Interactive Visual Feedback for Mixed Reality Stroke Rehabilitation

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ABSTRACT

This poster describes interactive visual feedback for mixed reality stroke rehabilitation as part of a coordinated submission of posters on mixed reality stroke rehabilitation at Arizona State University. The Mixed Reality Rehabilitation project aims to develop a real-time multimedia system for upper extremity rehabilitation of stroke survivors through task-oriented physical therapy. Posters representing the system are accompanied by a video demonstration. This paper describes the design and function of the visual feedback as one component of the overall rehabilitation system. The visual feedback is designed to inform the subjects of the spatial aspects of their movement as a reaching task is performed. The use of an abstract virtual environment facilitates therapy sessions by removing the subject from his or her own action space, allowing a re-contextualization of the physical task at hand and promoting learning at the level of generalizable movement principles.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems - *Artificial, augmented, and virtual realities.*

General Terms

Design, Experimentation

Keywords

Mixed Reality, Stroke Rehabilitation, Visual Feedback

1. INTRODUCTION

As the leading cause of adult disability in the United States [1], stroke poses major challenges to develop effective rehabilitation that actively promotes motor function recovery. Experiential media systems create environments in which immersion and interaction of the participant results in learning from the individual's experience. Creating an interactive environment in the context of physical therapy increases subject motivation and engagement, leading to active participation and learning by the stroke survivor.

The Mixed Reality system enhances two major aspects of traditional task-oriented therapy for stroke rehabilitation, analysis of subject movement and feedback reflecting subject performance. Motion capture allows for real-time monitoring and analysis of the subject's arm, hand and torso movement during a reaching task. Reach performance and results are coupled to multi-modal feedback, also articulated in real time. For further description of the overall system design, please refer to the accompanying poster "Integrating Arts and Computation in Mixed Reality Stroke Rehabilitation."

The interactive feedback component of the system is crucial to a) distancing the subject from the challenges of the physical task, b) intuitively communicating amplitude of error and direction for improvement and c) maintaining subject engagement in repetitive task-oriented therapy. Through the use of music composition and visual arts principles, the audio and visual feedback together create an informative and meaningful experience for the subject. The integrated multimodal feedback utilizes the ability of visuals to better communicate spatial/target information, and the ability of audio to better communicate complex time series data associated with the reaching task [2]. For further description on the role and implementation of audio feedback, please refer to "Parametric Musical Sonification for Mixed Reality Stroke Rehabilitation." The visual feedback is designed to improve the subject's reaching performance, with minimum spatial error with respect to a direct path to the target, as well as appropriate hand speed and hand orientation [3].

2. VISUAL FEEDBACK ENVIRONMENT

The physical system set-up in part includes a table and chair facing a large screen display, flanked by 2 speakers. The subject seated at the table wears a total of 12 markers on his or her torso, right arm, and hand, tracked by 8 motion capture cameras. The large screen display provides an immersive environment for motor skill training that is less likely to cause cyber-sickness than a completely immersive virtual environment [4].

2.1 Role of Abstract Environment

The screen displays a sequence of interactive graphics, collectively referred to as the "abstract environment." Previous virtual environments used with stroke patients have directly represented the physical environment by displaying an arm, table, and drinking cup as reaching target. As the patient moved his or her arm, the virtual arm moved accordingly to directly reflect the subject's movements. This environment is useful for orienting the subject by demonstrating his or her direct control of the graphics with hand movement. However, it is not as successful in removing the subject from his or her own action space as a visually abstract environment.

In a traditional physical therapy setting, the subject can focus on the challenges presented by the impaired arm and/or hand, which may be detrimental for recovery. Several studies have demonstrated that motor skill learning required for successful rehabilitation is better accomplished by shifting the learner's attention to more remote effects within a distant action space [5]. Our system maps the patient's movement while he or she is performing a traditional therapy task (reaching to grasp/touch) to the composition of an interactive artwork. The mapping helps distance the patient from the actual task of reaching by having him/her focus instead on the development of cognitive and movement strategies that better perform the interactive composition. The system intuitively communicates to the subject measures of performance and improvement direction for all key aspects of his or her movement. The system includes training in hybrid (physical-virtual) environments that help connect the subject's learning in virtual environments to execution of daily functional tasks in the physical realm. Within this rich interactive context, the patient is empowered to abandon compensatory strategies and relearn premorbid movement patterns.

