AUGMENTED REALITY BASED REHABILITATION SYSTEM WITH SELF-DESIGNED DATA-GLOVE

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Abstract: In this research, a rehabilitation system based on Augmented Reality has been developed to recover hand motions. With the self-designed data-gloves and Augmented Reality technology, intuitive human-computer interaction has been developed to provide entertaining and engaging rehabilitation programs. A self-designed data-glove is used to detect the grasping movements of the patient's hand, collect the physical information of the patient and provide tactile feedbacks according to the performance of the patient. With the advantages of seamless merging of virtual and real elements, controllable environment and intuitive interface, Augmented Reality based rehabilitation systems can provide entertaining exercising programs to the patients. In the developed rehabilitation system, multimodal feedbacks are provided to reduce the fatigue and make the patients more engaged in the rehabilitation sessions.

1 INTRODUCTION

It is expected that the proportion of people aged above 60 years old would reach 19% by 2050, and there would be a growing proportion of individuals who suffer from disabilities due to illnesses related to ageing. Rehabilitation plays a huge part in the recovering process to maintain and restore the maximum movements and functional ability of the body throughout the lifespan of the individuals. With effective rehabilitation systems, motor functions can be recovered, the independent living ability can be enhanced and the cost in healthcare can be reduced. There are three key factors in motor functions recovery, namely, early intervention, task-oriented training and repetition intensity (Malouin et al., 2003). Therefore, an effective rehabilitation system should be able to provide repetitive training with affordable costs and easy monitoring of the recovering progress with set goals.

Although conventional rehabilitation systems have been proven to be useful in recovering of the motor functions (Kwakkel et al., 1999), they have disadvantages, such as boring content, high cost and lack of digital monitoring. New technologies can provide a novel paradigm for therapy methods to address these issues. Augmented Reality (AR) technology (Azuma, 1997) augments a user's view of the real world by superimposing virtual objects with the physical world. With an AR-based interface, the users can interact with the virtual objects in a real environment.

In this paper, a rehabilitation system for hand movements based on AR technology, sensors and video games is presented. A sensor-based data-glove has been developed to detect the grasping movements and provide tactile feedbacks so as to support intuitive human-computer interaction allowing patients to interact with virtual objects in a real environment using natural hand movements. Virtual elements which can be interacted using the data-gloves are designed in the video games based on AR technology to provide the entertaining exercising environment.

2 RESEARCH BACKGROUND

Traditional rehabilitation processes to recover motor functions are usually carried out with external devices, e.g., the nine-hole pegboards, the exercise hand skate, and repetitive practices. In these systems, the exercises are closely monitored by the therapists. A limitation in these traditional rehabilitation systems is boredom, which is usually observed in rehabilitation programs requiring

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intensive practice. Tedious practices without fun and entertainment tend to reduce the motivation of the patients. Another limitation is the high cost of these rehabilitation systems, which would impose considerable financial burden on the patients and make it difficult for them to undergo the practices needed to effect neural and functional changes. There is no data collection function in these systems, as conventional rehabilitation systems are designed without sensors such that digital information of the performance progress cannot be collected.

Providing an enhanced environment by augmenting virtual objects into the physical world seamlessly, AR technology can provide an intuitive interface to rehabilitation systems. Luo et al., (2005a) developed rehabilitation system integrating AR and assistive devices for hand opening actions of stroke survivors. Dynamic feedbacks of the subject performance are provided. Luo et al., (2005b) also designed a rehabilitation system to facilitate the rehabilitation of the grasp-and-release tasks, where users without muscle strength can move virtual objects without difficulties.

Sucar et al., (2008) developed a web-based gesture therapy system using AR to provide intensive motion training at low cost. Visual feedback of the patient's performance is provided and the practice progress is illustrated through a simple statistical chart. AR-REHAB (Alamri et al., 2010) is an AR rehabilitation system to increase the immersive feeling of the post-stroke patients. Fiducial markers are used to track the hand movements of the patients, which are analysed to evaluate and monitor the performance of the patients. AR-based games (Burke et al., 2010) have been reported to support upper limb rehabilitation, where AR markers are used to augment everyday objects and track the movements of these objects. This project takes into consideration the principles in game designs to enhance the user engagement.

Wang et al., (2010) developed an AR system with the use of air pressure detecting devices. Based on the physical condition of the users, which is measured using pressure sensing devices, the parameters of the game are adjusted to ensure that patients with different extents of hand impairments can interact with the game. Correa et al., (2009) created an AR system to facilitate accessing music by the disabled patients, where patients without muscle strength can use this system. The AR Piano Tutor involves virtual objects augmented onto a real MIDI keyboard in a video captured scene which represents the user's viewpoint (Barakonyi and Schmalstieg, 2005). However, a patient with limited finger strength and control may not be able to depress the physical keys. Zhang et al. (2010) projected a virtual piano onto the real environment and a self-designed data-glove with flex sensors is used to measure the flexing angles of the fingers.

