A Real-Time, Multimodal Biofeedback System for Stroke Patient Rehabilitation

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ABSTRACT

This paper presents a novel real-time, multi-modal biofeedback system for stoke patient therapy. The problem is important as traditional mechanisms of rehabilitation are monotonous, and do not incorporate detailed quantitative assessment of recovery in addition to traditional clinical schemes. We have been working on developing an experiential media system that integrates task dependent physical therapy and cognitive stimuli within an interactive, multimodal environment. The environment provides a purposeful, engaging, visual and auditory scene in which patients can practice functional therapeutic reaching tasks, while receiving different types of simultaneous feedback indicating measures of both performance and results. There are two contributions of this paper – (a) identification of features and goals for the functional task, (b) the development of sophisticated feedback (auditory and visual) mechanisms that match the semantics of action of the task.

Categories and Subject Descriptors

J.3 [**Life and Medical Sciences**]: Health; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *auditory (non-speech) feedback, screen design, interaction style*

General Terms

Design, Experimentation, Human Factors

Keywords

Biofeedback, Analysis, Action-feedback coupling

1. INTRODUCTION

The goal of this paper is to design a real time multimodal biofeedback system for stroke patient rehabilitation. The problem is important – every 45 seconds, someone in the United States suffers a stroke [3]. It results in functional deficits of neuropsychological and physical functions in post-stroke survivors. Up to 85% of patients have a sensorimotor deficit in the arm, such as muscle weakness, abnormal muscle tone, abnormal movement synergies, and lack of coordination during voluntary movement [2]. Biofeedback can be defined as the use of instrumentation to make covert physiological processes more overt while including electronic options for shaping appropriate responses. The use of biofeedback allows the patient who has sensorimotor impairment to regain the ability to better discriminate a physiological response [5].

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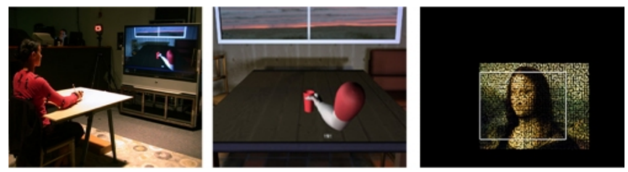

Figure 1: Left: biofeedback space. Middle: transition environment. Right: abstract environment.

Virtual reality (VR) is an emerging and promising technology for task-oriented biofeedback therapy [6]. This has significant potential in being more effective for task-oriented therapy training because it can offer real-life experiences by providing visual, auditory and physical interactions in an engaging manner. In our system, we present two key contributions:

- *Analysis*: We developed domain specific, highly detailed motional analysis to promote therapy of the reaching functional task.
- *Feedback*: Development of three multimodal feedback environments, with increasing levels of complexity, and coupled to the three semantic goals: *reach*, *open* and *flow*.

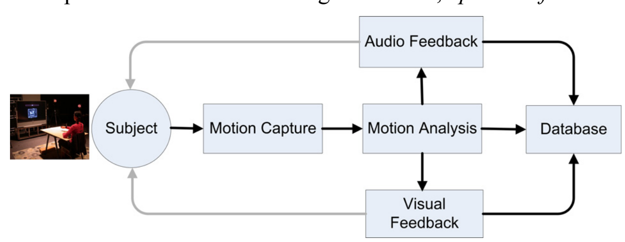

Figure 2: The biofeedback system diagram

2. THE BIOFEEDBACK SYSTEM

The Biofeedback system integrates five computational subsystems: (a) Motion capture; (b) Motion analysis; (c) Audio feedback; (d) Visual feedback; and (5) Database for archival and annotation. All five subsystems are synchronized with respect to a universal time clock. Figure 2 shows the system diagram. The motion capture subsystem uses six calibrated and infrared cameras with up to 100 frames per second to track 3D reflective markers that are placed on the subject. The real-time motion analysis subsystem smoothes the raw sensing data, and derives an expanded set of task specific quantitative features. It multicasts the analyzed data to the audio, visual and archival subsystems at the same frame rate. The audio and visual subsystems adapt their auditory and visual response dynamically to selected motion features under different feedback environments. The archival subsystem continuously stores the motion analysis as well as the feedback data with universal timestamp, for the purpose of annotation and off-line analysis. Personalized distributed and synchronized annotation is presented in real time for therapists, motion analysis, audio and visual feedback researchers to annotate from different perspectives.

