Final Report

Title: Home-based Rehabilitation for Children with Cerebral Palsy using Wearable Technologies

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1. Introduction:

The goal of this project was to design an intelligent framework for home-based neuo-rehabilitation for children with cerebral palsy. We used two commercially available wearable devices - two Myo armbands and a pair of augmented reality eyeglasses - and a learning from demonstration (LfD) algorithm to design a framework that can help someone to perform rehabilitation exercises in the home/community settings.

2. Project Goal:

In this short-term, limited-budget project we wanted to design a preliminary prototype and test its feasibility and utility with one participant with CP. We designed this prototype to meet the specific rehabilitation requirements of our participant: a 17 year-old boy with CP who has been working with our team and is very enthusiastic to try new technologies that have potential to help his condition. Our participant has a flexed right wrist due to CP which makes it difficult for him to do normal activities with his right hand. To maintain the functional joint range of wrist and forearm as well as to facilitate the neuromotor performance of this patient, a set of rehabilitation exercise should be deployed and practiced with proper supervisions or monitoring. The exercise includes stretching assisted by the less-affected arm, unilateral arm movement (reaching, repetitive forearm supination-pronation), and bilateral arms movement (one hand stabilizing object while another hand manipulating it). It is often the case that he either forgets to perform the home-practices or feel less motivated to perform them. We intended to design a system that will enable him to perform structured mass practice at home.

Fig. 1 Commercially available wearable devices used in the project (left) a Myo armband (right) a pair of R-7 augmented reality eyeglasses

We used two commercially available wearable devices in this project: a Myo armband by Thalmic Labs Inc. and an augmented reality eyeglass, R-7, developed by Osterhout Design Group (http://www.osterhoutgroup.com/home). The Myo armband, as shown in Fig. 1, provides position data from a 9 axis IMU and 8 channel EMG data to indicate muscle activation subjected to different activities. The R-7, as shown in Fig. 1, is a fully untethered AR eyeglass equipped with various on-board sensors (IMU, altitude sensor, light sensor, and humidity sensor). R-7 has an auto-focus camera and dual stereoscopic see thru display.

3. Work completed:

<u>System overview:</u> The framework we designed performs in the following way

i. Demonstration: During a clinic visit, a therapist, after assessing the patient's level of impairment, will demonstrate the recommended exercise. To build the proposed framework, the therapist will use simple predefined verbal cues to indicate the key states of the exercise while demonstrating it to the participant. Examples of such verbal cues are: *Let's start from this position* (to indicate the hand position at the beginning of an exercise), *hold your hand like this* (to indicate an intermediate stage of the exercise), *you finish at this position* (to indicate the end of an exercise), etc.

ii. Learning: The patient will be wearing the Myo armband during this demonstration phase. Our framework processes therapist's verbal cues along with the EMG signals and IMU data from the Myo armband to segment and learn different motion components of the exercise along with the time sequence that is required to be preserved for executing the entire exercise. We have employed Gaussian mixture modelling followed by Gaussian mixture regression to learn exercise sequence from multiple demonstration data. We have further developed a Markov Decision Process (MDP)-based framework which drives a 3D avatar to provide a participant prompt and feedback when he deviates from trajectories prescribed by the therapist.

