Chapter 9

Virtual Reality and Serious Games in Healthcare

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Abstract. This chapter discusses the applications and solutions of emerging Virtual Reality (VR) and video games technologies in the healthcare sector, e.g. physical therapy for motor rehabilitation, exposure therapy for psychological phobias, and pain relief. Section 2 reviews state-of-the-art interactive devices used in current VR systems and high-end games such as sensor-based and camera-based tracking devices, data gloves, and haptic force feedback devices. Section 3 investigates recent advances and key concepts in games technology, including dynamic simulation, flow theory, adaptive games, and their possible implementation in serious games for healthcare. Various serious games are described in this section: some were designed and developed for specific healthcare purposes, e.g. BreakAway (2009)'s Free Dive, HopeLab (2006)'s Re-Mission, and Ma et al. (2007)'s VR game series, others were utilising off-the-shelf games such as Nintendo Wii sports for physiotherapy. A couple of experiments of using VR systems and games for stroke rehabilitation are highlighted in section 4 as examples to showcase the benefits and impacts of these technologies to conventional clinic practice. Finally, section 5 points some future directions of applying emerging games technologies in healthcare, such as augmented reality, Wii-mote motion control system, and even full body motion capture and controller free games technology demonstrated recently on E3 2009 which have great potentials to treat motor disorders, combat obesity, and other healthcare applications.

Keywords: Virtual Reality, video games technology, serious games in healthcare, adaptive games, flow experience, games-based therapy, dynamic simulation, motor rehabilitation.

1 Introduction

Virtual reality (VR) or virtual environment (VE) can be defined as a computing technology that generates simulated or artificially three dimensional (3D) environment, which imitates reality (Sisto, Forrest & Glendinning, 2002c). VR presents a convincing

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interface that allows the user to engage with the computer-generated environment in a naturalistic way (Schutheis & Rizzo, 2001). Through 3D computer graphics via advanced input and output devices, users believe they actually perceive sensory information that is similar to that of the real world. In very simple terms, virtual reality can be defined as a synthetic or virtual environment which gives a person a sense of reality. It comprises a range of computer technologies that present information in a form that people perceive as similar to real world.

VR system can be classified into three categories: immersive, semi-immersive and non-immersive. Immersive VR systems are properly the most widely known VR systems where the user either wears a Head-Mounted Display (HMD), or a Head-Coupled Display (HCD), or uses some form of head display unit. Visual, auditory and tactile sensory aspects of the VE are delivered to the individual through visual display units and speakers within a HMD unit, data gloves or body suits. Additional movement may be obtained using joystick, space ball, 3D mouse, other hand-held sensors, or cameras.

In non-immersive VR, the user is placed in a 3D environment that can be directly manipulated with a conventional graphics workstation using a monitor, a keyboard and a mouse.

A semi-immersive VR system comprises of a relatively high performance graphics computing system coupled with either a large screen monitor, or a large screen projector, or multiple television projection systems. Using a wide field of view, semi-immersive VR system provides a better feeling of immersion or presence than the non-immersive system. Readers are referred to Kalawsky (1996) for detail comparison of the three types of VR system.

Two principal features of VR are (1) the user can control the viewpoint in the VE with six degree of freedom; and (2) the user can interact with objects within the VE (Wilson, 1997). When the user interacts with the VE through mouse, joystick, glove, or other input devices, the force or pressure, i.e. haptic feedback, will also be fed back to the user, hence the user can experience a sense of touching, including the weight, surface texture of the object (e.g. smooth, rough, soft, hard, sticky), and the force from the simulated environment, such as the gravity. These features have been very attractive to the digital entertainment, video games and the media industry. More recently, VR technology has been applied to medicine and healthcare to improve patient treatment and care. For instance, Rose *et al* (1996) reviewed four areas in neurological rehabilitation that VR could be applied to, i.e. assessment, training, interaction and enablement. In stroke rehabilitation, VR has been used as a rehabilitation intervention for both upper limb and lower limb. Rose *et al* (1998) evaluated the effectiveness of active participation versus passive observation of VEs in memory retaining after brain injury and the results showed significant improvement in spatial recognition tests in participants using VR. Readers are referred to Crosbie *et al* (Crosbie 2007) for a review on applications of VR in stroke rehabilitation. VR applications have also been developed to improve the lives of children with disabilities. VR systems could help to minimise the effects of a disability, improve patients' quality of life, enhance social participation, and improve their life skills, mobility and cognitive abilities, while providing a motivating and interesting experience for children with disabilities (McMomas 1998). Sun & Zheng (2004) applied non-immersive VR in using a virtual intravascular endoscopy to assess the effect of suprarenal stent struts on the renal artery with ostial calcification. VR has also been applied in medical training, such as laparoscopic surgery training. Cates (2007) suggested that VR simulation should be used in medical training to allow inexperienced physicians to acquire meaningful new procedural skills without jeopardizing patient safety in the process.

In VR application for healthcare, VR technologies are aliased with other technologies. For instance, Jaffe et al. (2004) used an immersive VR system (HMD and a video camera) in conjunction with treadmill training, Crosbie et al. (1997) applied a non-immersive PC based VR system with a motion tracking system in the stroke rehabilitation interventions.

In this chapter, we will first introduce VR devices in section 2. Section 3 will discuss the combination of VR and video games technologies and its applications in healthcare, focusing on dynamic simulation and using adaptive game play to keep players (patients) in the *flow*. Next, some experimental research and results are discussed in section 4, followed by the conclusions and the future directions of applying VR and video games technologies in healthcare, such as Augmented Reality (AR), full body motion capture and controller free games technology which have great potentials to treat motor skill disorders, combat obesity, and other healthcare applications.

