

Media Adaptation Framework for Mixed Reality Stroke Rehabilitation

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ABSTRACT

This paper presents a design of media adaptation framework for mixed reality stroke rehabilitation. The problem is important as the effective media adaptation frameworks help patients recover generative plans for arm movement with potential for significantly shortened therapeutic time. The media adaptation problem has significant challenges – (a) high dimensionality of adaptation parameter space (b) variability in the patient performance across and within sessions (c) remain attentive and motivated during a long and tedious session. The major contribution of this paper is the development of a task-based media adaptation framework which addressed task adaptation, intensity adaptation and parameter adaptation. We apply this framework for three real stroke patient rehabilitations with excellent results.

Categories and Subject Descriptors

J.3 [Life and Medical Sciences]: Health; H.5.3 [Group and Organization Interfaces]: Computer-supported cooperative work;

General Terms

Algorithms, Experimentation, Human Factors,

Keywords

Media adaptation, Decision making

1. INTRODUCTION

The goal of this paper is to design an adaptive, customizable protocol for media adaptation for a specific type of an experiential media system – a stroke patient rehabilitation system [1,2]. In this system, the knowledge that is to be transferred is restricted to a simple, but important functional task – to reach out and grasp a cup. This simple task is enormously challenging for stroke patients, who have lost the ability to control their arm, and hence must be re-trained (i.e. they need to relearn the necessary motor control) to perform the task. Since experiential media systems are integrated with the physical world, the parameter space that is required to adapt the system, so as promote optimal transfer of knowledge, is very large (~250 parameters in our system). Determining which parameters need to be changed, online, is therefore a highly challenging task.

There has been prior work on biofeedback therapy. Virtual Reality (VR) is an emerging and promising technology for task-oriented biofeedback therapy to improve motor function in individuals with stroke [3]. VR can provide an effective human computer interface that allows users to interact with a complex, highly detailed and engaging multimodal feedback in response to physical action. This has significant potential in augmenting traditional task-oriented therapy training. It has been shown that task learning in a VR can be transferred into real world task

performance [4]. Holden et al. [3] utilized VR to train reaching and hand orientation of stroke patients by developing a virtual mailbox environment with different slot height and orientation. However, these systems are fixed and *not* adaptive to patients.

The main contribution of this paper is in the development of an adaptive, customizable media adaptation framework in our biofeedback system for stroke rehabilitation. We apply this framework on real stroke patient rehabilitations. The experimental results proved that our adaptation framework works well.

2. MEDIA ADAPTATION OVERVIEW

In this section, we discuss the media adaptation problem in our biofeedback system [1], present the key challenges of adaptation problem and finally propose our solution.

2.1 The Problem

The media adaptation problem is *how to adapt the biofeedback environment to help subject acquire a generative plan for reaching and grasping movement*. In our mixed reality stroke rehabilitation, we have three kinds of adaptations: (a) task adaptation, (b) intensity adaptation and (c) parameter adaptation.

Task adaptation: We predefined 12 rehabilitation tasks in our system. The complexities of these 12 rehabilitation tasks increase gradually. These 12 rehabilitation tasks are divided into three steps: reaching, flow and grasping.

Intensity adaptation: The intensity refers to the upper bound of number of sets for each task. If the number of the sets for the current task exceeds the upper bound, we jump to another task to avoid boredom.

Parameter adaptation: The therapist and media expert can add variations within the task by adapting control parameters that include the movement error thresholds for movement parameters, individual media streams, verbal instructions and tangible feedback.

The media adaptation is important for several reasons: (a) patients are very different in terms of their capabilities, (b) there is significant performance variability within the same patient across different days and (c) we need to change the environment for patients to learn all the variables of the motor plan (d) the environment change helps patient's engagement in rehabilitations. Note that while the adaptation is important, we can not change too quickly, as this will affect learnability and patient engagement.

2.2 Why is it difficult?

The media adaptation is challenging because of three reasons:

1. *High dimensionality* – the dimensionality of the space for both subject's arm movement and environment parameters are very high. There are more than one hundred parameters related

with multi-joint coordinated arm movement training and environment parameters.

2. *Consistency* – we have had over 30 sessions with the patients and a key observation of stroke rehabilitation is that the subject physiological conditions are different across sessions.
3. *Engagement* – it is challenging for the subjects to remain attentive and motivated during a long and tedious session and they easily become physically and mentally tired.

2.3 Rehabilitation Procedure

We now introduce the rehabilitation procedure by using our biofeedback system. Let us denote every subject visit as *session*. For each session, there are several sets. In each set, the environmental conditions (e.g. physical state, audio and visual parameters) remain fixed. Each set includes ten reaching trials. In each trial, the subject reaches out the right arm toward the virtual target, grasps the target and returns back to the rest position. Figure 1 shows the rehabilitation procedure.

