Self-Rehabilitation based on User Interactive Environment

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ABSTRACT

It has been reported that 53,000 stroke events annually with ongoing costs are nearly $500 million per year for physical therapy care. This paper aims to provide effective and active rehabilitation for patients suffering from upper limb paresis, using gaming based a therapy technique. By disguising the tasks into more entertaining, patients are motivated to train for longer and more frequently. The advantage of this system can be a self-managed, at-home therapy system; reducing fatigue for physical therapists, and the time required for therapist-patient sessions. The system incorporates a virtual reality (VR) environment displaying both the games and a human model as feedback of the patients' actions whilst playing the games. Two games were developed; a "Whack-a-Mouse", and Rolly games, each targeting improvement of muscle strength, control, accuracy and speed. The difficulty of the games can be varied to suit a number of impairments and patient progress is monitored. The games are played using a Nintendo Wii controller. The successful improvements with lower costs associated with this system, are marked improvements for patients suffering from such a debilitating condition.

Keywords

Games, virtual reality, Self-Rehabilitation, Active Therapy

INTRODUCTION

It has been reported that 53,000 stroke events and 400 new cases of spinal cord injury (SCI) occurs annually contributing to the 9,000 persisting cases of SCI. Stroke and SCI account for over a quarter of chronic adult disability in Australia. Ongoing costs associated with treatments of disability and long-term care is nearly $500 million per year for physical therapy care. The prevalence of these debilitating conditions in Australia increases every year [1].

People who suffer from paretic or paralysed upper extremities after spinal cord injury (SCI) or stroke are faced with a debilitating lack of control over their own body. Recent studies have confirmed that the motor impairment can be remedied by intense use and acquisition of new motor skills required for cortical reorganisation, in addition active movement in task-orientated, repetitive activities shown to improve motor skills and muscular strength. It also prevents muscle atrophy, osteoporosis and spasticity which can occur due to lack or inadequate treatment. The tasks can be disguised into something more entertaining for the patient, such as within a game, thus motivating them to train for longer and more frequently [2].

The work in this paper is to build a system is that provide a self-managed or at-home for upper limb rehabilitation system, to provide active rehabilitation that motivates and entertains patients to train for longer and more frequently, and without the overstraining risks associated with other gaming systems and large costs with existing robotic rehabilitation systems. The advantage of self-rehabilitation is that it reduces fatigue for therapists and the time required for therapist-patient sessions thus reducing cost for the user, also allowing the patient to be in the comfort of their own home. Overall it focuses on motivating the patient to learn and develop their skills and coordination at their own pace, as well as providing useful feedback for the therapist and patient.

1.1 Active Therapy

Research studies have confirmed that the application of feedback during rehabilitation after stroke, cerebral palsy, incomplete paraplegia, Spina Bifida or arthritis is quite effective in facilitating recovery. An advanced method is by providing a virtual environment, where the patient activity such as speed, muscle active and motion patterns are displayed either graphically or audio-visually, providing a realistic image of the patient. The aim is to provide a clear and understandable method of providing information about their performance [2].

Active participation allows recovery of the undamaged brain from functional inactivation due to the stroke, which allows for reorganisation of synaptic connections, it increases blood flow in areas around the lesion. However, passive range of motion is also a standard part of treatment; it is considered effective at preventing contractures. It alters the inhibitory state of the central nervous system (CNS) and subsequently affects behavioural responses. Those undergoing intense movement therapies showed significant cerebral blood flow compared to those undergoing standard care, these results show that movement coordination is more beneficial for recovery than muscle strengthening. One new technique contribute to active therapy is virtual reality

1.2 Virtual Reality

Virtual Reality is a motivational tool and has shown to increase the time patients train as well as the frequency. It is neuroscience based; it activates the processes for observation and execution, learning and recovery. It is a specific training method of the capabilities of the user as it allows flexibility in creation of different scenarios depending on the need of the patient. It also measures performance quantitatively and allows for continual monitoring of the patient over time.

The 3 main purposes of using VR in therapy according to Reiner et al. [3] is to provide biofeedback to the patient, augment a real scenario by adding audio-visual features and to increase patient motivation. Biofeedback allows the patient to know about the quality of the motions performed, and virtual scenery can encourage active movement instead of passive. Studies have shown that it promotes the improvement of functional parameters such as muscle force, active range of movement and motor recovery.