2 VR Devices

An implementation of a VR application consists of a set of devices, such as computers, gloves, haptics feedback devices, motion tracking devices and display devices (HMD, projectors, VR goggles or screens for examples). This section will describe some of state-of-the-art VR devices.

2.1 Haptic Force Feedback Devices

In VR, the user is able to interact with the objects in VE. The term haptic refers to sensing and manipulation through touch (Srinivasan & Basdogan, 1997). Haptic feedback is the use of sense of touch in a VR system to provide ‘real feeling’ to the user. Using haptic feedback, the user could sense the pressure or force when carrying out rehabilitation exercises or training tasks, such as moving a ball in a virtual room, the ball will stop moving when colliding with a virtual wall or the virtual roof; when the user moves the ball on different type of surface, the user can feel the difference between a smooth surface and a rough surface from haptic feedback. The first type of feedback is an example of force feedback and the second one is an example of tactile feedback.

Haptic feedback has been incorporated in the development of haptic devices to improve the user’s interaction with the VE (Laycock & Day, 2003). Fig. 1 illustrates the processes associated with haptic rendering when the user manipulates a haptic device. The following section reviews some of the haptic devices used in healthcare rehabilitation.

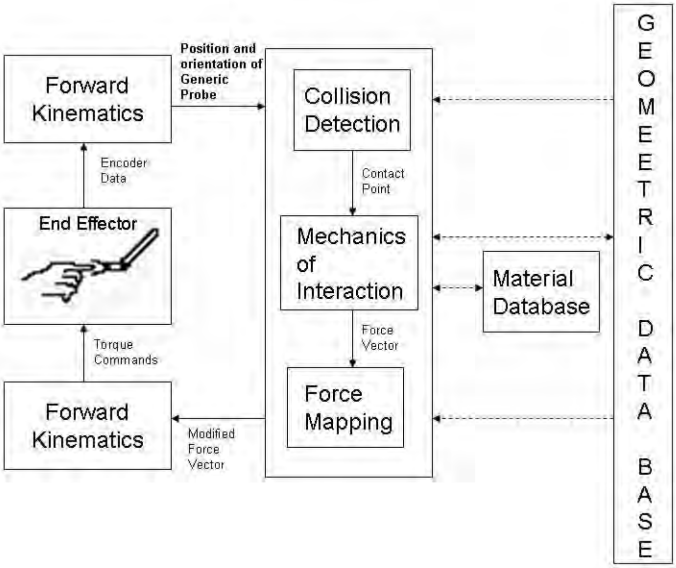

Fig. 1. The processes associated in haptic rendering with a force display. The solid and dashed lines represent the process flow and information exchange respectively (reproduced from Srinivasan & Basdogan, 1997)

One of the most popular haptic devices is PHANTOM (Personal Haptic Interface Mechanism) force feedback devices from Sensable Technologies. The PHAMTOM series have been widely used in VR applications, e.g. Steinberg et al. (2007) developed a haptic 3D dental training simulator and practitioners found its tactile sensation was realistic for teeth though not satisfactory for gingiva. PHANTOM Desktop or Omni devices offer affordable desktop solutions while the Premium models provide larger workspaces and higher forces. Fig. 2 illustrates the PHANTOM Desktop haptic feedback device. It consists of a kinematic framework with three rotational degrees of freedom, and a 3D force feedback workspace of 160Wx120Hx12D mm. The user interacts with the device by gripping a stylus attached to the distal point of the framework. The range of motion aligns with the hand movement pivoting at wrist. It provided three dimensional position sensing, three dimensional force feedback and three dimensional stiffness feedback. PHANTOM Premium devices provide a workspace up to 838Wx584mmx406Dmm (Premium 3.0), 6 degrees of position sensing, and the range of movement can be full since movements are pivoting at shoulder (Premium 3.0). The device is nominally passive (i.e. it does not resist the motion of the user), but motors located on each of the joints can be selectively activated to convey the illusion of contact with a rigid surface.

Fig. 2. PHANTOM Haptic Devices, from http://www.sensable.com

CyberGrasp system is another force feedback haptic option from Immersion's CyberGlove device (www.immersion.com). It provides force feedback to both hand and fingers for the user to naturally interact with complex 3D VE, and to control end-effectors in telerobotic applications that requiring a high level of dexterity. The CyberGrasp system (Fig. 3) includes three main components: CyberGlove (www.cyberglovesystems.com), position tracker and exoskeleton. The CyberGlove is the core of the system. It is used to measure the joint angles of the fingers, hand and wrist. The CyberGlove data is used to render a graphic hand on the screen or to control a telerobotic manipulator. The exoskeleton is in charge of providing force feedback to the user by restricting the finger movements.

2.2 Tracking Devices

Glove-Based Tracking Devices

Since the late 1970s people have studied glove-based devices for analysis of hand gesture. Gove-based devices adopt sensors attached to a glove that transduces finger flexion and abduction into eletrical signals for determining the hand pose (Zhou, 2004).

The Dataglove (originally developed by VPL Research, the pioneer of virtual reality technology and networked 3D graphics) is a neoprene fabric glove with two fiber optic loops on each finger. Each loop is dedicated to one knuckle and at one end of each loop is an LED and at the other end is a photosensor. The fiber optic cable has small cuts along its length. When the user bends a finger, light escapes from the fiber optic cable through these cuts. The amount of light reaching the photosensor is measured and converted into a measure of how much the finger is bent. The Dataglove requires recalibration for each user (Hsu, 1993). One potential problem is that if a user has extra large or small hands, the loops will not correspond very well to the actual knuckle position and the user will not be able to produce very accurate gestures (Aukstakalnis and Blatner 1992).

