34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

A Feasibility Study of an Upper Limb Rehabilitation System Using Kinect and Computer Games

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Abstract— **A new low-cost system for rehabilitation of the impaired upper limb for stroke survivors is presented. A computer game was developed specifically for this purpose and the user's impaired upper extremity is tracked using a downward-pointed Kinect, an inexpensive motion capture system commercially available from Microsoft. A Kalman filter was implemented to reduce data jittering. Patients are required to move their impaired arm, sliding it on top of a transparent support, in order to play the game. The game is personalized to the patient through specific settings that adapt to the patient's range of motion and motor control at the start of the game as well as performance during the game. The final score is proportional to the arm's movement speed. A feasibility study was carried out with one stroke survivor. The game was played for ten days and usability surveys were answered before and after the study. The patient was engaged with the game, found it easy to understand and reported willingness to use it in the home environment and enjoyment of the use in the clinic.**

I. Introduction

Stroke occurs when blood flow to an area of the brain is interrupted when a blood clot blocks an artery or a blood vessel breaks [1]. This causes brain cells to die and brain damage occurs. Stroke is one of the leading causes of adult disability in the United States and the third leading cause of death [1]. Stroke survivors may present with impaired speech, memory, and movement depending of the location of the affected area in the brain and the magnitude of the stroke. Ultimately goals of rehabilitation seek for stroke survivors to regain enough movement and control of their limbs to perform their activities of daily living [2]. However, the number of rehabilitation sessions a patient attends are limited and the goals may not be fully achieved, and in some cases rehabilitation is focused more on lower-limb rehabilitation to help subjects regain their walking abilities [3]. Additionally, the availability of transportation for the patient to get to the rehabilitation clinic, the amount of time and help their relatives and friends can provide to help in their commuting, economic situation and insurance policies can all limit a patient's rehabilitation. Thus, identification of novel modalities that allow continued focus on movement is imperative for improving rehabilitation of the upper limb of stroke survivors.

This work was supported in part by the Fulbright Program, through its funding of I. Pastor as a Fulbright Scholar.

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Home based interventions have the potential to provide stroke survivors additional rehabilitation opportunities. It also has the advantages of a more familiar and private atmosphere and it eliminates the need to commute. Recent developments in Virtual Reality and tracking devices (e.g. a web cam with passive markers) offer novel tools at low cost, resulting in rehabilitation systems suitable for home use [4, 5].

Research on the use of Virtual Reality for rehabilitation has been ongoing for several years. Motion capture systems and serious games (e.g. games that are not for entertainment) have been proposed to help in the rehabilitation, for applications ranging from chronic pain [6] to stroke [7]. Even though these systems showed promising results, the high cost, the requirements of big spaces and the complexity of installing and setting up the tracking systems makes them inappropriate for rehabilitation outside of the clinical environment, for example in the home environment.

Lower cost tracking devices greatly decrease the overall price of such rehabilitation systems that are designed for use away from the clinic. For instance, several groups are working with webcams to track patient's hand or objects using passive markers [8-10]. The use of a camera and active markers, such as infrared LEDs has also been proposed [11]. The Nintendo Wii remote [12] is another inexpensive method of evaluating movement, and has been used for therapy [8]. Even though good results have been obtained by these groups there are some issues that limit the use of the systems at home or make implementation difficult away from a lab setting. The patient's clothes can interfere with the tracking of passive color markers if similar colors are present. Changes in the room's lighting can also decrease the trackers accuracy or make it stop working. Another disadvantage of using a single camera is that only 2D tracking is possible limiting rehabilitation exercises to just planar movements. In addition, when active markers or Wii remotes are used the patient has to hold or wear a device. This can be troublesome and uncomfortable. Furthermore, low functioning patients might not be able to grab the devices or open their hands to grip the trackers.