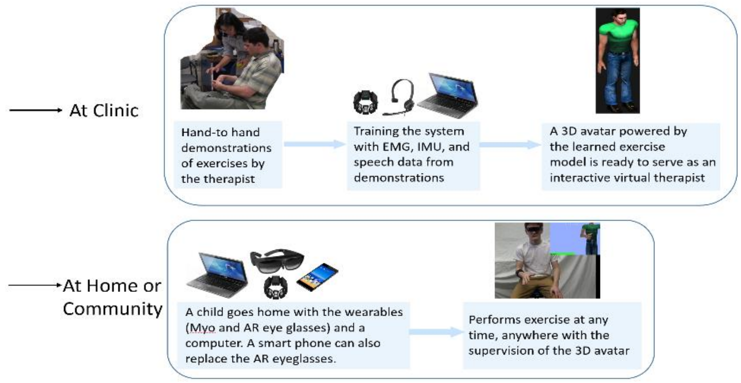

Fig. 2 Overview of operation of the home-neurorehabilitation framework

iii. Coaching: After the clinic visit, the participant will go home with three devices: a Myo armband, an AR eye glass, and a notebook computer that runs all the necessary software (essentially, a number of ROS nodes). The participant will be able to activate the program using a very simple user interface. During specific times of a day, as recommended by the therapist, the participant will wear the armband and the R-7 glass and will practice the exercise. The 3D avatar will guide him through the exercise sequences. During this time the system will continuously capture and analyze the accelerometer data and the EMG signals. If the participants fail to adhere to the recommended rehabilitation regime, the 3D avatar (powered by the MDP model) will automatically generate corrective prompts and feedback. Fig. 2 shows an overview of the proposed system. Fig. 3(left) and 3(right) show an example case of demonstration and coaching, respectively.

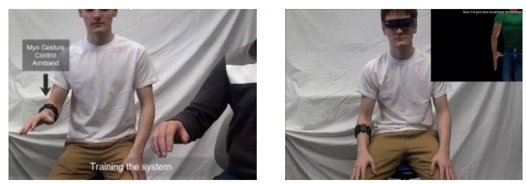

Fig. 3 (right) A trainer (r) is demonstrating an exercise to a hypothetical patient (l) and (left) the patient is practicing with the help of the 3D avatar

<u>User study:</u> We conducted an IRB approved pilot study to evaluate the prototype with a group of lay users. A rehabilitation scientist, the co-PI, participated in the study as the demonstrator and acted as the therapist for the participating `patient' group. Three female undergraduate students in exercise physiology (age group 18-22) at the University of Massachusetts Lowell participated in the study as 'patients'. two other unique exercises. The home-program for each patient was to practice these three exercises twice a day for twenty to thirty minutes using the 3D avatar and the patient interface. A brief training of how to use the patient interface was also provided to each of the three patients. Each of this training sessions lasted approximately thirty minutes. During the second phase of the study, each patient took the system to their home for three days and used it to adhere to the home-program prescribed by the therapist. Upon completion of the three days' evaluation period, participants were asked to the following questions that measure their overall impression of the IHR as a home-program to help adherence to a rehabilitation regime.

Responses from participants were recorded on a 5 point Likert scale (Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree).

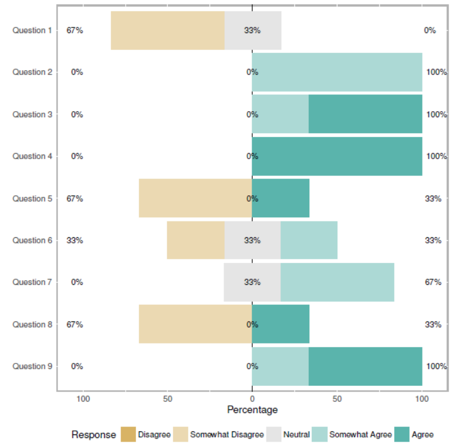

Fig. 4 Responses from the user study

1. It was easy to set up the hardware
2. It was simple to start up the home program
3. It was intuitive to follow the home program
4. I was compliant with the home program
5. I felt that I was receiving rehabilitation service every day
6. I enjoyed this home program
7. I feel that the 3D avatar is interactive and understands what I am doing
8. The home-program helped me to perform the exercise when I was confused about what to do next
9. I would follow the directions the home program

Participants responses are shown in Fig. 4. The questions measured the participant's impression about our framework on four categories:

- Ease of use: Question# 1, 2, 3
- Utility & potential benefit from a clinical standpoint: Questions# 4, 5, 10
- Technical accuracy of the LfD System: Questions# 7, 8
- Perceived Enjoyment of the System: Question# 6

The participants were also asked to answer to the following questions in their own words.