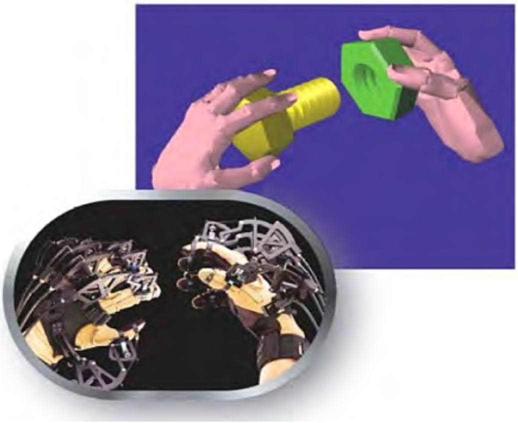

Fig. 3. The CyberGrasp system

The CyberGlove system includes one CyberGlove (www.cyberglovesystems.com), its instrumentation unit, a serial cable to connect to a host computer, and an executable version of the VirtualHand graphic hand model display and calibration software. To accomplish the measurement of the position and orientation of the forearm in the 3D space, the position tracker, which can be Polhemus Trackers (www.polhemus.com) or Ascension Trackers (www.ascension-tech.com) for example, measures the position and the rotation of the hand in the 3D space, is, mounted on the glove wristband. The CyberGlove has a software programmable switch and LED on the wristband to permit the system software developer to provide the CyberGlove wearer with additional input/output capability. The instrumentation unit provided a variety of convenient functions and features including time-stamp, CyberGlove status, external sampling synchronization and analog sensor outputs.

Based on design of DataGlove, PowerGlove was developed by Abrams-Gentile Entertainment (AGE Inc.) (http://www.ageinc.com/tech/index.html) for Mattel through a licensing agreement with VPL Research. PowerGlove consists of a sturdy Lycra glove with flat plastic strain gauge fibers coated with conductive ink running up each finger; measures change in resistance during bending to measure the degree of flex for the finger as a whole. It employs ultrasonic system (back of glove) to track roll of hand (reported in one of twelve possible roll positions), ultrasonic transmitters must be oriented toward the microphones to get accurate reading; pitching or yawing hand changes orientation of transmitters and signal would be lost by the microphones; poor tracking mechanism. Whereas the Dataglove can detect yaw, pitch and roll, the PowerGlove can only detect roll, and provides 4D information, i.e. x, y, z and roll.

Initial Sensors

All body movements will have concurring accelerations and decelerations, which can be applied for movement tracking or detection. Micromachined inertial sensors, including accelerometers and gyroscopes, are silicon-based sensors. They are small in size and can be worn on the body. The working principle of these sensors is based on the measurement of inertia, and can be applied anywhere without a reference. Due to these advantages, an extensive amount of research has been carried out to evaluate their use for tracking human movement.

Accelerometers are instruments that measure the applied acceleration acting along a sensitive axis. Conceptually, a single axis accelerometer consists of a mass, suspended by a spring in housing. The mass is allowed to move in one direction and the displacement of the mass is a measure of the difference of acceleration and gravity along the sensitive axis given by the unit vector. To track human motion one is needed for each of the three planes of motion. A triaxial accelerometer (TA) can be constructed by mounting three such single axis accelerometers together or by using a single mass with three translational degrees of freedom.

Measurement of human movement can be summarised into three types: inclination (angle to the vertical), orientation (relative angle of limbs or body) and ambulatory measurement (for example, monitoring activity, training of motor skills during daily life), the latter requires both measurement of inclination and orientation. Accelerometers measure the gravity vector and the acceleration, and can not provide information about the rotation around the vertical and therefore do not give a complete description of orientation. Gyroscopes measure angular velocity and can be combined with accelerometers to estimate orientation. A combination of accelerometers and gyroscopes will then be an approach to obtain both inclination and orientation information.

Typically, angular orientation of a body segment is determined by integrating the output from the angular rate sensors strapped onto the segment. A relatively small offset error on the gyroscope signal will introduce large integration errors. The magnetometer is an instrument for measuring the direction and/or intensity of magnetic fields. It is sensitive to the earth's magnetic field. It gives information about the heading direction in order to correct drift of the gyroscope about the vertical axis.

One example of the initial sensor is the Xsens MTx (Xsens Dynamics Technologies, Netherlands). It is a digital measurement unit that measures 3D rate-of-turn, acceleration and earth-magnetic field. It provides real-time 3-D orientation data in the form of Euler angles and Quaternions, at frequencies up to 512 Hz and with an accuracy better than 1 degree RMS. An MTx miniature inertial orientation sensor, with 2g acceleration range and 900 deg/sec rate-of-turn range. Readers are referred to Zheng et al, 2005 for a detail review on inertial sensor technologies.

Motion Tracking

Human motion tracking systems generate real-time data that represent human movement (Mulder, 1994). Sensors or markers are placed on the body to measure the distance to, or orientation or position of an external source. Alternatively, sensors or markers can be attached to anatomical landmarks on the body and used to calculate their relative positions in space.

Motion tracking systems can be classified according to the position of the sensors and sources (Kalawsky et al. 1993), or according to the motion tracking techniques, such as electromagnetic position and orientation trackers, acoustic position and orientation trackers, mechanical position and orientation trackers, electrostatic position and orientation trackers, and video and electro-optical tracking systems for example. Zhou et al (2004) suggested the following classifications: non-vision based system, vision-based tracking systems with markers and vision-based tracking systems without markers, and robotic-guided tracking systems . Examples of non-vision based systems include MTx, MotionStar (http://www.vrealities.com/motionstar.html), InterSense (www.intersense.com/), Polhemus and Glove-based devices. Systems such as Qualisys (http://www.qualisys.com/), VICON (http://www.vicon.com/), and CODA (www.codamotion.com/), are vision-based tracking systems with markers.

