. H. Kim, S. K. Agrawal, and J. P. Scholz, "Robot Assisted Gait Training with Active Leg Exoskeleton (ALEX)", IEEE Trans Neural Syst Rehabil Eng, Vol. 17, No. 1, 2009, pp. 2-8.

[14] A. S. Merians, D. Jack, R. Boian, M. Tremaine, G. C. Burdea, S. V. Adamovich, M. Recce, and H. Poizner, "Virtual Reality Augmented Rehabilitation for Patients Following Stroke", Phys Ther, Vol. 82, No. 9, 2002, pp. 898-915.

[15] J. C. Stewart, S. C. Yeh, Y. Jung, H. Yoon, M. Whitford, S. Y. Chen, L. Li, M. McLaughlin, A. Rizzo, and C.J. Winstein, "Intervention to Enhance Skilled Arm and Hand Movements after Stroke: A Feasibility Study using a New Virtual Reality System", J Neuroeng Rehabil, Vol. 4, No. 21, 2007, pp. 1-6.

[16] A. Y. Dvorkin, R. V. Kenyon, and E. A. Keshner, "Reaching within a Dynamic Virtual Environment", J Neuroeng Rehabil, Vol. 4, No. 23, 2007, pp. 1-4.

[17] S. Subramanian, L. A. Knaut, C. Beaudoin, B. J. McFadyen, A. G. Feldman, and M. F. Levin, "Virtual Reality Environments for Post-stroke Arm Rehabilitation", J Neuroeng Rehabil, Vol. 4, No. 20, 2007, pp. 1-5.

[18] S. Subramanian, C. Beaudoin, and M.F. Levin, "Arm Pointing Movements in a Three Dimensional Virtual Environment: Effect of Two Different Viewing Media", Conf Proc IEEE Virtual Rehabilitation, Vancouver, BC, 2008, pp. 181-185.
[19] D. Jack, R. Boian, A. S. Merians, M. Tremaine, G. C. Burdea, S. V. Adamovich, M. Recce, and H. Poizner, "Virtual Reality-enhanced Stroke Rehabilitation", Neural Systems and Rehabilitation Engineering, IEEE Transactions on, Vol. 9, No. 3, 2001, pp. 308-318.
[20] X. Luo, T. Kline, H. Fischer, K. Stubblefield, R. Kenyon, and D. Kamper, "Integration of Augmented Reality and Assistive Devices for Post-stroke Hand Opening Rehabilitation", Conf Proc IEEE Eng Med Biol Soc, Shanghai, 2005, pp. 6855-6858.
[21] M. S. Cameirao, S. Bermudez i Badia, E. D. Oller and P. F. M. J. Verschure, "Using a Multi-task Adaptive VR System for Upper Limb Rehabilitation in the Acute Phase of Stroke", 2008 Virtual Rehabilitation, Vancouver, BC, 2008, pp. 2-7.
[22] J. J. Chang, W. L. Tung, W. L. Wu, M. H. Huang, and F. C. Su, "Effects of Robot-aided Bilateral Force-induced Isokinetic Arm Training Combined with Conventional Rehabilitation on Arm Motor Function in Patients with Chronic Stroke", Arch Phys Med Rehabil, Vol. 88, No. 10, 2007, pp. 1332-1338.
[23] J. Broeren, K.S. Sunnerhagen, and M. Rydmark, "A Kinematic Analysis of a Haptic Handheld Stylus in a Virtual Environment: A Study in Healthy Subjects", J Neuroeng Rehabil, Vol.4 No. 13, 2007, pp. 1-8.
[24] S. V. Cobb, S. Nichols, A. Ramsey, and J. R. Wilson, “Virtual Reality-induced Symptoms and Effects (VRISE): Comparison of Head Mounted Display (HMD), Desktop and Projection Display Systems”, Displays, Vol. 29, No. 2, 2008, pp. 58-69.