R-SAM: A Robust Stroke Rehabilitation System Augmented by Smartphone and Additive Manufacturing

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1. INTRODUCTION

Approximately 795,000 people with stroke live in the U.S. each year [1]. After a short period of inpatient rehabilitation service, stroke survivors will usually receive home exercise programs [5]. Unfortunately, these home programs can be insufficient to stroke recovery because of people’s low adherence caused by the lack of instructions and motivations [4]. Recently, technologies (e.g., virtual reality and robotics) make in-home exercises more intriguing. However, issues still remain including obtrusiveness (i.e., heavy and static setups [2]) and low adaptability (i.e., rigid hardware and software designs [3]). To this end, we propose R-SAM, a lightweight, adaptive, robust stroke rehabilitation system augmented by smartphone and additive manufacturing. It utilizes a smartphone based rehab analyzer providing real-time instructions and fine-grained performance reports. Supported by the additive manufacturing (i.e., 3D-printing), R-SAM produces adaptive and real-life simulated rehab tools.

2. R-SAM SYSTEM OVERVIEW

Our framework comprises two modules, including a smartphone based rehab analyzer and a rehabilitation tool manufacture (Fig. 1). The former provides three exercise focuses with three quantitative measures targeting at a variety of activities of daily living (ADL). The latter utilizes 3D-printing technique producing customizable rehabilitation tools. The two modules are eventually integrated into one. A user performs our designed ADL exercises by using the integrated product and receives real-time instructions and performance reports. Details of each module are discussed as follows.

2.1 Smartphone Based Rehab Analyzer

Our rehab analyzer provides transporting, rotating, and fractionating focus exercises as shown in Fig. 2. Transporting exercises involve vertically and horizontally moving an object. Rotating exercises include pouring water from a cup and twist an object. Fractionating exercises train a patient’s dexterity of upper extremity. All designed exercises are based on careful consultations with rehabilitation professionals utilizing repetitive task-oriented exercises related to ADL, which have demonstrated a great impact on stroke patients’ upper extremity functional recoveries [7].

In order to quantify performances of different types of exercises, we extract three quantitative measures from data obtained by the smartphone’s sensors.

(1) Normalized Jerk Score (NJS):

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NJS = \sqrt{\frac{1}{2} \times \int_{t_1}^{t_2} \left( (a'_x)^2 + (a'_y)^2 + (a'_z)^2 \right) dt \times \frac{\Delta t^5}{a^2}},
\]

where \(a'_x, a'_y, a'_z\) are the first derivative of the three-axis accelerations, \(\Delta t = t_2 - t_1\) is the duration of movement, and \(a\) is the amplitude of movement. NJS quantifies the performance of transporting focus exercises. According to [8], the reduction of smoothness leads to a higher jerk level (i.e. the change in acceleration over time). The jerk should be normalized since it can be affected by movements’ durations and trajectories [8]. NJS should be larger than zero and the smaller the score, the smoother the movements.

(2) Zero-crossing rate (ZCR): This is used for quantifying rotating focus exercises’ performances. As the amplitude of this kind of movements is difficult to define and unify, NJS is not suitable for measuring the performance of rotating movements. ZCR, a common analysis of signal’s frequency content, counts the number of zero axis crossed by a signal in a time interval [6]. In order to measure the frequency of sharp changes in movements, we extract ZCR from the derivative of acceleration data recorded by smartphone over the duration of movements.

Figure 1: Our system, R-SAM, consists of a smartphone based rehab analyzer and a rehabilitation tool manufacture. Combining the two, a user can experience motivated and instructed ADL exercises.
Each participant performed six exercises as presented in and five healthy elders (age: 70.

Fractionating focus: turn key and dial number. Rotating focus: vertical cup and horizontal bowl. Pouring focus: pour water.

3. EVALUATION

Three mild to moderate stroke patients (age: 66.3 ± 5.51) and five healthy elders (age: 70.6 ± 9.45) volunteered for our experiment which is approved by an active IRB protocol. Each participant performed six exercises as presented in Fig. 2, with the same set of rehab tools for limiting variables that may effect the quantitative measures since we want to validate the consistency and the reliability of R-SAM’s performance measures across different populations. The experimental results are presented in Table 1, where SP and HE represent all stroke patients and all healthy elders.

In vertical cup exercise, the average NJS of SP is much higher than the mean score of HE such that all SP’s movement is much rougher. In horizontal bowl exercises, only minor NJS differences between both groups because each patient was using both hands that (s)he can heavily rely on a healthy side of the body. In the rest of six exercises, SP obtain much low performance score (i.e., higher mean ZRC and lower mean ACC) than HE. Overall, R-SAM’s measurements remain consistent across the two groups of people.

The aforementioned experiment is a pilot study in a laboratory environment. In order to further testify the reliability and the usability of R-SAM, we are currently preparing a longitudinal residential study. Each participant will receive a set of 3D-printing tools, a compatible smartphone and independently practice an in-home rehabilitation exercise program for a month. Hopefully, by the end of the longitudinal study, we are able to fully evaluate our R-SAM.

4. REFERENCES