2.2 Visual Feedback and Phases of Reach

The abstract environment displays an image consisting of small particles that coalesce or move apart depending upon the subject's reach progression and performance. A reach is segmented into six phases, each with corresponding audiovisual feedback. This paper describes only the corresponding visual feedback associated with each phase.

2.2.1 Overview of Particle Movement

The image is broken into a 60x40 grid of particles. Each particle is a quad polygon with four vertices and four texture coordinates. The vertices locate the particle in three-dimensional space, while the texture coordinates provide a two-dimensional mapping to a color from the image. Each particle has an offset that locates its relative original position in the picture. The motion of the particles has five components: four motion vectors - explosion, turbulence, horizontal pull, and vertical pull - and rotation angle. The position of a particle is calculated with a translation of the motion vectors followed by the rotation. Hand orientation controls the image rotation angle (Figure 1a). The difference between the expected hand orientation angles and subject hand orientation angles is mapped to image rotation [2].

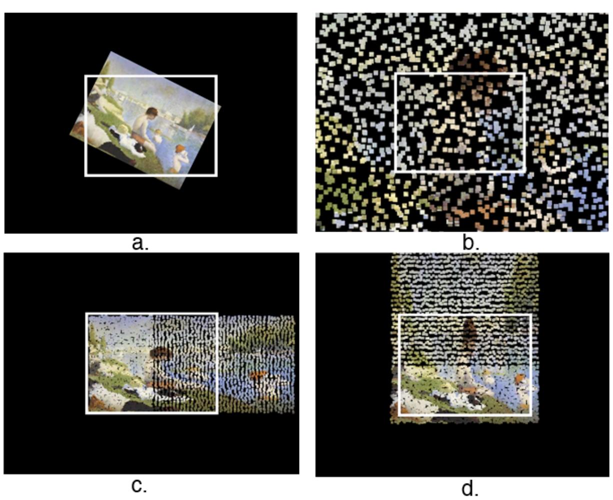

Figure 1. Abstract environment visuals (a) Image particles rotate with hand orientation. (b) Image explodes towards subject until particles fill the screen. (c) Subject reaches too far to the right of target location. (d) Subject reaches too far above the target location.

2.2.2 Phases

The target image is initially displayed inside a white frame, which informs the viewer of its appearance upon completion of the reach task. In order to increase engagement, the image may be customized depending upon subject interest. In the initial *ready check* phase, the subject is in rest position, and the system checks if the subject is ready to start reaching. If the subject is slouching, the particles move around slightly to blur the image. The image focuses after the subject corrects his or her posture. Once the patient is ready to begin the reach, the phase shifts into *reaction*, in which the image explodes. During image explosion, the particles quickly separate and approach the foreground of the virtual space, filling the screen (Figure 2b). The resulting perception is that the particles have moved closer to the subject and away from their initial position. The completion of image explosion signals the subject to begin *reaching.*

As the subject's hand begins to move away from the rest position, the particles move closer together as they recede back into virtual space towards their starting position. The effect of the particles assembling positively reinforces the subject's forward hand movement toward the target by (1) pulling the subject further into the virtual space with particle motion and (2) encouraging the subject to view an intact image upon task completion. The z' distance is the shortest distance from subject rest position, z' = 1, to the target position, z' = 0. As z' distance approaches 0, the particles return to their origin and reassemble the picture. A non-linear mapping function is used to control particle coalescence, which allows the subject to quickly view the assemblage of the picture. If the subject reaches past the target position, the image shrinks to a smaller size than the frame to indicate overshoot. Image size correctly adjusts as the subject retracts his or her hand.
For each subject, the system is initially calibrated to determine a customized and adjustable reaching path appropriate for the subject's abilities. The path is surrounded by an adjustable 3-dimensional volume (called the tolerance hull), which accounts for adjustments during movement for the specific subject. During reaching, particles move back in space to ultimately assemble the picture as long as the subject's hand trajectory remains within the customized hull. Moving outside this hull-space in any direction will result in the particles shifting in the direction of error (Figure 1c,d). The resulting stretch of the image provides real-time feedback for the subject to adjust his or her reach accordingly to reduce error. For more information on system adaptation and customization, please refer to "Media Adaptation Framework for Mixed Reality Stroke Rehabilitation."