1. How many times did you charge each of the devices?
2. In your own words, write your thought about the program.
3. In what ways could the home-program improve to fulfill your needs?
4. Would you recommend a system like this to loved ones, who require constant reminders to perform tasks and activities?

The first question is related to the sustainability of the current hardware. Questions 2, 3 are asked to obtain input for the iterative development of the system, and question 4 is to measure the overall appeal of the system.

A significant aspect of the study is that other than the initial training, participants did not receive any expert supervision or technical support for the system. The study was intentionally designed in this way in order to investigate the potential of an LfD-powered system to be operated by lay users.

Due to the small number of participants we do not perform any statistical analysis of the survey data. Instead we perform an analysis of participants' responses using descriptive statistics in order to understand the lessons learned from the second development cycle. We consider the responses of the participants on the four categories of questions as positive (if answers are 1 or 2), neutral (if the answer is 3), or negative (if the answers are 4 or 5). 60% of the participants had a positive attitude towards the ease of use of the system. One participant expressed concern about the cumbersome process of hardware setup. With respect to clinical utility and potential benefit for therapeutic applications, all participants agreed that they would follow the directions provided by the system to adhere to the home program. However, concerns were expressed by 60% of the participants that the proposed framework did not provide them with the feeling of having a 'virtual therapist' by their side when they practiced at home. The inability of the system to provide physical assistance, instead of corrective prompts, contributed to this negative attitude toward the proposed system. With respect to the technical elegance of the system, all participants reported that although the avatar was interactive, it did not provide enough feedback to them to proceed when they were stuck during an exercise. With respect to perceived enjoyment, 60% of the participants claimed they did not enjoy using the program and considered it not engaging enough. Participants explained many of their responses (especially negative attitudes) while answering the four subjective questions. For example, all participants commented that the IHR was not motivating or engaging enough and suggested that providing more rewards/encouragements for the patient in a personalized way and creation of an interactive game environment can significantly increase the appeal of the system. Participants also emphasized on the importance of robust hardware which is in line with previous findings which suggest that despite the intelligence of the underlying system, faulty hardware drastically reduces the perceived overall quality of a system. Finally, all participants agreed that they would recommend the system for home rehabilitation to their loved ones if all of their concerns are resolved.

4. Budget:

The grant was mostly used to purchase materials to conduct the user study reported in this proposal (Table shows the breakdown of expenditures). As per the study design, participants needed to bring the system (a laptop, an R-7, two Myo armbands, a headset for speech-based interaction with the program) to their homes and practice with it for three days. The SIGHT grant helped us to purchase a laptop, a wireless adapter, a Myo armband (one of our existing Myo armbands was not functioning properly) and a stereo-headset. We also purchased a Camcorder and required accessories (case, micro-SD card, tripod) to video-tape the first demonstration session of each participant so that a participant can watch it at home in the case s/he needs help on setting up the system for the first time. Finally, in preparation for our future studies, we purchased a corrective lens for our CP participant to be used with the R-7 eyeglasses.

General Description and Business Purpose of Purchase	Amount (USD)
Hardware for robot systems: Lenovo IdeaPad Y700	1299.00
Hardware for robot systems: Penguin Wireless N Dual-Band USB Adapter for GNU / Linux	95.95
1 Myo armband	208.77
R-7 Corrective for participant	175.00
Camcorder+case	549.99+14.99
Micro-SD card	29.99
Stereo-headset	19.99
Tripod	59.99
Total	**2453.67**

Overall, we believe that the support from SIGHT enabled us to carry out the user study to evaluate our first prototype framework for home neurorehabilitation. We deeply appreciate this support.

5. Conclusion and Future Direction:

We have recently secured an internal grant($10K) from University of Massachusetts Lowell to conduct a pilot trial to test our initial prototype with a child with cerebral palsy (Prof. Wu as a PI and Prof. Begum as co-PI). The pilot trial is currently underway. We will collect end-users' feedback and iteratively retrofit the design of our home-rehabilitation framework.

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