A Validation Study of Rehabilitation Exercise Monitoring Using Kinect

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INTRODUCTION

In rehabilitative health care, a carefully designed physical exercise plan could be instrumental to the recovery of a patient provided that the patient. Exercise programs are prescribed to address specific problems, and are often individually tailored by a clinician due to the presence of co-morbidities and additional impairments. It is critical that the patient perform the proscribed program correctly and with adequate practice repetitions (in the range of thousands) (Kleim and Jones, 2008), otherwise, the exercise may be ineffective, or even dangerous (Escamilla et al., 2009; Tino & Hillis, 2010).

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). 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; Zhao et al., 2014; Tamei et al., 2015; Ebert et al., 2015). Other studies have aimed to characterize the accuracy of the Kinect sensor; however, these validation studies have focused primarily 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 validation study on using a Kinect-based system for physical therapy exercise monitoring. Instead of comparing the joint positions or angles

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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 limitation, 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. In early 2011, Microsoft released an official driver for Kinect and a software development kit (SDK). 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 for Kinect v1, and up to four skeletons each with 26 joints for Kinect v2 (Lun and Zhao, 2015). 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.

VALIDATION STUDY

To validate the use of Microsoft Kinect for rehabilitation 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 was recorded by 8 cameras The Cortex motion results were used to establish the ground truth for the study according to its established accuracy.

Our study has gone through three phases. During the initial phase, we attempted to carry out a mechanical point-to-point comparison between the two systems based on coordinate transformation. This proved to be difficult because it would require the Kinect sensor to be placed in a known location and a known tilt angle to the Cortex system. In the second phase, we attempted to focus on the comparison of relative movement between joints and the angles formed between adjacent segments during the movement. This effort was partially successful because it did not require coordinate transformation. However, a comprehensive comparison was still difficult because the positions of the markers used in the Cortex system did not correspond strictly to the joint positions reported by the Kinect sensor. Figure 1 shows a partial comparison of results we obtained in the first two phases for the hip abduction study. By exploiting the floor clipping plane APIs, we managed to compare the height of the knee and ankle during the hip abduction motion (i.e., right knee and right ankle) reported by the Kinect sensor and that captured by the Cortex system. As shown in Figure 1(b), the Kinect results were fairly close to those captured by the Cortex system. Figure

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