Feasibility Study of Using Microsoft Kinect for Physical Therapy Monitoring

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INTRODUCTION

In preventive and rehabilitative health care, physical exercise is a powerful intervention. However, many people do not adhere to the prescribed program (Bassett, 2003) which may require in the range of thousands of practice repetitions (Kleim and Jones, 2008). Also, exercises may be performed incorrectly, making the exercise ineffective, or even dangerous (Escamilla et al., 2009; Tino & Hillis, 2010). Exercise programs prescribed to address specific problems, and even many preventative wellness programs for healthy older adults, must be individually tailored by a clinician due to the presence of co-morbidities and additional impairments. The current state-of-the-art for exercise instruction and monitoring is usually limited to written instructions, exercise recording logs, and simple repetition counting devices. Unfortunately, this practice has a number of problems:

- The patient does not receive any feedback on the quality of the prescribed exercises.
- The clinician has no way of knowing whether or not the patient has carried out the prescribed exercises correctly and with the required number of repetitions.

Correct adherence to supplemental home exercise is essential for safe, effective, and efficient care. The lack of correct feedback during independent in-home exercise is therefore a serious concern. The use of simple counting devices helps verify the exercise repetitions. However, such simple, commercially available devices cannot fully capture all the required movements beyond the most simple, such as counting steps or recording overall amounts of activity (Wagner et al., 2012; Yang & Hsu, 2010), and are, therefore not useful for most prescribed home exercises.

The release of the Microsoft Kinect sensor, which is equipped with a depth camera capable of measuring 3 dimensional positions of the objects in its view, has triggered tremendous interest in its use to monitor in-home physical therapy exercises (Chang et al., 2013; Chang et al., 2012; Garcia et al., 2012; Gibson et al., 2012; Guerrero & Uribe-Quevedo, 2012; Huang, 2011; Zannatha et al., 2013; Pastor et al., 2012). This is not surprising because:

- The Kinect sensor can be programmed to provide continuous feedback about correct exercise performance to the patient exercising at home, as it simultaneously records the session for review by the therapist.
- Kinect is an inexpensive device. The first generation of Kinect sensor is available commercially for around $100, which is about the cost of a single physical therapy session.

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Hence, a Kinect-based system could facilitate proper performance of the exercise or fitness program, increase patient accountability, allow the clinician to correct any errors in exercise performance, and allow program modification or advancement as needed. Hence, the Kinect sensor based system could potentially provide sufficient feedback and guidance to patients performing clinician prescribed in-home exercises, significantly minimizing costly and inconvenient trips to outpatient centers, and improving the effectiveness and outcomes of courses of treatment.

Many existing clinical trials with Kinect-based systems appear to have proceeded without comprehensive validation tests (Chang et al., 2013; Chang et al., 2012; Garcia et al., 2012; Gibson et al., 2012; Guerrero & Uribe-Quevedo, 2012; Huang, 2011; Zannatha et al., 2013). Other studies have aimed to characterize the accuracy of the Kinect sensor; however, these validation studies all focus on the movements within the frontal plane for a subset of the joints or segments (Clark et al., 2013; Obdrzalek et al., 2012; Mobini et al., 2013). In this article, we report our study on the feasibility of using a Kinect-based system for physical therapy exercise monitoring. Instead of comparing the joint positions or angles formed by key segments with respect to a (usually far more expensive) reference system, we take a completely different approach by focusing on the feasibility of using such a system to assess the correctness rules for a few common exercises in physical therapy. The correctness rules are readily implementable in a computer program for real-time motion tracking and feedback.

Due to space limitations, we only present results for two exercises, namely hip abduction and toe touch. In the standing hip abduction exercise, one leg is moved into hip abduction without any additional sagittal plane hip flexion/extension or transverse plane hip rotation. The pelvis, knee, and ankle remain stationary. In the standing toe touch exercise, the trunk bends forward and the arms reach to touch the floor. Motion occurs primarily as sagittal plane spine and hip flexion with concurrent shoulder flexion. When done correctly, there is minimal movement of the elbows, wrists, knees and ankles. We show that, although the Kinect-based system is capable of assessing many correctness rules for these exercises, it fails in the presence of significant self-occlusion, especially for the toe-touch exercise.

BACKGROUND

Microsoft Kinect was initially released as an add-on device for the Xbox 360 game console. Kinect enables a person to interact with a game using gestures and voice commands via what is referred to as the Natural User Interface. As such, a key functionality of the Kinect sensor is to detect human motions based on a depth camera, which is equipped with an infrared laser project and a monochrome CMOS sensor. The depth camera is capable of capturing video data including 3 dimensional position information for each pixel, and with up to 640x480 pixel resolution and up to a 30Hz frame rate. Kinect is also equipped with a microphone array to facilitate voice control.

Soon after the release of the Microsoft Kinect, open source drivers for the device and libraries for software development were developed (Borenstein, 2012). In early 2011, Microsoft released an official driver for Kinect and a software development kit (SDK). As of the writing of this article, the latest SDK is version 1.8. Perhaps the most useful feature of the SDK is skeletal tracking, via which, an application can receive pre-processed frames containing up to two skeletons each with 20 joints, including head, shoulder center, left shoulder, right shoulder, left elbow, right elbow, left wrist, right wrist, left hand, right hand, spine, hip center, left hip, right hip, left knee, right knee, left ankle, right ankle, left foot, and right foot (Jana, 2012).

Also very useful in the Microsoft Kinect SDK are its floor clipping application programming interfaces (APIs). Each skeleton frame includes a floor clipping plane vector containing the coefficients of the floor plane equation. Based on the floor clipping plane vector, we can calculate the vertical height off the floor clipping plane of each joint. In our study, we exploited the APIs to assess the correctness of some of the exercises.

FEASIBILITY STUDY

To assess the feasibility of using Microsoft Kinect for physical therapy monitoring, we compared the skeletal joint results obtained from Kinect to those obtained concurrently by a Cortex motion capture system (Motion Analysis Corp, Santa Rosa CA) (2010). The subjects wore a full Helen Hayes marker set and each exercise

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