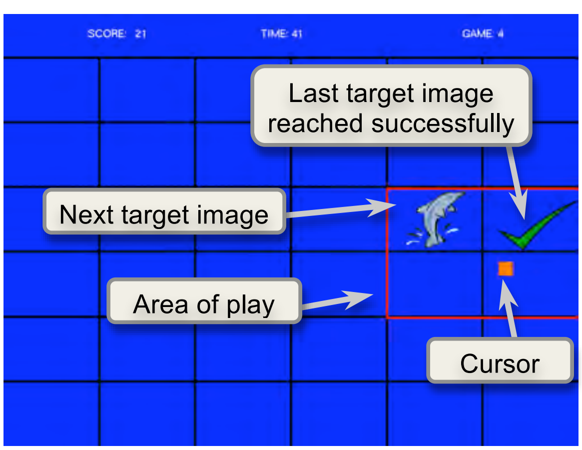
The commercially available Microsoft Kinect [13] is a recently available low-cost tracking alternative, and does not require users to hold or wear any specialized equipment for tracking. Its reasonably high accuracy (xy resolution = 3mm, z resolution = 1 cm [14]) and low price makes it a good tracking alternative for a home based rehabilitation system. Schönauer *et al*. [6] compared the performance of this device with a Motion Capture system and found Kinect cannot measure as many parameters and has a lower accuracy. However, their study demonstrated a custom game that was nevertheless controlled well with Kinect [6].

The Kinect has been commercially available for less than two years. A Kinect has been used to estimate the pose of the lower-limbs of a person using a wheeled walker [15] and to improve the measurements of inertial sensor [16] and wearable haptic devices [17]. A Kinect has also been used in rehabilitation, to track a patient's upper body in games targeted to treat balance issues [18]. Typically, for the skeletal system calibration, the patient has to stand about two meters away from the Kinect with their arms up and hold this position without moving for a few seconds. This calibration method is not appropriate for stroke rehabilitation since most survivors are unable to complete this procedure.

The Kinect is small and affordable, making it an excellent tool for use in home-based rehabilitation. In particular, when used at home a Kinect-based system can encourage increased use of the upper extremity for stroke survivors. The system presented here uses this device pointed downward to track the patient's hand to play a game designed specifically for upper limb rehabilitation of stroke survivors. The calibration process is easy for a patient with a weak upper extremity and only requires the patients to move their hands in a waving motion on a flat surface at table height for the upper limb system calibration. Furthermore, no extra accessories, such as markers or hand supports, are required.

This paper presents a new system for the rehabilitation of the impaired upper limb of stroke survivors using computer games and Kinect. Section II describes the system proposed and the feasibility study. Sections III and IV contain the results and discussion, followed by conclusions in Section V.

(a)



(b)

Figure 1. (a) Illustration of the system's setup; (b) Screenshot of the game.

II. Method

A. Hardware setup

The system requires patients to sit in front of a table with a stand holding a Kinect pointed toward the floor, a hand support parallel to the table, and a monitor. The setup is shown in Figure 1(a). The software runs on a Dell Inspiron M501R Laptop connected to a 20'' monitor. The game is shown on the monitor, and to play it, the patient moves the affected hand while resting on the support.

The arm support is needed because due to the patients' lack of strength and mobility of their impaired upper limb, it can be difficult to keep the arm raised for extended periods of time. The easiest approach is for users to slide their arm on top of a table. However, the Kinect has difficulty tracking the hand when it is in contact with an opaque surface, since a combination of depth data and 2d image analysis are used for tracking. To solve this issue, a transparent surface was placed parallel to and 15 cm above the table. To maintain a comfortable height for the user's arm, a table with a lower height was used. The Kinect was placed pointing toward the table using a custom stand, as illustrated figuratively in Fig. 1a. A distance of 1-3.5 m is specified for tracking the skeletal configuration, but a shorter distance can be used for tracking only the hand. Thus, the Kinect was placed 70 cm above the transparent support so that only the playing area in its field of view, to keep movement of the upper body out of view.

B. Software setup

1) *Interaction with Kinect:* Data was obtained using an open source driver provided by PrimeSense [19], the company who developed Kinect. Motion tracking middleware NITE, developed by Open Natural Interaction (OpenNI) [20], was used for tracking. NITE provided 3D coordinates of the tracked hand. These data were available as real world coordinates and as projective coordinates. To decrease jitter and noise, a Kalman filter was implemented.