All of the above commercial available systems require specialist setting, dedicated space and expensive equipments. They also restrict body movement to some degree. For example, robotic-guided tracking systems are limited in the range of human motion and, in particular walking or other transitional motion, Glove-based systems are disadvantaged by wires attached to each sensor. 3D optical tracking systems, such as Vicon or CODA, are being used for rehabilitation in clinical environments. They comprise one or more video cameras or sensor arrays, interface with PC and active or passive markers. The CODA system is pre-calibrated and uses active (light emitting) sensors (markers) that can be set up at a new location without recalibration. It can use up to six sensors units altogether and can track 360 degree movements. The VICON system uses multiple video cameras with passive markers and must be calibrated each time it is relocated. Both systems calculate the 3-D coordinates of each of the markers in real time. However, operation of the systems, mounting of markers and interpretation of the kinematic data requires bioengineering expertise and they are limited to a laboratory environment and are not suitable for use at domestic home (Zheng et al, 2005).

3 VR Games for Healthcare

Games beyond entertainment have been explored in various application domains such as education and training for decades. Typical applications of VR and games technologies in health care include therapy, pain relief (Sharar et al. 2008), surgical procedures (e.g. pre-operative planning, intra- and post-operative applications, augmented surgery, and remote surgery), patient education, medical training, skill enhancement and rehabilitation (Ma and Bechkoum, 2008), etc. To date, such applications have improved the quality of healthcare, the quality of life of patient, accessibility to healthcare, and reduce the cost of healthcare.

3.1 Dynamic Simulation

Dynamic simulation, a.k.a. physically-based simulation, is an important feature in VR. It creates realistic motions of virtual objects based on the laws of Newton's laws of motion. The behaviour of virtual objects and their responses to external force and torque are simulated in a physically realistic manner. Physics simulation models objects with physical properties, such as mass, inertia, barycentre, joint constrains, restitution and surface friction — it can make objects in virtual worlds not only *look real* but *act real*. Typical dynamic simulation includes collision detection (and response) and the simulation of gravity, friction force, and kinematics in motor actions. Physics can be applied to rigid bodies or deformable bodies such as human tissues. Rigid body dynamics plays an important role in motor rehabilitation and is especially needed when dexterous manipulation of virtual objects is concerned.

Originated in engineering simulation and high-end video games, it has been recently introduced to VR systems in healthcare. For instance, the advantage of using VR in clinical settings of motor rehabilitation is that by virtue of its programmability, environments and the type and difficulty of tasks can be modified according to the user's capacities and therapeutic goals. Dynamic simulation provides more flexibility on experiment configuration in which not only object positions, orientations, and size can be modified but also gravity, restitution, force and torque damper, and joint constrains can be reliably modified, thereby creating a very individualised set of rehabilitation tasks which would be impossible to achieve with the user's residual motor control in the physical world. These tasks can then be reliably recreated over a period of several weeks or months and participant's outcome can be assessed. The addition of dynamic simulation to the VR therapy can increase patients' experience of immersion in virtual environments, which may in turn increase engagement and activity enjoyment and thereby improve clinical outcome.

The quality of dynamic simulation that is required in a VR system is application specific. In the cognitive and affective domains of learning where the focus of training is more on attitudes such as using VR therapy for treating phobia, high physical fidelity is not always required. However, in medical simulation such as surgical procedures, high quality physical fidelity, such as using haptic feedback to provide accurate feeling of tissue characteristics, is so important that without it the skills acquired in the virtual world may not transfer to the real one or the operation may fail. In the motor rehabilitation domain, previous research suggests that physics fidelity may be important for motor rehabilitation. Viau et al. (2004)) compared movement kinematics of identical tasks of reaching, grasping, transporting, placing and releasing a ball in a real and a virtual environment. Their results showed that there is a slight change in motor patterns when grasping and placing a ball in the two reality conditions for both healthy subjects and hemiparesis patients with motor deficits, which was mainly due to lack of collision handling in the virtual environment. The results suggest that dynamic simulation in VR rehabilitation may reduce the difference of movement strategies in the virtual and real world, which may be an important factor in the transferability of virtual skills to the real world.

Dynamic simulation in serious games for healthcare can be implemented using state-of-the-art game engines, either commercial engines like Havok Physics and Emergent Game Technologies' Gamebryo or open source engines such as OGRE and ODE. Notably, many commercial game engines, e.g. Ageia PhysX, Epic's Unreal Engine and Unity Technologies' Unity engine, provide free licenses for educational, non-commercial applications, or for independent developers (i.e. Indie games). These tools have been prosperously adopted in indie games industry recently, and they provide great low-cost solutions for serious game developers as well.

3.2 Serious Games for Healthcare

The recent emergence of serious games as a branch of the digital games field has introduced the concept of games designed for a serious purpose other than pure entertainment. Health care is a major application domain for serious games. To date the application of serious games to health care, such as PlayStation 2's EyeToy, GestureTek's Irex system, and Nintendo Wii, has primarily been used as a tool that gives players a novel way to interact with games in order to promote physical activities. Many studies have identified the benefits of using serious games in rehabilitation and therapy. Since games technology is inexpensive, widely available, fun and entertaining people of all ages, if combine with conventional healthcare it could provide a powerful means of encouraging patients more effectively.

