A Home-based Adaptive Mixed Reality Rehabilitation System

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ABSTRACT
This paper presents an interactive home-based adaptive mixed reality system (HAMRR) for upper extremity stroke rehabilitation. This home-based system is an extension of a previously designed and currently implemented clinical system. The goal of HAMRR is to restore motor function to chronic stroke survivors by providing an engaging long-term reaching task therapy at home. The HAMMR system tracks movement of the wrist and torso, and provides real-time, post-trial, and post-set multimodal feedback to encourage the stroke survivor to self-assess his or her movement and engage in active learning of new movement strategies. This experiential media system uses a computational adaptation scheme to create a continuously challenging and unique multi-year therapy experience through the use of multiple, integrated audio and visual feedback streams. Novel design features include creating an over-arching story for the participant, the ability of the system to adapt the feedback over multiple time scales, and the ability for this system to integrate into any home.

1. INTRODUCTION
Stroke is a leading cause of disability in the United States. On average, every 40 seconds, someone suffers a stroke in the US, leaving millions of people in the US with chronic upper-extremity impairments. The extent and severity of these impairments vary across stroke survivors, necessitating comprehensive rehabilitation systems that can provide meaningful experiences based on individual needs. However, repeated visits to receive clinical-based therapy can be costly to a stroke survivor, both financially and logistically [1]. Recent research has led to the development of telerehabilitation systems for home-based therapy [2]. Telerehabilitation systems generally lack automated real-time system adaptation of the tasks and feedback in response to user performance and progression, instead relying on constant therapist adjustment and telepresence. The optimal content and structure of task performance feedback are areas of ongoing research.

The Home-based Adaptive Mixed Reality Rehabilitation system (HAMRR) attempts to address the shortcomings of current home-based therapy systems. HAMRR is based on the design features and practical application of an Adaptive Mixed Reality Rehabilitation system (AMRR) [3] developed in our lab. The AMRR system provides an environment that integrates physical elements and interactive audio and visual feedback streams to train reach-and-grasp tasks and promote active motor learning. Preliminary results from the AMRR system show improvement in the stroke survivors’ movement quality and Wolf Motor Function Test (WMFT) scores [4]. Also, improvements in movement quality are highly correlated to the associated media feedback [5].

Compared to AMRR, HAMRR provides three novel contributions: (a) a low-cost, home-integrated physical design that supports multimodal sensing, (b) an engaging and hierarchical multimedia feedback design, from real-time to summary feedback, where the experience of evolving feedback streams facilitates active learning by gradually reducing dependency on media feedback and facilitating new motor planning strategies, and (c) a semi-supervised adaptation framework that automatically customizes the therapy tasks based on the participant’s progress and therapist’s goals.

2. HAMRR SYSTEM
The mixed reality rehabilitation system integrates motion capture, kinematic analysis, interactive audio and visual feedback, and a semi-supervised adaptation scheme.

2.1 System Overview
The physical setup of our HAMRR system, seen in Figure 1, includes a media center, a table, and a chair. The media center includes an iMac computer, two speakers, and three infrared Opti-Track cameras. The table is lightweight, such that it can be removed from the media center when not in use. There are three interchangeable tangible objects (base, button, and cone) that can be inserted into the table [6]. The tangible objects feature pressure and touch sensing to detect participant manipulation. The chair is embedded with force sensing resistors to coarsely track the participant’s torso movement. Compared to the AMRR system, the HAMRR system significantly reduces sensing cost and simplifies participant’s setup. The participant need only wear a wristband adorned with a single reflective marker used for 3D hand tracking.

HAMMR architecture, seen in Figure 2, features six main components. The sensing component collects 3D marker position of the wrist, force and contact data from the tangible objects, and force magnitude from the chair. These data streams provide the basis for feature extraction of hand position, velocity, and coarse torso position during the reaching tasks, and are used to create feedback. This system creates an evaluation report based on the participant’s performance data, which can be reviewed by the therapist as needed and used computationally to automatically
customize the adaptation framework [7]. HAMRR also has a system dialog component that can guide the participant through exploring new feedback and task environments.

2.2 Multimodal Feedback

Our HAMRR system intuitively communicates to the participant levels of performance and direction for improvement by using three types of feedback – tangible feedback from color LEDs embedded within an object, auditory feedback, and visual screen-based feedback. The feedback is designed to provide a dynamic multimodal experience that evolves over time, incentivizes training, facilitates active learning, and accommodates more complex tasks. Therefore, the feedback is structured to provide information about the movement at three different levels: (a) real time, (b) post-trial summary, and (c) post-set summary. For any training set (which includes several reaches), only one of these three levels is utilized.

Real-time feedback is coupled to the participant’s hand trajectory and speed, which are key features for completing a reach. The LEDs embedded within the object base change color based on the participant’s trajectory error. Green signifies minimal deviation from an efficient reference trajectory, yellow signifies moderate deviation, and red signifies a large deviation. The objects also have embedded task completion indication light to signify when the required interaction has been performed. Real-time auditory feedback communicates reaching speed to the participant by note density. The sound is designed to encourage the participant to reach with a smooth, natural speed.

In post-trial summary, a visual representation of trajectory performance for a reach is communicated by the color and spatial distribution of stones in the water, seen in Figures 3a and 3b. In post-set summary, presented after a set of reaches, either visual or auditory feedback communicates to the participant a movement specific affective tag of performance, such as overall disjointed or slow movement. For example, seen in Figure 3d, abrupt changes in the boat’s contour communicates a pattern of reaching without elbow-shoulder joint coordination. Visual tags include trajectory inaccuracy, jerkiness, disjointed movement, and task incompleteness. Sonic affective tags (sonic images) are provided within the affective summary level to indicate abrupt acceleration, slow movement, reach time consistency, and hesitant movement. Parameters such as harmonicity, attack and decay, texture, and note density are used to differentiate the sonic images.

![Figure 3 HAMMR Visual Feedback](image)

(a) represents an efficient reach and (b) represents trajectory error to the right, each after a trial. (c) represents an efficient task completion and (d) represents disjointed movement with trajectory deviation, each after a set.

2.3 Adaptation

HAMMR is designed to provide therapy without the presence of a therapist. The type of tasks, tangible objects and locations, and feedback streams are designed to be adaptable in order to offer a challenging and engaging personal experience. HAMMR employs a utility function to determine the adaptation decision (represented by a change in system parameters) based on (a) a prior established week-long sequence of tasks, (b) the history of foci and tasks for previous sets, and (c) the participant’s performance [7].

The adaptation is structured as a semi-supervised framework, using a probabilistic graphical network representation. The adaptation framework customizes the system in the participant’s daily training automatically and allows a therapist to review the rehabilitation progress weekly, and fine-tune the training strategy.

3. DEMONSTRATION SETUP

We will demonstrate how the participant will setup and interact with the system during a typical therapy session. The demo subject will wear a wristband with a single reflective marker. The demo subject will interact with the system dialog to setup the table space with the appropriate tangible objects for that session. Our demonstration will then show how the demo subject can interact with task and feedback tutorials. The demo subject will progress through the real-time, post-trial, and post-set feedback streams to demonstrate the components of the overall experience and how they scale in structure.

4. REFERENCES