A Technology for Computer-Assisted Stroke Rehabilitation

Min Hun Lee
Carnegie Mellon University
Pittsburgh, PA, 15213 USA
mhlee@cmu.edu

ABSTRACT

Improving functional ability after a stroke requires task-oriented physical rehabilitation with the supervision of a therapist. However, with increasing medical costs and a shortage of rehabilitation specialists, post-stroke survivors sometimes receive a limited amount of individual treatment.

This paper proposes a low-cost computer-assisted rehabilitation system, called Virtual Coach that evaluates and guides a post-stroke survivor to engage in rehabilitation correctly at home with minimal supervision of a therapist. This system includes two major components: 1) motion analysis modules that evaluate exercise performance and guide a desirable joint trajectory and 2) a dialogue interface to provide feedback. The evaluation function of motion analysis modules computed exercise performance scores of 15 post-stroke survivors and achieved a 78% agreement with a practicing clinician. After developing a guidance function, the usability of the system will be evaluated with post-stroke survivors and therapists and iteratively improved.

Author Keywords

Intelligent agent; motion modelling & analysis; uncertainty quantification; stroke rehabilitation.

INTRODUCTION

Stroke is a disease that results in death to cells in part of the brain due to poor blood flow. The damage may lead to an inability to move limbs on one side of the body. Most stroke survivors engage in rehabilitation, which involves a task-oriented exercise to recover functional ability with the guidance of a therapist [4]. A positive functional recovery is highly dependent on receiving motivational and individualized rehabilitation sessions. Unfortunately, post-stroke survivors encounter a difficulty with receiving timely and comprehensive rehabilitation due to the limited time of therapists [5].

In recent years, researchers demonstrate the feasibility of developing low cost computer-based rehabilitation systems [3]. One strategy is to employ a motion based game that motivates a patient's participation [1]. However, this game-based approach does not provide clinical relevance. It is difficult to correlate the results of rehabilitation games with the improvement of a patient's functional ability.

Another approach is to perform action/gesture recognition, which determines the correctness of a motion [2]. Unlike a game-based approach, a gesture recognition-based approach can provide clinical relevance while motivating the patient to increase the number of correct movements. However, the number of correct movements cannot provide the detailed feedback. This binary analysis (i.e. correct or incorrect) may de-motivate the patient, who can only perform part of an exercise. In addition, the same number of incorrect movements does not necessarily represent the same level of functional ability. Even if two patients have the same number of incorrect movements, they may have different degrees of the range of motion. Thus, binary analysis is not sufficient for a therapist to follow the progress of patient's in-home rehabilitation.

To enhance experience of using a computer-based in-home rehabilitation system, this research addresses the following research questions: (1) how can a system automatically provide detailed motion analysis? (2) how closely can the system reproduce therapist's analysis? (3) can this system guide a desirable exercise movement?

PROPOSED RESEARCH

This paper proposes a Virtual Coach system that assists a post-stroke survivor to engage in rehabilitation with minimal supervision of a therapist. Building upon a Kinect sensor, this system utilizes machine learning algorithms to develop two motion analysis modules: evaluation and guidance modules. The evaluation module classifies 'correct' and 'incorrect' movements. It quantifies the probability of performing an correct movements. The guidance module analyzes the desirable joint position of an exercise. When a post-stroke survivor performs an exercise incorrectly, this system can provide corrective instructions. Upon completing an exercise trial, this system provides a performance score to encourage a post-stroke survivor's more active participation in the rehabilitation program. A therapist can easily track the quality of in-home exercise adherence and the progress of a post stroke survivor.

Experimental Design

Based on the discussion with a therapist, this work utilizes three upper limb exercises: E1 - *'Bring a cup to the mouth'*, E2 - *'Switch a light on'*, and E3 - *'Move forward a cane'*. These exercises are examples of task-oriented exercises for stroke rehabilitation. These exercise are selected due to their correspondence with major motion patterns: E1 to elbow flexion, E2 to shoulder flexion, and E3 to elbow extension.

We also specify three performance metrics to evaluate exercise

IUI'18 March 7–11, 2018, Tokyo, Japan

ACM ISBN 978-1-4503-4945-1/18/03.

DOI: https://doi.org/10.1145/3172944.3173146

performance: *'Precision*, *'Smoothness'*, and *'Compensation'*. The *'Precision'* represents how accurately an exercise is performed, the *'Smoothness'* indicates the level of trembling, the *'Compensation'* checks whether a participant involves any compensatory movement (e.g. leaning torso forward)

Data Collection

We utilize a Kinect v2 sensor (Microsoft, Redmond, USA) to record the trajectory of the selected body joints and capture video frames at 30 Hz. We recruit 15 post-stroke survivors with different level of functional abilities and 11 healthy subjects. A post-stroke survivor performed 10 repetitions of each exercise on both affected and unaffected sides. A healthy subject performed 15 repetitions of each exercise on a subject's dominant side. In total, each upper limb exercise contains 465 trials: 315 trials of correct movements and 150 trials of affected movements.