It has been suggested that playing games can improve neuromotor coordination, and VR-based games have been designed to engage patients' active participation in motor learning and to treat sensori-motor deficits (Huang et al. 2006). For instance, Ma and Bechkoum (2008) described a series of VR games for bilateral upper limb training for stroke patients: catch-the-orange game, shield-ball game, fishing game, and whack-a-mouse game. Fig. 4 shows a screenshot of the fishing game and a photo of a user playing the game. In this game, the player is in a under water world using his/her hands catch fish which are swimming randomly in the water. The player can see the virtual representation of his/her hands on the screen or through a HMD. The

Fig. 4. The fishing game screenshot and interface (Ma and Bechkoum, 2008)

hand movement is captured through a sensor attached on each hand. When both hands collide with a fish, the fish does a little struggling, i.e. wagging its tail drastically on the spot which is implemented by speeding up the speed of swim animation whereas not changing position, and regarded as caught. It then disappears and the number of fish caught is incremented on the Head-Up-Display (HUD). If only one hand collides with a fish, it swims away and escapes. All fish swim in a random manner. If two fish collide with each other, one of them will swim away and the other continue its movement. There are simple Artificial Intelligence (AI) built in the fish object.

The gravity in this under-water virtual environment is also set to zero to free the fish. The size of target area in the 3D space, the size of the fish and their swimming speed, and the size of the virtual hands can all be adjusted to suit individual participant's needs or his/her in-game performance.

VR games have also been explored recently as a non-pharmacologic pain relief techniques for treating treating burn patients (Sharar et al. 2008) due to the intense cognitive distraction they provide. The experiments suggest that immersive VR games are logistically feasible, safe and effective in ameliorating the pain and anxiety experienced in various settings of pain.

In addition, the technique is applicable to a wide age range of patients and is particularly well-adapted for use in children (Gershon et al. 2004). BreakAway's *Free Dive* (Emergent, 2009) is one in the growing wave of video games designed for pediatric pain management. It is a VR undersea exploration adventure game that invites players to swim with sea turtles and tropical fish as they hunt for hidden treasure. HopeLab's *Re-Mission* (HopeLab, 2006)—a third-person shooter that stars a cell-blasting nanomachine and features a voyage-like plot—was designed for educating young cancer patients. The game cleverly provides information about various kinds of cancer and the medicine used to fight it. Studies have proven its efficacy in educating the youngsters who play. The game was tested via a randomised trial on 375 patients, both male and female aged between 13 and 29 (Kato, 2008). The results showed a significant increase in quality of life, self efficiency cancer related knowledge for adolescents and young adults with cancer. Patients in the intervention group showed lighter serum levels of chemotherapy and higher rate of utilisation of antibiotics, suggesting an increased adherence to cancer chemotherapy regimens. The participants in the game intevention group also went through their treatment with a better knowledge and understanding of cancer and related therapies.

Off-the-shelf console games such as Nintendo Wii sports (boxing, tennis, bowling, and golf etc.) have being used for rehabilitation of patients with cerebral palsy (Deutsch, 2008) and hemiplegia to to aid their recovery and regaining strength and ability through repetitive physical exercises. Wii's intuitive control design allows for control through natural movements without restriction of sensors and cables. Wii sports and Wii Fit are currently being used in rehabilitation therapy for patients undergoing treatment following stroke, traumatic brain injury, spinal injury, and combat injury. The Hines Veterans affairs hospital in Chicago even installed a Wii game station in their spiral injury unit to assist physical rehabilitation following various surgical procedures. Previous research on the console (Kerrigan et al. 2008) has demonstrated that Wii's active gameplay is an effective tool for physical exercise, and that Wii games are more useful in limb extension exercises and in burning calories.

Emotional and psychological impact of game play can be immense. VR games have also been used to support the social-emotional development of teenagers with autism spectrum disorders (Khandaker, 2009) and to treat different types of psychological phobias, e.g. spider phobia, social phobia/public speaking anxiety, fear of driving/flying, agoraphobia, and other mental health problems (Gregg and Tarrier, 2007).

3.3 Flow and Its Application to Serious Games

Understanding how people engage in video games has implications for the development of effective serious games. *Flow* is a term that has been coined (Csikszentmihalyi and Csikszentmihalyi, 1988) to define the experience of becoming engaged in activities in which challenges and skills are progressively balanced. When challenges and skills are out of balance, people feel overwhelmed—the challenges exceed the individual's skills—which results in anxiety and stress; and when the challenges do not engage an individual's skills he feels underwhelmed and becomes bored.

With increasingly realistic graphics and intrigue story lines, the flow theory has been applied to video games (Charles et al., 2005 and Gregory, 2008) and game designers have been implementing flow in games to reach a larger demographics. Gregory (2008) summarised that the flow experience in gaming can be achieved through well-designed game mechanics and interactivity:

- Clear goals—the player is aware of what he or she wants to do. At any moment of the game play, the player should have a clear goal which might be short-term or long-term.
- Immediate feedback—the player knows how well he or she is doing at any moment. Cause and effect are reasonable and obvious. Every action the player performs has immediate feedback, preferably multimodal feedback.
- Challenges match skills—the skill level of a player is in balance with the tasks
- Deep concentration—the player focuses all attention on the task at hand and is able to dismiss irrelevant stimuli that may interfere with concentration.
- Control is possible—a feeling of mastery is gained
- Self-consciousness disappears—the player feels able to transcend the limits of the ego
- The sense of time is altered—the gamer either loses track of time or time seems to pass with rapidity
- The activity is intrinsically rewarding—the experience is worth engaging for its own sake

Among these, challenge-match-skill is especially critical for games for healthcare and rehabilitation purposes. Ideally, rehabilitation should be targeted to the individual needs of patients. Patients have a wide range of abilities and tasks which are impossible for some can be trivial for others. It is usual to tailor a rehabilitation session to individual patients according to the type of injury, their capabilities, and therapeutic goals. Typically this is done by assessing the patient in a number of standardised tests prior to the rehabilitation session. The therapist can then create a suitably challenging set of exercises for the patient. A key principle in rehabilitation is matching therapeutic tasks to the patients' abilities in order to enable them to improve residual capabilities without causing fatigue and frustration. This is a time-consuming part of the physiotherapist's duties, as constant monitoring is required to ensure the tasks remain adequately challenging throughout the sessions, which typically last for several weeks.