The feedback provided needs to be displayed suitably for the user. Patients with neurological diseases or injuries may also suffer cognitive defects, therefore they benefit from reducing values and a visually appealing display such as a traffic light or a smiling face to reflect performance, whereas patients suffering from spinal cord injury often prefer a complete set of data including history of past performance values. A more advanced method is to have a representation of a realistic scenario, which allows the patient to immerse themselves in the virtual environment, as incorporated in the Lokomat gait training system, ARMin [3], and Gentle/G system [4]

This sort of simulation and feedback is possible with the use of robot aided devices, as they contain sensors, motors etc. that can input the data into the VR or control system to emulate the motions of the patient or to output as feedback.
However in this work, we do not need to have a robot, and without needing to buy too many sensors, It focus on the need of a system that could simulate the movement of the patient with as little hardware as possible, such that it is easier for the patient to use and cheaper for them to attain.

2. SYSTEM CONTROL ARCHITECTURE

Our system control Architecture built based on four layers that reflect the main controller of the system.

The input layer is comprised of the Wii controller and mouse. The mouse is for user input into the GUI. The Wii controller is interfaced with the system, such that raw data sent from the device is recognised when sent to the control or display layer, shown by the blue arrows in Fig. 1. This has done to reduce program cycle times and reduce the computational load.

The control layer manipulates data sent from first layer to display on the VR environment. The display layer is the output of the system; showing the GUI for user input and the effects of user interaction shown on the VR as an interactive environment.

3. HUMAN MODEL

The human model was developed to provide visual feedback of user actions either in free motion or when playing the games.

Development was progress on the creation and simulation of an arm to creating an entire human body that could also be manipulated by an adaptable control system. Consequently providing a more pertinent graphical representation for the user and allowing for a more flexible system that can be used in a variety of applications. There is potential for it to function in a control system for an exoskeleton structured robot or controlled prosthetic.

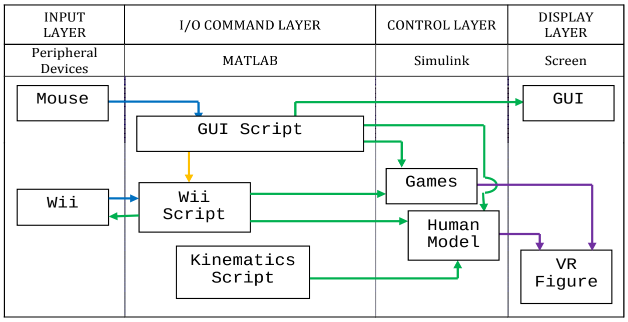

Figure 1. System Control Architecture

The development was based on the mathematical and kinematic models of the arm to calculate the individual position and orientation of each link by specifying the position of the end-effector.

The mathematical model of the arm was formulated using Denavit-Hartenberg (D-H) convention. The D-H model was created by relating each link's frame of reference on the arm with the preceding link's frame of reference, where the frame of reference is established depending on the translation and rotation in the x-axis (a and α respectively) and the translation and rotation in the z-axis (d and Ɵ respectively). Each property used in D-H convention is constant, except if the joint is a revolute type, where rotation in the x-axis (α) is variable, or when the joint is prismatic, where translation along the z-axis (d) is variable.

The cylinders represent the axis of rotation for each joint. The mathematical model was applied to the structure from the shoulder to the hand, even though this may consist of up to 9 degrees of freedom (DOF), a 6 DOF model was chosen as the kinematics applied can only calculate up to 6.

D-H method was chosen as it only requires 4 parameters to describe the relationship between links making the calculations easier and faster to compute, whereas pose matrix uses 6 parameters, 3 parameters to describe the orientation of the frame and the other 3 to describe the orientation of the link in Euler angles. The D-H parameters were tested by altering the initial orientation of each link to match the orientation of VR model arm and then visually observing the rotation of each link.

3.1 Kinematic Model

Once tested, the D-H parameters were then used to develop the forward kinematics of the model. Forward kinematics calculates the end-effector position in terms of each of the joint variables. This is done by determining a homogeneous transformation A_i which is a product of the D-H parameters of one link.

Each homogeneous transformation matrix is then multiplied with the next link's matrix until the last link is reached. The forward kinematics of the last link in the X, Y and Z global axis is determined in the last matrix.

The X, Y and Z coordinates were then used to calculate the inverse kinematics. The inverse kinematics calculates the joint variables in terms of the end-effector position. This is done by differentiating each joint angle with respect to time which provides the angular velocity of the joint rotation with respect to the end-effector joint angular velocity The Jacobian is used in the model such that at every time unit, an updated end-effector position is computed from the previous joint angles determined by the forward kinematic equations.

3.2 VR Model

The human model was created in *V-Realm Builder*. It was decided to use a pre-built model 'Hiro' from *DAZ Studio 3*. This was exported as a Wavefront Object (.OBJ) to *V-Realm Builder*. Since the model was built for animation purposes, when imported into *V-Realm Builder*, all the body parts were separated in groups on the node tree, it was then saved as a World file (.WRL). The parts of the model that required manipulation were the links from the shoulder to the digits.