2) *Game:* A game was designed and developed specifically for upper limb rehabilitation of stroke survivors. The game fulfills requirements developed in conjunction with the physical therapist team at the University of Utah's Rehabilitation and Wellness Clinic. Specifically, the objective of the game is to increase range of motion, with an ultimate goal of improving motor recovery and functional use of the impaired upper extremity.

To meet this objective, the game requires the patients control a cursor on the screen by moving their hand. The goal of the game is to select images that randomly appear in any cell of a 6X6 grid. To select an image, patients need to locate the cursor inside the appropriate cell. Figure 1(b) shows an annotated screen shot of the game.

The game has a total of 10 rounds. For each round, the image randomly appears within different areas of the screen outlined in by a red rectangle (the "area of play"), as shown in Figure 1(b). This allows different portions of the range of motion to be targeted. The number of cells in the area of play increases gradually, making the game harder as it progresses. The size of the playing area is 2X2 for the first four games. Then, the size increases to 3X3 for games 5 and 6 and to 4X4 for games 7 and 8. The last two games are played on the entire screen (6X6). The first four games are played in bottom, left, top and right 2X2 areas of the screen, respectively (Figure 1(b) shows an area of play in the right 2X2 area of the screen). Games 5 and 7 are played in the area where patients obtained the lowest score in the first four games. It is assumed that the lowest score corresponds to the area that requires the most effort and therefore additional targeted use by the patient. Games 6 and 8 are played in the opposite area of the screen so patients can rest from the previous workout.

Each round lasts between one and two minutes and there is a break of half the length of the round between them. Rounds are one minute long for the first two days of the study and their duration was periodically incremented every two days until they reached two minutes on the final days. To maintain the patient's interest the topic of the images shown changes every session. Household chores, transportation means, furniture are some of the topics that were used.

Before starting to play the game, the user is asked to move the hand as far as possible to the left, right, away from and towards the body. These data is used to calibrate the range of motion required to play the game according to the user's abilities. The range of motion and the score of every round are stored for future analysis.

C. Testing protocol

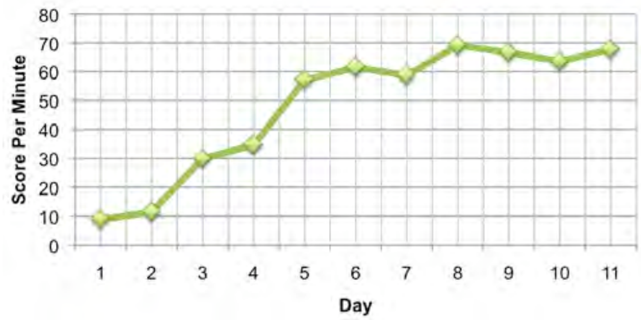
A preliminary study was implemented to evaluate the acceptance of the system, and to investigate the efficacy. The study was carried out with one stroke survivor. The patient played the game once a day, for ten consecutive weekdays (Monday through Friday). Before the study began, a pre-test was carried out in order to obtain patient's range of motion and teach the user how to play the game. Teaching the patient how to play the game before the study begins is intended to decrease score improvement due to game learning. The Fugl-Meyer upper extremity motor score was obtained before and after the study to determine if any improvement was achieved. The Fugl-Meyer is a stroke-specific, performance based impairment measure and provides information on motor recovery [21]. The patient also answered usability surveys before and after the study in order to analyze her expectations about and the acceptability of the system.

D. Recruitment

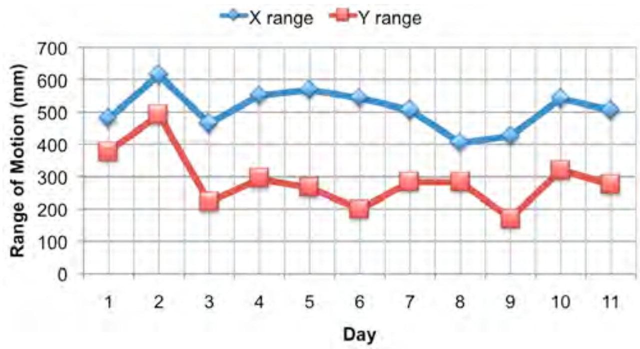
A 46 year old female participated in the study. She suffered a stroke 25 months before the study began when a brain tumor was being removed. She stayed in the hospital for two months and has been doing therapy at the University of Utah Rehabilitation and Wellness Clinic, an outpatient exercise facility for stroke survivors, three times a week for 20 months. Her Fugl-Meyer upper extremity motor score was 16/66, indicating severe disability with hemiplegia.