The key issue to implement challenge-match-skill and to achieve the *flow* experience of gameplay is adaptivity. This is also another advantage of games for healthcare, no matter it is a VR game or 2D flash game. Taking motor rehabilitation as an example, the VE and training tasks are easily customized and the system can assess the motor function recovery of users and adjust level of difficulty to users' performance.

Adaptation is one technique that VR therapy systems and games can exploit to benefit a group of users with a wide range of abilities. In order to maintain patient motivation, rehabilitation tasks should be set at an appropriate level of challenge. Also, for the patient to stay engaged in the process, he or she should experience a feeling of immersion in the virtual environment. Charles et al. (2005) applied the flow theory to adaptive game design, and they suggested that the game should find a balance between the annoyance of an activity that is perceived as trivial and the frustration of one that is perceived as too difficult. This is even more important in the context of VR rehabilitation due to the repetitive nature of the exercises and the limitations of the players (patients).

In post-stroke rehabilitation, a physiotherapist will typically design motor therapy exercises for a stroke patient based on a number of factors, such as the patient's age, gender, culture background, usual handedness, and his or her medical condition (e.g., time since stroke, left or right hemiplegia and cognitive, sensory, and motor abilities based on standardised tests like the Line Cancellation Test). Not only the difficulty level of the exercises but also the body parts activated during the task may be adapted to individual patient's needs. For example, tasks may be developed to train a specific movement such as wrist extension in order to increase range of motion or endurance of the wrist joint. This data, taken together, forms an individual patient profile which can then be used to initially configure the system to present a suitably challenging, individualised rehabilitation session. Various elements of the simulation can be customised according to the user profile. These include the number and type of objects, their sizes, speed, mass, distance from the patient, distance of object transportation etc.

Additionally, data collected during the game session can be used to further improve the patient experience. Such in-session data (e.g., the time taken to perform a task or achieve a goal in a game, the accuracy rate or stimuli-response time) can be used to evaluate the initial configuration of the system. If tasks are not being successfully completed then the objects or game elements in the simulation should be reconfigured to make them easier. Objects can be made larger (easier to grasp), for example, or moved closer to the patient (easier to reach). Alternatively, if activities are being completed much too quickly it may be that the activity is too easy for the patient, and corresponding changes can be made to make the task more challenging.

The ability to dynamically adjust the difficulty of the simulation is a key benefit since in addition to offering a tailored solution which suits the patient's individual needs it also decreases the dependence on human therapists to monitor and provide similar solutions.

3.4 Train a User by Modeling Him—User Profiling

User profiling, initiated from online commerce (such as cookies and user profiles in tracking technology) to build records over time and to assess user preferences, has also been used in serious games and VR rehabilitation systems. Depends on the purpose of a system, the parameters in a user profile vary. Many of them require assessing the users.

In our motor rehabiliation VR system (Ma et al. 2007), we have constructed a patient model using traditional symbolic classifiers based on patients' age, time since stroke, left or right hemiplegia, impairment and functional measurement, and hemispatial neglect. Table 1 below shows the profile of three patients participating in the case study. For each patient, three Motricity Index (MI) [9] and Action Research Arm Test (ARAT) [10] scores are given, representing their status before training, post training, and 6 weeks after training. Patients 1 and 3 have no hemispatial neglect, while patient 2 has a mild deficit.

In the Catch-the-orange game we had developed, the player holds a basket with either one hand (for unilateral upper limb training) or two hands (for bilateral training) to catch falling oranges which fall from random positions on trees onto a target area (Fig. 5A). The position and orientation of the virtual basket are controlled by a sensor attached on a real basket, which the user holds with one hand or both hands (Fig. 5B). If the patient tilts the basket, he or she may not able to catch the oranges and the ones already in the basket may fall to the ground. The target area on the x-z plane, the falling speed of oranges (controlled by simulating gravity in the virtual environment), the time between oranges falling and the size of oranges and the basket can all be adjusted to suit individual patient's skills. All sensor data is recorded to disk, allowing post-therapy visualisation of the trajectories and analysis of joint angles, velocity, acceleration and range of movement.

Table 1. Examples of patient profiling: Motricity Index [9] is for impairment measurement, and Action Research Arm Test (ARAT) [10] is for functional measurement

	Patient #1	*Patient #2*	*Patient #3*
Age	76	62	42
Gender	M	F	M
Years since stroke	4	4	1
Usual handedness	R	R	R
Left/Right hemiplegia	L	L	L
Motricity Index	77,77,81	62,73,77	77,79,77
ARAT	3,6,11	4,11,19	54,53,54
Hemispatial neglect	None	Left-sided	None

A. a screenshot of the game

B. A user playing the game

Fig. 5. The *Catch-the-orange* game

In the Catch-the-orange game, the sense of depth is enhanced through the use of depth cues such as shadows, perspective, relative motion, occlusion, and most effective of all, a transparent vertical stripe of each orange which is still in the air (Fig. 5A). An experiment showed that using the depth cue of transparent vertical stripe improved the sense of depth perception in the user.