Initially, the 'Collar' group consisted of the chest, shoulder and part of the upper arm, such that the upper arm would not rotate around the shoulder joint as required for simulation. Thus some shape editing was required to separate the top part of the upper arm and attach it to the rest of the upper arm. This proved to be quite difficult due to the lack of shape editing capabilities in *V-Realm Builder*, thus it required creating two identical 'Collar' group objects and cutting away the unwanted part for each, thus creating separate upper arm and shoulder. The cutting also proved difficult due to the high resolution/fine mesh structure of the model, as it required selecting the individual geometric shapes to be deleted.

Once that was complete, focus was turned to the structure of the arm on the node tree. As the arm structure is an open kinematic chain, the links had to be rearranged in the node tree such that the parent link pointed to the child link i.e. the upper arm was the parent link to the forearm child link and the forearm was the parent link to the hand child link and so on to the end link; the last link of the digits. The digits were arranged such that they were brother links as they had the same parent link. Each finger was separated into three parts: the distal, middle and proximal phalanges while the thumb only having two: distal and proximal phalanges. They were rearranged such that the proximal phalange was the parent to the middle phalange child link which was parent to the distal child link. This parent-child relationship was incorporated to ensure any motion of the parent link will have an effect on to the child links in the simulation.

a maximum of three separate transforms for the particular link was created; labeled with prefix X, Y and Z. They were also then arranged in the node tree such that they had a parent-child relationship. Each link could be rotated individually in the X, Y and Z planes as this is what was required when linked to the kinematic model. The final product is shown in as show in Fig. 2 was used in this system.

While for finding the Virtual Force Field, initially, the 'Cartesian control' control system in the robotics toolbox was used to calculate the position of the end-effector. However even it was successful, it is prove to be computationally heavy.

Thus it was decided to compare the VFF method [5] against the 'Cartesian control' was able to run faster. VFF is a type of torque based position controller; it works by determining the virtual torque that is required to move the end-effector to a particular position.

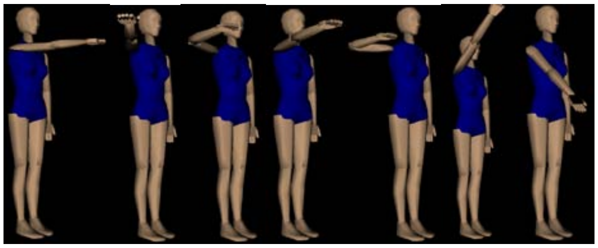

Fig. 2 Human Model in V-Realm Builder

The inputs to the system are read from the *Wii* controller that specifies the intended X, Y and Z coordinates for the end-effector to move to.

For each X, Y and Z coordinate the variation between the intended and actual values are calculated. This difference is the distance that the end-effector needs to travel in each axis.

The virtual torque is then calculated the distance required to move. This is done by combining the distances in an array to be multiplied by the virtual force, for simplicity a force constant was used. The virtual torque is then multiplied with the inverse Jacobian to provide the joints' virtual torque required per time step, as the *Jacobian* calculates the derivatives of the forward kinematics which is the time steps for the end-effector, thus the inverse block inverts the Jacobian and outputs the time steps for each joint.

Testing the VFF control system was done visually with the VR interactive environments by comparing the location of the hand of the model to the current position input initially using slider bars, and then using the *Wii* controller. The VR output displays the VR interactive environments response to the user movement in the X, Y and Z axes, screen captures of the right arm are shown in Fig. 2.

4. GAMES

The means of the games was to show that whilst providing a range of movement that is safe and appropriate for exercising the arm, they also motivated the user to play for longer periods of time and for more frequently.

All games are controlled and displayed in VR interactive environments; each game provides scoring and has the potential to record high scores. The games are played with the use of the *Wii*

Two games, the Rolly and *Whack-a-Mouse,* had designed.

4.1 Rolly game

The Rolly game was developed to exercise the pronation/supination of the wrist or the medial/lateral rotation of the forearm or upper arm by requiring the user to control the beam angle with the rotation of their arm or wrist whilst holding the *Wii* controller. The purpose of the game is to keep the ball balanced on the beam. The user is then required to roll the ball off the beam when instructed to and balance it again on the next beam. This is continued until 7 successful attempts are achieved; otherwise they are required to restart at level 1. Difficulty is increased by reducing the coefficient of friction of the beam, causing the ball to roll faster. Scoring is based on how many levels can be completed sequentially.