III. Results

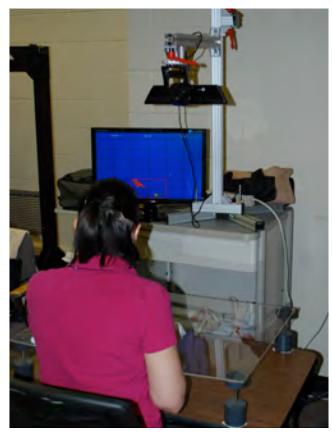
Figure 2 (a) and (b) show graphs of the patient's score and range of motion over the testing period. Day one corresponds to the pre-test, and days two to eleven correspond to the ten days of actual testing. Figure 2 (c) is a picture of the patient playing the game. The patient's Fugl-Meyer score was 16 (unchanged) after the study. Table 1 lists the survey questions with the pre- and post-test responses from the patient.



(a)



(b)



(c)

Figure 2. (a) Plot of score per minute versus days; (b) Plot of range of motion versus days; (c) Picture of patient playing the game

IV. Discussion

The patient attended all the sessions and was engaged with the game. She would remember the score obtained the previous day, and she tried to improve each day. The system's acceptability by the patient was high, as indicated by the scores in Table 1. Specifically, she found the game easy to understand, comfortable to play and she stated that she was willing to use the system at home. The use of the system over the two weeks period changed her perception of the game, as evidenced by her improvement on her rating of the statement, "Computer game based therapy is more enjoyable than classical therapy," from "strongly disagree" before the study to "agree" after it.

TABLE 1. SURVEY RESULTS

Survey Question	Pre-test	Post-test
Computer game based therapy can improve arm mobility	Strongly agree	Agree
Computer game based therapy is more enjoyable than classical therapy	Strongly disagree	Agree
It will be comfortable to play a computer game for therapy	Agree	Strongly Agree
The computer game for therapy will be easy to understand	Strongly Agree	Strongly Agree
I would be willing to use the system at home every day	N/A	Agree

The patient's game score increased throughout the study. The increase was bigger in the first week but also improved during the second. The game's score is proportional to the arm's movement speed, but may not correspond to motor recovery. Future studies may need to vary the intensity (e.g. difficulty, practice time, etc.) or type of patient recruited in order to observe an improvement in motor recovery.

An unanticipated aspect was that the subject repeatedly helped move her impaired arm with her healthy arm. Although this may be an appropriate adaptive strategy, at this point, the main goal of the research is to evaluate whether this system can provided targeted rehabilitation to the impaired limb that results in improved performance. We will next recruit target patients with more initial mobility (such that they do not feel a need to provide assistance with their healthy arm) by requiring a Fugl-Meyer score above 33.

V. CONCLUSION

The system developed provides a potential in-home novel rehabilitation system for stroke survivors. Its low-cost and easy-to-use characteristics makes it suitable for the home environment. In addition, the game is personalized to the patient's abilities each time it is played, by adapting to the range of motion and areas that are more difficult for the patient. In this initial study, the system's acceptability by the patient was high. The patient was engaged with the game and enjoyed the study. The patient's game score increased, although this may or may not be related to the playing of the game. The game will now be implemented in a larger study, with a higher number of subjects to further evaluate the efficacy and the interest levels of the subjects in having such a system available to them in the home environment.

ACKNOWLEDGMENT

We are grateful to the study subject for her time, and to our colleagues in the Univ. of Utah Rehab. and Wellness Clinic, particularly David Miller, for their assistance in recruiting subjects and accommodating our study.

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