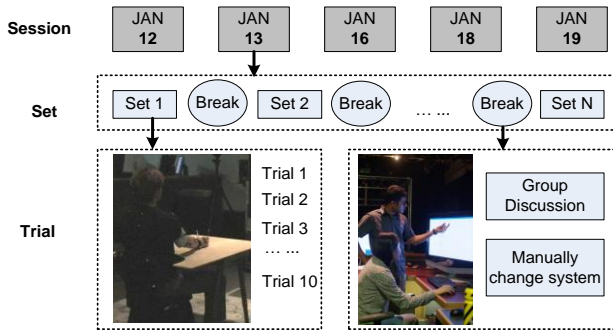


Figure 1 Rehabilitation procedure.

2.4 Overall Adaptation Structure

The adaptation includes three steps:

- *Reaching* – we focus on achieving desirable movement speed, reaching time consistency and end point accuracy. It primarily trains reaching movements. It includes three tasks (i.e. 1A, 1B and 1C).
- *Flow* – we concentrate on constraining compensations, improving joint function and synchrony and achieving an improved velocity profile. The movement complexity increases as reach and touch movements are primarily executed. It includes three tasks (i.e. 2A, 2B, and 2C).
- *Grasping* – we introduce forearm rotation, grasping and an enhanced focus on trajectory accuracy. It includes six tasks (i.e. 3A, 3B, 3C, 3D, 3E and 3F).

The complexity in reaching step is smaller than flow and the flow has smaller complexity than grasping. Within each step, the task with larger index has larger complexity (e.g. 1A<1B<1C). In each task, we have a movement performance improvement goal for the subject to achieve with respect to a set of movement parameters. A task is considered complete when the indicative movement improvement thresholds for the task are achieved. A step is complete when all constituting tasks have been completed.

Approximately 16 sessions are needed for the completion of the full protocol (completion of all three steps for all four targets). Each session should not exceed one hour or 120 reaches (12 sets of 10 reaches) to avoid fatigue. If fatigue appears earlier the session should be temporarily stopped or ended depending on the

level of fatigue. Each session should start with a set of physical cup reaches at the target location where the previous day ended. Then the session should continue with a repeat of the last mixed reality set used in the previous session. However, if all three steps for a target location have been completed in the previous session then the current session should start with a physical cup reach to a new target location followed by Task 1A in the new target location.

3. ADAPTATION DECISION MAKING

We now discuss the adaptation decision making procedure between two consecutive sets. Figure 2 shows the adaptation decision making diagram. First we need to check if the subject stays in the current task long enough (intensity adaptation) to avoid boredom. Second, we decide to move task forward/backward or stay in the current task based on the patient performance. Finally, if we stay in the current task, we decide how to change control parameters to help patient rehabilitation.

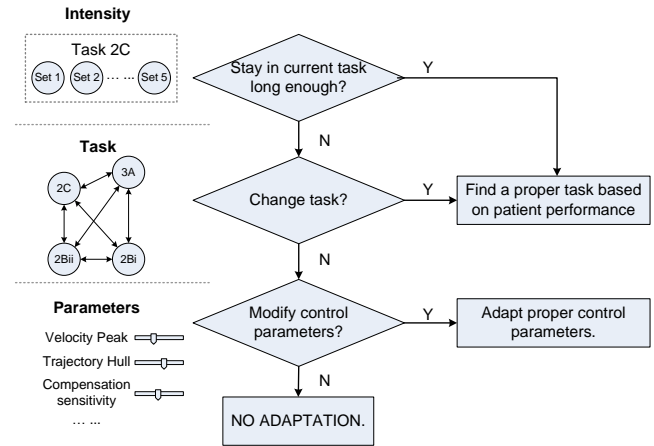


Figure 2 Adaptation decision making diagram.

3.1 Intensity Adaptation

Task intensity refers to the upper bound of number of sets to stay in the task. There is no lower bound. If this upper bound is achieved, we move the task to avoid boredom even if the subject has not achieved the thresholds of movement improvement for the current task. This is because that boredom with repetitive tasks and improvement in movement must be balanced. Boredom with a task and loss of interest can reduce performance. Repeating, or even realizing a task, to gain small improvement in movement should only be done if that improvement is crucial.