3 METHODOLOGIES

3.1 System Architecture

The proposed system shown in Figure 1 aims to help patients to improve their grasping strength as well as train their hand-eye coordination via AR-based game play with a self-designed data-glove. The system hardware includes a standard computer, an off-the-shelf webcam and a self-designed data-glove. With the force sensitive resistors sewn on the glove, the data-glove can detect the grasping force applied on the fingers. The multiple threading method and the function of the playlist in the OpenGL library are used to ensure that the system would work in real time without any time lag.

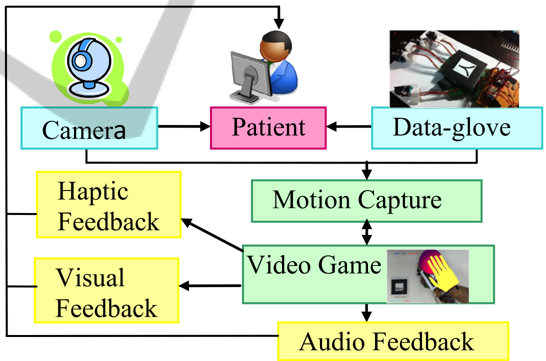

Figure 1: The system architecture.

A "burst the balloon" game has been developed to train the grasping movements of the patient's hand. The virtual balloons are rendered in the real environment by tracking a marker using ARToolKit (ARToolKit, 2002). With another marker on the data-glove, the virtual hand overlaid on the real hand would interact with the virtual balloons. The collision between the virtual balloon and the patient's hand is determined by detecting the collision between the virtual balloon and the virtual hand using the VCollide library.

Upon collision between the virtual balloon and the virtual hand, the balloon will burst when a sufficient amount of force is applied. Performance will be based on the number of balloons burst out of a total of twenty balloons. There are also different levels of difficulties that the user can choose to suit their rehabilitation progress. With a higher difficulty level, balloons will appear at faster speeds and a greater force will be needed to burst the balloons.

Multimodal feedbacks, namely, visual, audio and tactile feedbacks, are provided based on the performance of the patients. These feedbacks are important performance indicators. They can further encourage the practice and maintain the interest level of the patients. The feedbacks are provided mainly in two aspects, viz., the change of the context in the gaming environment and the display of the quantitative information of the performance.

The scoring module in the system is designed to record the accuracy of the patient interaction with the system. Rendering the quantitative information recorded by the scoring module onto the screen can provide the patients with performance feedbacks. The quantitative information can be stored, making it convenient for the therapists to monitor the recovering progress of the patients and analyse the effectiveness of the rehabilitation system.

3.2 Self-designed Data-glove

The data-glove shown in Figure 2 is used to detect the grasping forces of the fingers as the fingers interact with the virtual objects in the AR environment. The touching sense is applied to the fingers with a real ball held in the user's hand, as shown in Figure 3. The force sensing resistors (FSR) are sewn onto the glove to obtain the pressing forces of the fingers. The grasping movements detected by this data-glove can be transmitted wirelessly via Bluetooth to the system.

The data-glove is designed to be used in the AR-based rehabilitation system. Therefore, it should be able to be worn on patients whose fingers cannot move freely. Open-design is implemented to develop the data-glove in which Velcro belts are used to affix the data-glove to the hand, as shown in Figure 2.

This data-glove consists of five parts, i.e., the FSR module, the computing module, the information transmission module, the power supply module and the feedback module. The FSR module is used to detect the pressing forces of the fingers. The computing module, i.e., the microcontroller (Arduino Pro mini microcontroller) is used to collect the analogue signals from the sensors. The microcontroller also performs some preliminary information processing, such as converting the analogue signals into digital signals and basic computation. The information transmission module is based on the Bluetooth technology to achieve wireless information communication between the computer and the microcontroller. The power supply module includes a battery and a voltage regulator to ensure the microcontroller works under a stable voltage of 3.3V and the Bluetooth works under a voltage range of 3.3V~6V. For the feedback module, miniature vibration motors are mounted on each finger tip to provide tactile feedback when the hand is squeezing to burst the balloon.

