

# 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 HAMRR 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.

## Categories and Subject Descriptors

K.4.2 [Computers and Society]: Social Issues – *Assistive technologies for persons with disabilities.*

## General Terms

Algorithms, Design, Experimentation, Human Factors.

## Keywords

interactive, mixed reality, rehabilitation, adaptation, long-term usage, self-evaluation, affective multimedia, home healthcare

## 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.

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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, HAMMR 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

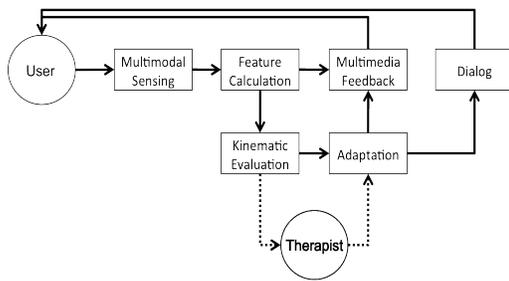
The physical setup of our HAMRR system (Fig 1) includes a media center, a table, and a chair. The media center is an iMac computer, two speakers, and three infrared Opti-Track cameras. The table is lightweight and can be removed when not in use. There are three interchangeable tangible objects that can 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.



Figure 1 HAMMR Physical Setup

HAMMR architecture features six components (Fig 2). 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



**Figure 2 HAMMR Architecture Design**

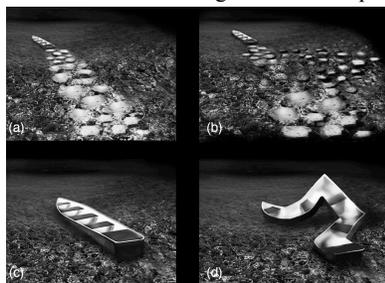
provide the basis for feature extraction of hand position, velocity, and coarse torso position during the reaching tasks and are used to create feedback. This system creates an evaluation based on the participant's performance data, which can be reviewed by the therapist and used computationally to customize the adaptation framework [7]. HAMRR has a system dialog component to guide the participant through new feedback and task environments.

## 2.2 Multimodal Feedback

Our HAMRR system intuitively communicates levels of performance and direction for improvement to the participant by using three types of feedback – *tangible* feedback, *auditory* feedback, and *visual* feedback. The feedback is designed to provide a dynamic multimodal experience that evolves over time, incentivizes training, accommodates more complex tasks and facilitates active learning. The feedback is structured to provide movement information at three 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 change color based on the participant's trajectory. Green signifies minimal deviation from an efficient reference trajectory, yellow signifies moderate deviation, and red signifies large deviation. The objects also have embedded task completion indication lights to signify when the required interaction has been performed. Real-time auditory feedback communicates speed to the participant through 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 is communicated by the color and spatial distribution of stones in water (Figs. 3a & b). In post-set summary, visual and auditory feedback communicate affective tags. For example, changes in the boat's contour communicate a pattern of reaching without proper joint correlation (Fig. 3d). Visual tags include trajectory inaccuracy, tremor, segmented movement, and task incompleteness. Sonic affective tags (or sonic images) are provided within the summary level to indicate



**Figure 3 HAMMR Visual Feedback**  
 (a) efficient trial (b) trial trajectory error  
 (c) efficient set (d) set of segmented trials

movements that are too fast, too slow, or hesitant. Parameters such as harmonicity, timbre, reverberation time, note attack and decay, and note density are used to differentiate the sonic images.

## 2.3 Adaptation

HAMMR is designed to provide unaided therapy. 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 subject will wear a single reflective marker. The subject will interact with the system dialog to setup the table space with the appropriate tangible objects. 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.

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