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ScienceDirect

Procedia CIRP 60 (2017) 488 – 493

www.elsevier.com/locate/procedia

27th CIRP Design 2017

An Interactive Upper Limb Rehab Device for Elderly Stroke Patients

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Abstract

Elderly stroke patients need intensive and task-specific rehabilitation exercises to improve manual dexterity. Most of the robot-mediated devices used for these exercises currently do not fully motivate them to complete the exercises or measure the progress of the therapy. In this study, we developed an ergonomic, portable upper limb rehabilitation device (QikRehab) with the help of interactive media. Interactive rehabilitation games with options to monitor the therapy progress is the design novelty of this device. Three prototypes on the console design and fabrication are investigated in sequence, which are evolved based on the feedbacks and comments from therapists. Two rapid prototyping (RP) technologies are utilized to fabricate the second and the third prototypes for initial user study and feedback collection. Four exercises including grip, pitch, twist and roll are designed on this console to simulate upper limb motions within activities of daily living. To motivate old adults to exercise more conveniently in either hospital or home, three interactive rehabilitation games (Pig Hole, Rat Hunting and Intensive Grip) are designed to motivate such exercises, the achievement obtained in the games are automatically recorded for movement ability assessment. Furthermore, we present several discussions on the pilot user testing through a workshop and follow up interview and suggest several future improvements of this device.

Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference

Keywords: Rehabilitation device; Rapid Prototyping; Interactive game

1. Introduction

Stroke patients need intensive and task-specific rehabilitation exercises to restore arm and hand function, which involve highly repetitive movements. Quite a number of robotic devices are available as a complementary tool for such exercises such as Tailwind, for people with partial paralysis [1]. Posteraro et al. [2] provided a robot-mediated therapy to chronic patients with motor impairment of upper limbs, and reported significant improvements before and after treatment. 20% to 30% stroke patients may suffer from post stroke depression [3]. These robotic devices may not improve patients' status from psychological perspective, and fully motivate them to complete exercises or measure therapy progress. Alankus et al. [4] reported that only 31% of patients perform the exercises recommended by their therapists. The greater the motivation to participate in rehabilitation tasks, the more likely patients will actively participate, and longer therapeutic sessions will lead to greater functional outcomes over the course of treatment [5].

Execution feedback has been introduced into rehabilitation exercise as a tool to provide a reference for therapist and guidance for patients. Spina et al. [6] utilized built-in inertial sensors in smartphone to monitor exercise execution and provide acoustic feedback on exercise performance and exercise errors. To monitor the feedback in a cost effective method, an interactive game is introduced so that stroke patients can play a more proactive role in monitoring and improving their daily skills. Home-based stroke rehabilitation games may help motivate stroke patients to perform the necessary exercises to recover [4]. Khademi et al. [7] developed a rehabilitation game to explore the differences of direct vs. indirect interaction in stroke rehabilitation. His study proved the benefits of indirect computer-assisted therapies in stroke rehabilitation. The ultimate aim is to let patients focus more on the game such that they would not realize that they are actually doing the exercises

Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference
doi:10.1016/j.procir.2017.02.040

[8]. Research has shown that functional, meaningful task practice combined with interactive gaming experience improves individuals' ability in daily living [9]. Broeren et al. [10] created a robotic arm with virtual reality (VR) to play specific game through grasping the sensing devices.

Some general gaming consoles such as Nintendo Wii, Microsoft Kinect and Sony PlayStation have been used for rehabilitation, with carefully tailored individual training needs [8]. They are not designed for stroke patients, need longer time to setup and some even require additional input from therapists to perform two actions simultaneously and hence, it is inconvenient for patients to practice. In addition, the existing gaming scenarios for rehabilitation have been designed by engineers, scientists, and health professionals, whose purpose is to build and test the overall functionality of the developed hardware. The developed exercise cannot link directly with activities of daily living, and the feedback provided was not sensitive to patient performance [11]. Colombo et al. [12] developed an evaluation metric to measure user performance on a specific rehabilitation system and used the metric to motivate users. The performance scoring was provided to patients by visual feedback to maintain patients' interest during the training. This scoring also help therapists to implement reinforcement techniques (such as giving positive feedback and commending patients for their efforts) to enhance training programs.