One feature also present throughout the reaching phase until completion is particle turbulence, which is a random, though contained movement of the particles, computed using the Perlin noise function [2]. Turbulence provides a dynamic visual cue to the subject that the reaching phase is not completed. The subject completes the reaching phase by satisfying a set of adaptable parameters customized to the subject. These parameters include hand presence in the grasping zone, hand orientation, low hand velocity, measures of shoulder and torso compensation movement, as well as maintaining these parameters for a specified amount of time.

After these requirements are satisfied, the subject enters the *grasping* phase. The target image is in focus and completely assembled inside the frame, which indicates grasp completion.

When the subject returns to the rest position, as the hand crosses the edge of the grasping zone, the current phase shifts into *returning*. Above the target image appears a diamond symbol that tracks hand movement, and a cross symbol that indicates the rest zone. Matching the diamond above the cross guides the subject to return to a position within the rest zone before resting the arm and entering the *stop* phase. This cycle completes one trial of the reaching task therapy.

2.3 Error and Feedforward Planning

Real-time visual feedback is mapped to hand movement and allows for spatial adjustments by the subject throughout a reach.
As the subject uses the system over several trials, he or she develops a memory of the muscle and feedback effects that are associated with correct performance. This feedforward effect contributes to planning by the subject for action in successive reaches [2]. In addition to the real-time movement of particles that follows hand trajectory, a visual summary of error also reinforces this planning process.

The current visual feedback used in the Mixed Reality system indicates the location of error in the 2-dimensional plane parallel to the display screen. However, it is difficult to easily understand the approximate moment along the hand trajectory at which an error occurred. A main challenge in using a two-dimensional representation of the physical reach is demonstrating information relevant to the third spatial dimension z'.

One approach to summarizing error during reaching is freezing selected particles as error occurs. When an image is stretched from one side due to hand trajectory error, selected particles from the stretched side are frozen in space. These frozen particles are also tinted a shade of red, ranging from low to high tinting to indicate when error occurred. The pattern of the frozen particles serves as memory for the subject to consider where and when error was made. Because the error is displayed during the reach, the frozen particles sometimes interfere with viewing real-time feedback and hand path adjustments. Also, the subtle gradation of red tinting alone makes it difficult to discern time of error along the path.

A future approach to summarizing error would display the summary for the subject upon task completion. To represent error, frozen particles would follow perspective lines leading towards the center of the image. The exaggerated perspective of the virtual space helps to indicate at what time of the reach error occurred. If error occurred towards the beginning of a reach, for example, it would appear closer to the viewer, while error made in later stages would appear more distant in space.

3. CONCLUSIONS

The audiovisual feedback used within the mixed reality system is intended to intuitively guide the subject. The more information that the stroke patient can independently detect for his or her learning, the more self-guided the therapy will become. The feedback used within the Mixed Reality project provides meaningful multi-modal information that maintains active engagement by the subject throughout the physical therapy session. The use of an abstract virtual environment removes the subject from concentrating on the challenges of the physical task at hand. Dynamic, engaging feedback based on arts principles avoids a passive rehabilitation experience. Active participation by the subject promotes neural plasticity for recovery of motor and cognitive function. Patient improvement as a result of using the system is evaluated by kinematic analysis of reaching trials over time. For more information on kinematic results, please refer to "Improvement in Reach Kinematics from Training in a Mixed Reality Stroke Rehabilitation Environment."

4. REFERENCES

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