After collecting the dataset, a therapist watched the recorded videos and evaluates an exercise in three performance metrics on 4-point ordinal scale (0-3).

Evaluation and Guidance Modules

To develop motion analysis modules that work across post-stroke patients with different physical conditions, this system computes physical measurements and pre-processes joint coordinates into normalized representations. The evaluation module trains binary classifiers with normalized features to determine the correctness of an exercise movement in terms of the three performance metrics. Based on the results of an experiment that compares classification accuracies between Hidden Markov Model (HMM) and Decision Tree (DT) for each metric, we selected DTs for the *'Precision'* and *'Compensation'* metrics and HMMs for the *'Smoothness'* metric. Using the binary classifiers, this system quantities a probability of being a correct movement and computes a performance score. The guidance module will incorporate motion modeling techniques [6]. As modeling a pixel-level individual motion path is expensive in computation, we will model a motion trajectory in lower-resolution with a bounding box. It can provide an corrective instruction on joint positions when a post-stroke survivor performs an exercise incorrectly.

Dialogue Module

We designed a state machine to provide audio feedback when an user performs an exercise. The dialogue module will communicate with the motion analysis modules. Upon receiving any changes in motion analysis, the state machine will transit to a corresponding state and generate audio outputs. The state machine is composed of four states: *'Initial'*, *'Feedback'*, *'Termination'*, *'Wrap-up'*. In the *'Initial'* status, this system will summarize the main goal of rehabilitation session as specified by a therapist. When a system detects any erroneous movement (e.g. incorrect joint positions or performance metrics), it will switch to the *'Feedback'* state. The system will inform which metric is incorrectly performed or guide how to correctly place a joint. If a post-stroke survivor keeps performing incorrect movements, this system will provide an inspiring message. After finishing each trial of an exercise, the state machine will move to the *'Termination'* state and announce a performance score. Once a participant achieves all pre-specified tasks or gives up in the middle of a session, the state machine will review overall session performance and remind the subject about the next session.

CURRENT PROGRESS AND FUTURE PLAN

For the evaluation module, we have developed binary classifiers to classify incorrect movements in three metrics with the following classification accuracies: above 90% for both precision and compensation metrics and around 82% for the smoothness metric. We have compared the quantified performance scores of the assessment module with the observation scores of a therapist. This system achieves around 78% agreement with a therapist using all three metrics. For the dialogue module, we have designed the state machine and built communication with motion analysis modules.

In the future, we will develop motion trajectory model for the guidance module and the prototype of a Virtual Coach system. We will evaluate the usability of this system with post-stroke survivors and therapists.

CONCLUSION

This research leverages machine learning algorithms to develop a Virtual Coach system that evaluates and guides a stroke rehabilitation program without the presence of a therapist. This technology is not limited to stroke rehabilitation, but applicable to other types of health-care services. The successful completion of this project has a potential to improve the practice of health-care services.

REFERENCES

1. Madeline Balaam, Stefan Rennick Egglestone, Geraldine Fitzpatrick, Tom Rodden, Ann-Marie Hughes, Anna Wilkinson, Thomas Nind, Lesley Axelrod, Eric Harris, Ian Ricketts, and others. 2011. Motivating mobility: designing for lived motivation in stroke rehabilitation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 3073–3082.
2. Yao-Jen Chang, Wen-Ying Han, and Yu-Chi Tsai. 2013. A Kinect-based upper limb rehabilitation system to assist people with cerebral palsy. *Research in developmental disabilities* 34, 11 (2013), 3654–3659.
3. Michelle J Johnson, Xin Feng, Laura M Johnson, and Jack M Winters. 2007. Potential of a suite of robot/computer-assisted motivating systems for personalized, home-based, stroke rehabilitation. *Journal of NeuroEngineering and Rehabilitation* 4, 1 (2007), 6.
4. Peter Langhorne, Peter Sandercock, and Kameshwar Prasad. 2009. Evidence-based practice for stroke. *The Lancet Neurology* 8, 4 (2009), 308 – 309.
5. Alexandra S Pollock, Lynn Legg, Peter Langhorne, and Cameron Sellars. 2000. Barriers to achieving evidence-based stroke rehabilitation. *Clinical Rehabilitation* 14, 6 (2000), 611–617.
6. Bodo Rosenhahn, Reinhard Klette, and Dimitris Metaxas. 2010. *Human Motion: Understanding, Modelling, Capture, and Animation* (1st ed.). Springer Publishing Company, Incorporated.