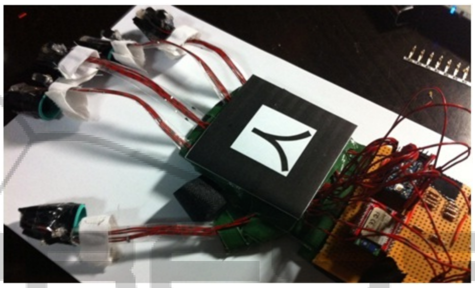

Figure 2: Self-designed data-glove.

Figure 3: A ball is held in the game.

When a larger pressure is applied to a FSR on the data-glove, the resistance of the FSR will be lower. In the circuit of the FSR, the microcontroller provides the power supply. The current in the circuit and the voltage between the two points of the resistor will be changed accordingly. The voltage is input into an analogue port of the microcontroller and converted to a digital value through the Analog-to-Digital converter in the microcontroller. Calibrations have been conducted to obtain the relationship between the voltage output in the circuit and the force applied to the FSR. Due to the limitation of the FSRs, the relation between the force applied and the change in the resistance is not directly proportional. In addition, there is only a limited useful operating range. After a series of calibrations, it is observed that all the FSRs on different fingers exhibit similar trends; therefore, only the limited range of 0N to 6N is used.

The self-designed data-glove is low cost and affordable to normal users. It is not only a great tool to improve on the user's condition, but at the same time monitor the patient's progress throughout the whole gaming process.

3.3 Burst the Balloon Interactions

The Burst the Balloon game is a simple and intuitive game that does not require complicated instructions and has a relatively short learning curve. When there are virtual balloons flying from the marker into the 3D space, the patient is required to move his hand with the data-glove to the position of the virtual balloon and squeeze the real ball at the same time. Therefore, the rehabilitation system can help patients improve their grasping strength as well as train their hand eye coordination ability.

Interaction between the virtual hand and the virtual balloons consists of two parts, i.e., coordinate transformation and collision detection. Since the virtual hand and the virtual balloons are rendered in two different coordinate systems on two markers, coordinate transformation is needed to compare the relative positions of the two virtual objects, using the camera coordinate system as a bridge between these two different markers (Figure 4). The "Hiro" marker associated with the virtual balloons is set as the base coordinate system. The coordinates of the "Hiro" and the "Kanji" markers in the camera coordinate system can be determined through analysing the images captured by the camera using the functions provided by ARToolKit. When signals from the FSRs show the fingers grasping, the position (i.e., x-, y- and z-coordinates) of the virtual hand in the "Kanji" marker coordinate will be transformed to a position in the "Hiro" marker coordinate system, and compared with the position of the virtual balloon using the VCollide library. If the virtual hand collided with the virtual balloon, it is assumed that the balloon is about to burst. After a collision has been detected, a balloon bursting sound is played, and the colour of the virtual balloon is changed from red to green, and the miniature vibration motors mounted on the finger tips are activated to provide tactile feedback. In this rehabilitation system, a real ball is held by the patient to provide more realistic touching sense and provide haptic feedbacks when the patient is pressing the ball.

4 IMPLEMENTATION

The rehabilitation system has been implemented on a P4 3 GHz PC equipped with 1 GB RAM, an ordinary web camera and a display device. The self-designed data-glove is used as the input device.

The rehabilitation system aims to allow the user to have a more interactive interface, with different levels of difficulty to choose from to provide suitable challenges during the game playing process, which needs to be considered when the patient's physical conditions have been improved. Therefore, the user interface should be designed to be interactive, user friendly, suitable for all ages and have different levels of difficulty.

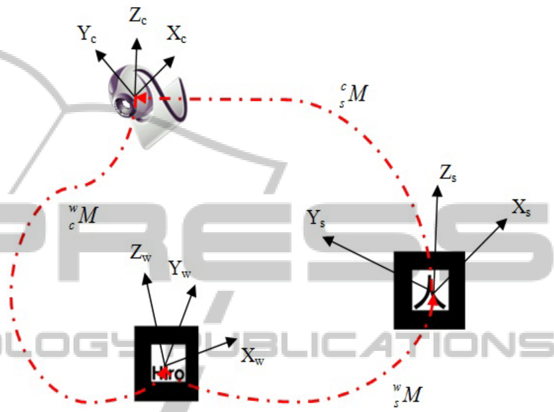

Figure 4: Coordinate transformation between two markers.

4.1 Preparation Stage

The data-glove is simple in design and ergonomic for use. The instructions to put on the data-glove are as follows: (a) Strap on the main Velcro across the palm of one's hand, as shown in Figure 5, (b) Slot in the respective finger into the main finger compartment, (c) Secure the finger compartment by strapping on the white Velcro just below the finger compartment to the respective finger, as shown in Figure 6, and (d) Secure the rest of the four fingers.