In short, rehabilitation games must be challenging enough to keep the interest and attention of elderly users, and patient-console interface should incorporate patient situation for active participation. With this consideration in mind, we developed an upper limb rehabilitation device QikRehab, to help medical professionals record and assess rehabilitation progress. It is a specifically designed game console with pinching, griping, rolling and twisting exercises.

Interactive media and rapid prototyping (RP) technology are introduced to change the scope and quality of our rehabilitation exercise design. RP can shorten time and cost for prototype fabrication, visualize prototype design, and eventually improve rehabilitation console design. It has been used for design evaluation purposes or fabrication of prosthetic sockets [13]. RP technology can be applied in full design/manufacturing cycle starting from obtaining data of the human anatomy to fabricate the customized console, and comparison of different console designs. Three interactive games "Pig Hole", "intensive Grip" and "Rat Hunting" are designed to motivate these exercises. Embedding this device in residential spaces could help patients to relearn and recall how to use their arms, hands and fingers, and precisely track and monitor patients' improvement.

The rest of the paper is organized as follows. The next section reviews design consideration and exercises involved in our rehab device design. This is followed by description of our console design and fabrication, and interactive user game design for rehabilitation exercise, which presents main components of QikRehab with their interactions. Then, we detail user experience results obtained through a workshop and follow up interview. Possible improvements that could be made to this device is also suggested.

2. Design consideration and Exercises involved

Rehabilitation devices usually include console design, and interactive game design. The former is a tangible tool to preform rehabilitation exercise, and the latter provides visual and auditory feedback to encourage patients for exercise. The device can also monitor patients' progress and improvement.

To prompt self-motivated rehabilitation experience in regaining both strength and flexibility of upper limb joint movement, the device should be: 1) portable to allow patients use it at the gym, bedside, or even at home, 2) multi-functional to cater for a wider range of exercise, so that therapists can help patients choose suitable functions after assessing their situation, 3) affordability for average-income patients, and 4) progress tracking to judge the improvement of patients more objectively. Generally, this design should adapt to motor skill level, link to meaningful tasks, provide appropriate feedback and therapy-appropriate range-of-motion, and divert patients' focus from exercise.

In this study, we have identified four motor functions from daily activities for rehabilitation device design: 1) pinching: a thumb movement in dressing (to loosen/tighten shirt buttons), feeding (to hold spoon/fork/knife in hand) and dialing a phone, 2) gripping: a hand motion to grip a bottle/cup, or hold a tool, 3) rolling: an arm moving forward and backward action to turn something, and 4) twisting: turning a bottle cap, a door knob or a cookware knob. The assessment is based on patients' performance to accomplish various defined tasks, rather than using a particular method to accomplish the task itself.

3. Console Design and Fabrication

As shown in Table 1, the first prototype is built using PVC material for the main body, a few plastics buttons, and two sets of Lego wheels. The daily activities on pinching, gripping, and rolling functions are described in the first column, the images of design features in this preliminary design is shown in the second column, and their corresponding design features are listed in the third column. The prototype is evaluated by experienced therapists and their feedbacks and comments are listed in the last column.

With the feedbacks from prototype 1, the design features are modified to be more ergonomic in Prototype 2, and some further improvements are made in Prototype 3. Table 2 lists the details of these improvements in the second and third column, and the user exercise of each feature is listed in the last column.

Fixed Deposition Modeling (FDM), a RP technology, is used to fabricate the body of prototype 2 with a layer thickness of 0.3mm. UP Plus 2 from Personal Portable 3D Printer (PP3DP) [14] is used for fabricating the device, with Acrylonitrile butadiene styrene (ABS) material. Since the build size of this machine is 140x140x135mm, the length of prototype 2 is designed to be 130mm.

Prototype 2 has been provided to two physiotherapists and five stroke patients in the rehab gym, Singapore General Hospital (SGH) for preliminary user feedback study. A few problems are found during this usage study: 1) the prototype size is too small to fit all electronics components; 2) the body