2.1 Action Analysis

We use 14 labeled 3D markers to represent subject and chair (11 markers on subject's arm and torso, 3 markers on the chair back). The label specifies the location of each marker. Using the 3D positions of these markers, we compute hand/shoulder trajectory, hand-target distance, eleven joint angles and shoulder/torso compensations. For each feature, we also compute both the first and second time derivatives of features (velocity and acceleration). Based on domain knowledge of the reaching and grasping arm action, we group these features into six levels, with level 1 being the most important. With these motion features, we can derive three sub-goals of reaching and grasping task: (a) *reaching* the target, (b) *opening* of the arm joints and (c) *flow* of the movement.

2.2 Coupling Action to Feedback

The structure of the feedback environment and its relationship to the achievement of the goals are based on well established principles regarding the role and function of art [4]. At the highest level of its structure the environment must communicate to the patient the messages that can encourage the accomplishment of the movement goals. These messages are: *reach*, *open*, *flow*.

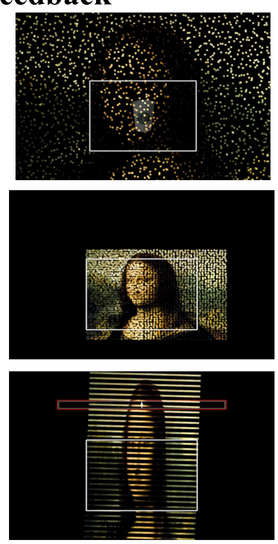

Figure 3: Visual feedback in the abstract environments. Top: particles begin to form the image as the hand approaches the target. Middle: Image pulled to the right when subject is off target. Bottom: Vertical bands appear when the subject has wrong target height.

The feedback images used are all well known paintings and the music played is based on well established rules of western classical music. Thus the content has a high probability of attracting and engaging the subject and deepening their immersion in the experience.

The overall idea driving the mappings is that spatial and target information is better communicated through visuals and complex time series data is better communicated through audio. The movement parameters allowing successful manipulation of the environment are the key parameters of an everyday reaching and grasping movement. Thus, the environment can be easily connected in terms of action to its goal and does not require unintuitive movement learning that is an artifact of the interaction.

The mappings and content follow a similar structural hierarchy as the movement parameters and goals with sub-message levels supporting the communication of each larger message. As is the case of movement parameters, there are feedback parameters that the subject can quickly understand and control, parameters that require practice to control and subconscious parameters supporting the achievement of the consciously controlled goals.

- *Reaching* is encouraged through the implied existence of a visual target, an image completion/reassembly task, a visual centrifuge effect pulling forward towards the target, and an accompanying musical progression that requires completion and encourages movement towards the implied target.
- *Opening* is encouraged through the control of a rich, resonant musical accompaniment.
- *Flow* is encouraged by pointalistic sound clouds in the main musical line, flowing particles in the visuals, a smoothly swelling and dipping, wave-shaped musical accompaniment, promotion of synchrony of the involved musical lines and an overall selection of relaxing sound timbres and images.

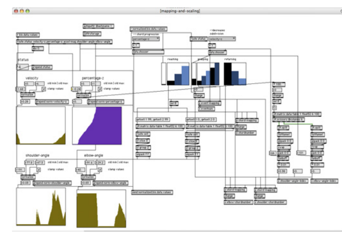

Figure 4: Audio feedback engine

3. DEMONSTRATION SETUP

We will calibrate the motion capture subsystem by following the standard calibration procedure provided by the Motion Analysis Corporation [1]. The demo subject will wear a body suit on which 11 markers are placed on the arm, hand and torso. At one end of the table, the domo subject sits on the chair where we place 3 markers. At the other end of the table there is a screen showing up the visual feedback. Six motion capture cameras are looking over the entire capture volume. We are planning to run *motion capture*, *motion analysis*, *audio feedback*, *visual feedback* and *archival* subsystems on three computers, play the audio feedback with two stereo speakers and show visual feedback using a projector.

Our demonstration will gradually switches from non-feedback environment, to transitional environment and to two feedback environments with different complexity. Each environment has exactly the same target position whether it is physical target or virtual target that has been put on the screen. Before each feedback or non-feedback environment demo, demo subject will be given proper instructions. The demo subject will experience environment as well as real-world for patient rehabilitation.

4. REFERENCES

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