4.2 User Interface

In order to facilitate usability, the user interface of the rehabilitation system is designed to give the user real time feedback on his/her current game play. The interface consists of the game title, score, level of difficulty and balloons remaining in the current exercising session, as shown in Figure 7.

Three different difficulty levels of the game, namely, easy, normal and hard, have been developed to cater to different capabilities of the users. They can be selected by pressing the 'E', 'N', 'H' key on the keyboard respectively. The parameters that are different between the levels of difficulty consist of the flying speed of the balloons and the amount of force to burst the balloons, both of which increase as the level of difficulty increases.

Figure 5: Put-on the data-glove.

Figure 6: Secure the finger compartment.

Figure 7: Interface of the rehabilitation system.

For each level of difficulty, twenty virtual balloons will appear from the marker. The user needs to move his hand to the position of the virtual balloon and squeeze it, as shown in Figure 8. If the pressure applied is larger than the force defined for the selected level of difficulty, the balloon will burst, playing a "pop" sound followed by vibrations from the miniature motors. There will be a visual cue where the balloon will turn from red to green, as shown in Figure 9. For every successful action, the score will be increased by 1. The final score will be rendered to indicate the performance. To restart the game, the user can select the level of difficulty using the 'E', 'N', 'H' key on the keyboard, after which the score and the balloon count will be reset.

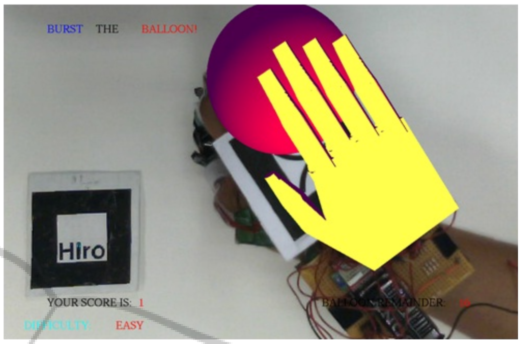

Figure 8: A virtual balloon is rendered in 3D space.

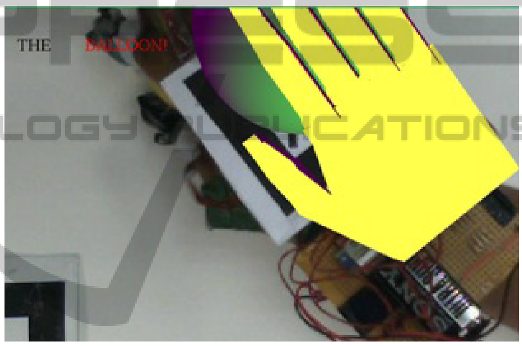

Figure 9: The colour of the balloon becomes green.

4.3 Discussion

Comparing the developed system with existing systems, the AR-based system presented in this paper has a number of advantages. The data-glove is low cost (SGD$150) as compared to commercial force measurement gloves, such as the CyberGrasp system with a cost of SGD$39000. The scoring module as well as the multimodal feedbacks can be monitored and indicate the patient's progress easily. The learning curve of the rehabilitation system is short. This avoids the hassle of explaining the instructions to the patients especially the elderly or mentally challenged patients. The system activates three main senses, namely visual, touch and hearing, of the users during the exercising processes.

There are a few disadvantages of this proposed system. The data-glove has limited force sensing capability, which is only up to 6N. The accuracy is also limited due to the natural property of the FSR. More advanced sensors can be implemented to overcome these limitations. Similar to other AR games, lighting and visibility of the markers would affect the rendering of the virtual objects.

5 CONCLUSIONS

In this research, a rehabilitation system based on AR technology and sensors has been developed to recover the grasping movements and the ability of hand-eye coordination of the patients. The first contribution of this research is the self-designed data-glove to measure the grasping forces applied to the fingertips. With this low-cost data-glove, the grasping forces and the physical condition of the patient can be estimated. The second contribution is the integration of this data-glove with the AR-based rehabilitation application to provide haptic, audio and visual feedbacks to the patients using a game play session. With a real ball held in hand, the patient can receive haptic feedback, while the virtual balloon rendered using AR technology can enhance the effectiveness of the rehabilitation system in engaging and entertaining the patients and facilitate the training of the hand-eye coordination of the patient. With this low-cost rehabilitation system, a patient can take intensive exercises at home.

Future work will include developing more levels of difficulty to make the rehabilitation system suitable for patients with different physical conditions. The developed system will be evaluated with a set of criteria. A user study with a large sample will be conducted to verify the effectiveness of the developed system and collect more quantitative information about the system performance to determine how this rehabilitation system can support and complement the rehabilitation process of the users.

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