The game provides immediate feedback via a Head-Up-Display (HUD) at the upper right corner of the screen, showing information such as player's name, number of caught oranges, number of miss, success rate and a time bar. A statistics window (Fig. 6) also shows score etc. when the game ends.

Non-adaptive Orange Catch Game

Score: 21

Miss: 6

Success rate: 77%

Duration: 79 seconds

Fig. 6. The Game over statistics window

Fig. 7 shows another serious game for bilateral training. In this game the player holds a virtual shield with either one hand or two (for bilateral upper limb training) to fend off iron balls which are shot from the opposite castle with a random initial positions originating from an x-y plane and with an initial +z force (towards the player) which influences the speed of the ball movement. The position/orientation of the virtual shield is controlled by a sensor attached on a real object (we used a tray in our lab), which the user holds with one hand or both hands (Fig. 7B). This game requires less depth cues than the Catch-the-orange game since the player’s movements are expected to be in the x-y plane. We adjust the alpha blend of the shield’s texture map to make the player to be able to see-through the virtual shield and hence to see the iron balls occluded by the shield. The gravity in this game is set to zero to avoid the balls reach the ground before they reach the player. The target area on the x-y plane, the size of the iron balls and their speed (controlled by the initial thrust on +z direction), the time between two shoots and the size of the virtual shield can all be adjusted to suit individual patient's skills or in-game performance.

The above VR games have two levels of difficulty. The first level is non-adaptive. All game parameters are set by the operator, or loaded from a previous session, or set by a computer program based on the patient profile. The configuration dialogue is shown in Fig. 8. Level two is adaptive. The game adapts its difficulty depending on the player’s in-game performance, for example, in the fishing game if the average time (seconds) for a player to catch one fish is less than a threshold, which means the game is too easy for him/her, the fish will become smaller and swim faster, and the virtual hands may become smaller too.

A. a screenshot of the game

B. a user playing the game

Fig. 7. The shield-ball game

4 Experiments and Results of Using VR in Stroke Rehabilitation

In the UK, stroke is the most significant cause of adult disability. Reports (DoH, 2000) showed that six months after stroke, 49% of patients need help with bathing, 31% of patients need help with dressing and 33% of patients need help with feeding. Research suggests that intensive and repetitive training may be necessary to modify neural organization (Miltner et al. 1999, Rossini et al. 2003). Stroke rehabilitation is one of the most prosperous research areas in healthcare where VR and games technologies have been applied to create new tools for intervention and influenced our current practice in post-stroke physiotherapy.

Width* (x) 40
Height* (y) 30
Depth* (z) 20
* 1 unit = 10cm
Size of fish 1
Hand size 2
Fish swim speed 3
Number of fish 3
Player's name Suzanne McDonough
Duration 2 minutes
☑ Dynamically adapt to player's performance

Fig. 8. The configuration dialogue of the fishing game

4.1 SMART Rehabilitation

Being the third biggest killer and the leading cause of severe disability in the UK, there is an increasing demand of providing stroke rehabilitation to improve the conditions and quality of life for stroke survivors. Repeat interventions are important to maintain and regain limb functions for people after stroke. However, inpatient rehabilitation length of stay for patients with stroke is decreasing in the UK, with limited outpatient rehabilitation. Therefore, there is a need to develop a low-cost, accessible, home-based rehabilitation system for post stroke users.

The SMART (www.thesmartconsortium.org) project, entitled ‘SMART rehabilitation: technological applications for use in the home with stroke patients’, was funded under the EQUAL (extend quality of life) initiative of the UK Engineering and Physical Sciences Research Council (EPSRC). The project aims to examine the scope, effectiveness and appropriateness of systems to support home-based rehabilitation for older people and their carers.

The SMART rehabilitation system consists of three components, namely (i) motion tracking unit, (ii) base station unit and (iii) web-server unit. The motion tracking unit consists of two MTx inertial sensors which are attached to the patient’s arm to track the movement during activities such as drinking or reaching. The MTxs record the movement information (positions and angles) of three joints, i.e. wrist, elbow and shoulder and then send wirelessly to the base station (PC) via a waist worn digital data box, “XBus”, for further processing by the decision support platform. The measurement of the 3D position and rotation of the user’s arm by the motion tracking unit is rendered to generate the movement of a avatar’s rehabilitation exercises in a 3D environment. The 3D rendering is applied to a virtual head and arm. In order to provide a reference for patients, stored target movement templates (3D renderings) are available which can be overlaid or mirrored on the screen to help the patient replicate the best movement. Fig. 9 shows two types of methods used in presenting the 3D information, one displays exercise movement and the target template movement in two separate windows; and the other displays them in the same window with the template movement as a ghost layer. Through preference settings, users are able to choose either mode. When the user carries out the rehabilitation interventions, such as drinking, reaching, the arm movement will be rendered in the 3D environment and compared to a virtual 'model' movement. Readers are referred to Zheng et al (2006, 2007) for detail description of the SMART rehabilitation system.