One extra set (and in exceptional cases two) past the upper bound is allowed only if the therapist and media expert believe that the subject's progress will benefit from the extra set(s). Therefore, a task is complete if either the movement performance threshold or the upper boundary of sets plus one has been reached

3.2 Task Adaptation

The task adaptation means how to select the next task after the current task is complete. The sequence of steps and tasks given in this protocol is the most gradual. Tasks can be skipped if subject's progress is faster (i.e. sub-goals related to a task have been achieved during earlier tasks). The task adaptation includes three parts:

1. *One step forward* – change task by gradually increase complexity (e.g. 2A→2B, 2C→3A, or 3B→3C)

2. *Skip (more than one step forward)* – a task can be skipped if the sub-goal of the following task fits the needs of the subject better at that point (e.g. 1B→2B). However, a return to the task skipped might be necessary later.
3. *One step back* – change task one step back (e.g. 2B→2A, 3A→2C). This is because the new task may bring a loss of some of the previous movement performance gains. This is likely due to the change or the increased challenge and should be expected. If the deterioration of earlier gained parameters persists for two sets then a move backward to the previous task might be needed to regain the performance or reinforce the attributes lost. One step back in the sequence, with verbal instructions that encourage the subject to pay attention to the deteriorating parameters should be the first strategy. If these parameters do not improve then a return for one set to the task that focuses on those movement parameters is allowed.

Note that every new task might need to be introduced by an “Intro/demo set”. The intro/demo set includes 3 to 4 non-assisted (intro) or assisted (demo) trials. They allow the therapist/system expert to introduce and explain the task. They also allow the subject to try the tasks and ask questions for clarifications.

3.3 Parameter Adaptation

The therapist and media expert can add variations within the task by adapting control parameters. Though adjusting control parameters, the therapist and media experts can help the subject to achieve the sub-goal of the current task effectively. The parameter adaptation includes six parts:

1. reaching/grasping task parameters (e.g. target position)
2. audio feedback parameters (e.g. musical instrument)
3. visual feedback parameters (e.g. the speed of image particles coming together)
4. physical environment parameters (e.g. table height)
5. tangible feedback (e.g. grasp cone or touch object)
6. verbal instructions (e.g. focus on elbow extension)

4. EXPERIMENTAL RESULTS

We now discuss the experimental results. We recruited three stroke patients to use our media adaptation framework in biofeedback system for rehabilitation. These three patients were suffered mild stroke in the right arm. They were unfamiliar with the system prior to the rehabilitation. Each patient did eight sessions in three consecutive weeks. The eight sessions include one physical pre-test, one physical post-test and six sessions of rehabilitations using our biofeedback system. Each session lasted approximately two hours. The rehabilitations are lead by a physical therapist that has one year experience of using our system.

Figure 3 shows the velocity jerkiness comparison between pretest and posttest for three subjects and for four target positions. We do not show the results for the subject 2 for the middle and off table target because the subject 2 did not finish the posttest successfully due to the system failure. We can see that the velocity jerkiness improves (decreases) for all three subjects for all four targets. This proves that our adaptation framework works well in improving velocity smoothness.

Figure 4 shows the torso compensation comparison between pretest and posttest for three subjects and for four target positions. We can see that the torso compensation improves (decreases)

significantly for all subject 1 and subject 3 for all four targets. We also observe that the torso compensation gets worse slightly for subject 2 for two targets. This is because subject 2 does not have torso compensation problem (small compensation for both pretest and posttest).

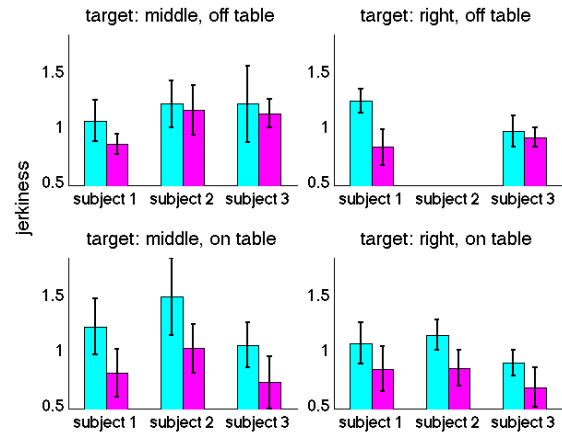


Figure 3 Jerkiness comparisons between pretest and posttest for three subjects for four target positions.

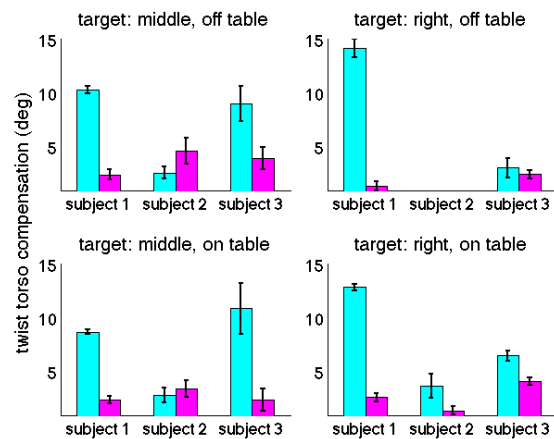


Figure 4 Torso compensation comparisons between pretest and posttest for three subjects for four target positions.

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