For rehabilitation purposes the game is intended to increase the range of rotational motion of the upper arm, forearm and wrist as well as increase strength and control of the muscles in use by isolating certain parts of the arm. By increasing the speed of the ball and the length of the bar, the user should improve on their reaction time and control of the muscles in use.

The resulting VR output from the *Rolly* block displays the VR interactive environments response to the user movement whilst playing the *Rolly* game, screen captures of the right arm are shown in Fig. 3.

The edge detection compares the X position of the ball and the X position of the edge of the beam depending on the length of the beam; the length is modified with the level of difficulty. The score is increased every time the ball falls when specified and in the correct direction. If the ball falls when specified, and the outcome of the X position of the falling ball compared to the X position of the ball after it has fallen (to determine if it has fallen right or left) matches the specified direction then the score is incremented. The ‘Reset’ output is on if those conditions are not met. The ‘High Score’ output is determined by comparing the current score with the previous score stored. And it resets when the program restarts. The score is hidden when the ball is falling.

4.2 The Whack-a-Mouse Game

The Whack-a-Mouse game was developed to exercise the forward movement of the arm and elevation and depression of the wrist to form a whack-like motion. The purpose of the game is to target the mice when they emerge from the ground by performing the ‘whack’ before they retreat back into the ground. The user is required to target as many mice as they can before the time runs out, the difficulty can be increased by increasing the number of mice and the speed of the mice. The score is based on the number of mice ‘whacked’.

For rehabilitation purposes the game is intended to increase the range of forward movement of the arm, range of movement and flexibility in the wrist, speed and overall accuracy in placement of the arm.

The *Whack-a-Mouse* controller is used to control of the human model whilst playing the *Whack-a-Mouse* game, such that the model mimics the actions of the user. The control system is required to simulate a ‘whacking’ motion. The change made in the *Whack-a-Mouse* the last angle; the wrist joint is manipulated independently to the arm, by inputting raw data from the *Wii* controller directly to the *Whack* block to simulate a joint angle. Display the resulting VR output from the *Whack-a-Mouse* block displays the VR interactive environments response to the user movement whilst playing the *Whack-a-Mouse* game, screen captures of the right arm are as Fig. 4. shown.

As shown the VR receives inputs to control the three mice. These inputs and the corresponding subsystems and outputs of each subsystem are shown in Fig. 4.

5. CONCLUSION

The main achievement is that the system allows the user to view their actions as feedback whilst they play the games, which is provided to engage the user, such they are motivated to exercise for longer. As well as with manual control of the arm in the X, Y and Z directions showing the force feedback for the user. The user is able to interact with the program easily through the GUI by selecting from a range of options each promoting self-rehabilitation. The success of the mathematical model, kinematic model and control system that was integrated into the system provided easy implementation of peripheral devices and a reduction in input data required to control the model. The games with the use of the Wii controller has the potential to provide active rehabilitation, for example when playing the *Rolly* game the aim is to increase the range of motion in rotation as well as control of muscles in stabilising the beam. With further work the accuracy of the Wii controller can be more achieved.

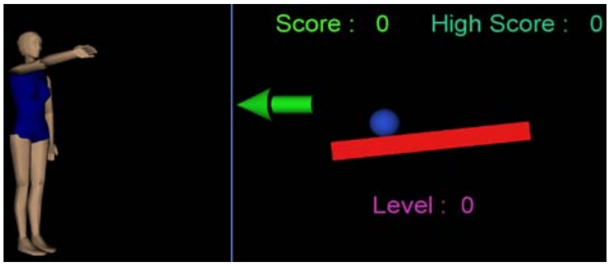

Fig. 3 Movement of the VR figure whilst playing the Rolly game

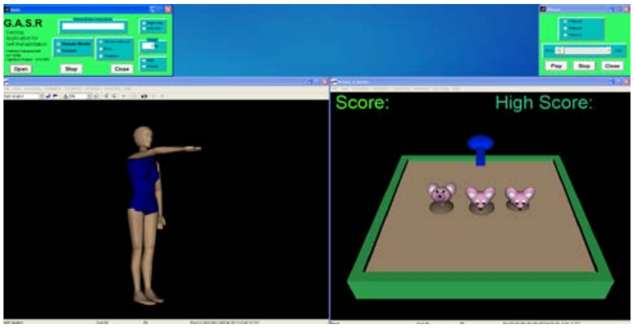

Fig. 4 Combined Human Model and Game Display

Future development is also required to implement an additional hand and finger rehabilitation component of the system would require feedback similarly done with the arm, this could be easily integrated into the current system. Thus this would include representing a grasping motion of the digits (fingers and thumb) either by hard coding the values or using a similar modified control system that is able to manipulate each digit individually.

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