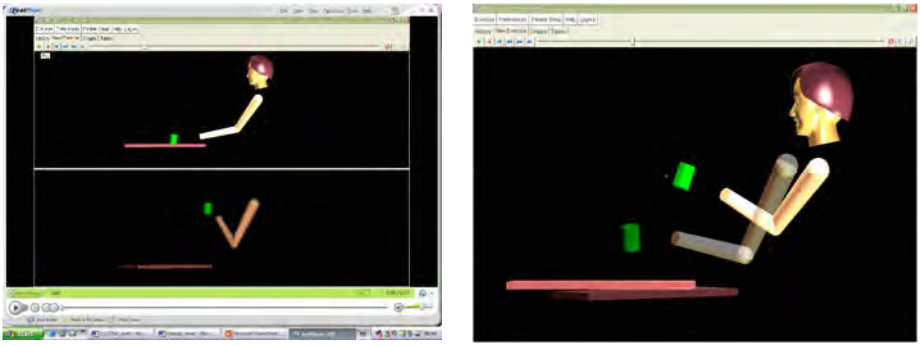

Fig. 9. 3D repesentation of a user avatar and target movement template in the Smart rehabilitation system (Zheng et al 2006)

4.2 VR Game Intervention for Movement Therapy

Ma et al. (2007) carried out an experiment on the VR game intervention described in section 3. Eight participants who suffer from post-stroke upper limb motor disorders participated the study (Table 2). A patient model was constructed for each participant, using traditional symbolic classifiers based on their age, time since stroke, left/right hemiplegia, impairment and functional measurement. They were 4 men and 4 women, mean age in years = 56.4±4.3 (standard deviation). All participants had a first hemispheric stroke, and all were right-handed. The mean time since stroke until beginning of the VR intervention was 10.7 months. 4 participants suffer from right hemiplegia and 4 from left hemiplegia.

The participants were divided into two groups. Participants S, J, F, R (group A) received both functional training (i.e. the users were asked to perform functional tasks such as reaching and grasping) and serious games intervention (i.e. the users were asked to play the VR games described in section 3), whereas participants P, B, E, C (group B) received functional training only.

Each participant attended ten supervised sessions. Three clinical assessments were performed for each participant before training, post training, and 6 weeks after training using Motricity Index (MI) and Action Research Arm Test (ARAT) scores.

Table 2. User profiles of the participants

Paticipants	Age	Gender	Mths since stroke	Usual handedness	L/R hemiplegia	MI	ARAT
S	49	Male	6	Right	Right	92,100,100	54,54,57
J	49	Female	6	Right	Right	73,77,73	45,54,50
F	66	Female	12	Right	Left	71,77,71	32,35,35
R	74	Male	8	Right	Left	100,100,100	57,57,57
P	45	Female	23	Right	Right	77,77,77	57,57,57
B	75	Male	12	Right	Right	77,85,100	54,55,57
E	69	Female	11	Right	Left	84,84,84	57,57,57
C	43	Male	10	Right	Left	77,79,77	54,53,54

Most participants showed improvement in short term, i.e. comparing post training scores to pre-training scores: MI(2)-MI(1) and ARAT(2)-ARAT(1)[1]. However, for some the intervention hasn't shown long-term clinical benefits, i.e. comparing scores at 6-week after intervention to pre-intervention scores: MI(3)-MI(1) and ARAT(3)-ARAT(1).

Since the sample sizes were small, a paired t-Test on each group and all participants was conducted to compare the effect of games intervention (Group A) with that of functional training (Group B). Three paired t_Test values (of group A, group B, and all participants) between MI(1) and MI(2) values were calculated, indicating the probability associated with participants' MI(1) and MI(2) scores with a one-tailed distribution, if the null hypothesis is true.

The results show that the probability of observing the improvement between MI(2) and MI(1) in Group A is 0.038997, in Group B is 0.13916, and for all participants is 0.012807. Therefore, the data support that all participants had significant improvement immediately after intervention (because 0.012807 is a very small probability and the null hypothesis is refuted), and that the intervention on Group A was more effective than the intervention on Group B (because 0.038997 is much smaller than 0.13916). Similar results were observed with the paired t-Test on each group associated with participants' ARAT(1) and ARAT(2) scores. Hence, the serious games intervention did have an impact on the recovery of movement.

Data analysis on tracking individual patient's in-game performance in the games also support the findings. Take participant J and F as examples, look at their improvements on ARAT and MI scores and game performance in the adaptive whackamouse game. Both participants' game performance improves significantly over the sessions in terms of their reaction speed, i.e. how many seconds it took them to hit a mouse and how many seconds a mouse stays still.

Having plotted their speed and interval on charts, we see exponential trend of their speed and intervals during the sessions, with the square of correlation coefficient around 0.8. Both parents show a significant improvement on speed of movement and response time. Correlating their game performance and their improvement in the real world in term of MI and ARAT scores, we find that the VR-based motor therapy

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[1] MI(1) indicates the MI score before training, MI(2) indicates the MI score after training, MI(3) indicates the MI score 6 weeks after training. Same for ARAT scores.

using both functional training and serious games was more effective than using functional training solely, in terms of improving motor functions shortly after completion of the intervention and it may bring long term benefits as well. For the experiment details and data analysis of this study, please see Ma and Bechkoum (2008).

Serious games therefore appear to have potential to become a useful tool for movement therapy, as well as virtual reality technology.

5 Conclusions and Future Work

This chapter has shown how VR and video games technologies can contribute to healthcare by providing motivating, realistic, and adaptive simulations. The integration of VR simulation with serious games adds richness to the virtual environment which has been proved to be motivational and beneficial in healthcare. Previous results of user trials and experiments, for instance, in physiotherapy, are very positive, showing VR and games intervention had an impact on the recovery of movement both in the real world impairment and functional measurements and in-game performance, with patients reporting that they enjoy playing the games.

Although the current state-of-the-art of VR and serious games in healthcare is a decade behind the digital entertainment industry, i.e. video games and 3D movies, the technological developments in today's games industry show some of the future directions of applying these technologies in medicine and healthcare, such as augmented reality, Wii-mote motion control, and even full body motion capture and controller free games technology demonstrated recently on E3 2009 which have great potentials to treat motor skill disorders, combat obesity, and other healthcare applications.

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