Journal of Hand Therapy xxx (2016) 1–8

Contents lists available at ScienceDirect

Journal of Hand Therapy

journal homepage: www.jhandtherapy.org

Scientific/Clinical Article

Modifying Kinect placement to improve upper limb joint angle measurement accuracy

Na Jin Seo PhD [a,b,*], Mojtaba F. Fathi MS [c], Pilwon Hur PhD [d], Vincent Crocher PhD [e]

[a] Division of Occupational Therapy, Department of Health Professions, Medical University of South Carolina, Charleston, SC, USA
[b] Department of Health Sciences and Research, Medical University of South Carolina, Charleston, SC, USA
[c] Department of Mechanical Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI, USA
[d] Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA
[e] The Melbourne School of Engineering, The University of Melbourne, Melbourne, Victoria, Australia

A R T I C L E I N F O

Article history:
Received 15 January 2016
Received in revised form
2 June 2016
Accepted 19 June 2016
Available online xxx

Keywords:
Kinect location
Accuracy
Motion capture
Arm movement
Upper limb joint angle
range of motion

A B S T R A C T

Study Design: Repeated measures.
Introduction: The Kinect (Microsoft, Redmond, WA) is widely used for telerehabilitation applications including rehabilitation games and assessment.
Purpose of the Study: To determine effects of the Kinect location relative to a person on measurement accuracy of upper limb joint angles.
Methods: Kinect error was computed as difference in the upper limb joint range of motion (ROM) during target reaching motion, from the Kinect vs 3D Investigator Motion Capture System (NDI, Waterloo, Ontario, Canada), and compared across 9 Kinect locations.
Results: The ROM error was the least when the Kinect was elevated 45° in front of the subject, tilted toward the subject. This error was 54% less than the conventional location in front of a person without elevation and tilting. The ROM error was the largest when the Kinect was located 60° contralateral to the moving arm, at the shoulder height, facing the subject. The ROM error was the least for the shoulder elevation and largest for the wrist angle.
Discussion: Accuracy of the Kinect sensor for detecting upper limb joint ROM depends on its location relative to a person.
Conclusion: This information facilitates implementation of Kinect-based upper limb rehabilitation applications with adequate accuracy.
Level of Evidence: 3b

Introduction

The Kinect (Microsoft, Redmond, WA) is a low-cost motion detection device, originally developed for gaming purposes. The Kinect provides kinematic data that used to be accessible only through traditional research purpose motion capture systems.[1-6] Yet, the Kinect costs only a fraction of traditional motion capture systems, is portable, and is less technically demanding to use. In addition, although typical research purpose motion capture systems require a person to wear markers over the body to track the person's limb motion, the Kinect captures limb motion without the need to wear any equipment on the body. This easy-to-use aspect of the Kinect is also complemented by user-friendly interfaces for obtainment of processed data, once developed for a specific application. These practical benefits of the Kinect have fueled development of Kinect-based applications for telemedicine. These applications include Kinect-based assessment tools to objectively quantify patient movements, evaluate rehabilitation progress, and aid planning of rehabilitation.[1,7-14] In addition, Kinect-based virtual reality rehabilitation games have been developed to motivate patients to continue therapeutic movements in the comfort of their home or typical environments such as school.[15-22] These Kinect-based rehabilitation applications have been shown to be well liked by both patients and therapists.[17,18,23] With its increasing popularity, a knowledge translation resource has been developed to support clinical decision making about selection and the use of

Conflict of interest: All named authors hereby declare that they have no conflicts of interest to disclose.

* Corresponding author. Division of Occupational Therapy, Departments of Health Professions, Medical University of South Carolina, 151B Rutledge Avenue, Charleston, SC 29425, USA. Tel.: +1 843 792 0084; fax: +1 843 792 0710.
E-mail address: seon@musc.edu (N.J. Seo).

0894-1130/$ – see front matter © 2016 Hanley & Belfus, an imprint of Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jht.2016.06.010

Kinect games in physical therapy.[24] Thus, the Kinect is considered a promising tool to aid rehabilitation.[25,26]

During the use of the Kinect sensor for movement assessment and/or rehabilitation games, the manufacturer recommendation is to place the Kinect horizontally in front of a person.[27] While this Kinect location may work well for detecting movements in the frontal plane, accuracy of the Kinect sensor may decrease for movements in the sagittal plane. It is because the Kinect's measurement error is the largest for the depth direction (ie, direction from the Kinect sensor to a person) compared to the horizontal and vertical directions. Specifically, the root mean square errors for the Kinect sensor is 6.5, 5.7, and 10.9 mm in the horizontal, vertical, and depth direction, respectively.[28] In other words, accuracy of the Kinect depends on its relative location to a person and movements being captured, and the Kinect accuracy may be improved by modifying the Kinect sensor location. For this reason, researchers have used different Kinect locations relative to the movement of interest. For example, Pfister et al[29] placed the Kinect 45 to the left of the person in the hope to best capture the knee and hip motions during treadmill walking. However, the optimal placement of the Kinect sensor has not been systematically investigated. The knowledge of optimal Kinect placement may contribute to increasing accuracy of joint angle measurements and utility of the Kinect. The likely reason that the optimal Kinect placement has not been established is that accuracy of the Kinect changes depending on the movements[30] due to the nonuniform measurement errors in the 3 axes, and thus, the optimal Kinect placement may vary depending on the movement of interest.

One of the movements of interest for upper limb therapy is target reaching.[22,31-42] Target reaching motion is typically used in upper limb rehabilitation settings as follows. First, people with movement disorders, such as due to stroke[22,31,32] and burn injury,[33] practice target reaching motion for therapy because it is one of the most important abilities for activities of daily living.[43] In addition, target reaching motion is used as part of outcome assessments of rehabilitation therapy programs for those with movement disorders after stroke[31,34-36] and peripheral nerve injury.[37] Likewise, target reaching motion has been used to characterize movement disorders for patients such as those with stroke[38-41] and muscular dystrophy[42] because of its ability to distinguish kinematic characteristics of patients from healthy controls or the unaffected side as well as its importance in our understanding of motor control.[44,45] Although target reaching motion is frequently used in upper limb rehabilitation settings, information regarding accuracy of the Kinect sensor in measuring all upper limb joint angles during target reaching motion is limited for varying Kinect sensor locations.[25]

Therefore, the objective of this study was to examine measurement accuracy of upper limb joint angles during target reaching movement using the Kinect and to determine the impact of adjusting the location of the Kinect sensor relative to a person on the measurement accuracy. Specifically, Kinect error in the range of motion (ROM) measurement was assessed as the difference in the upper limb joint ROM detected by the Kinect using Kinect for Windows Software Development Kit (SDK) (Microsoft, Redmond, WA) and by 3D Investigator Motion Capture System (NDI, Waterloo, Ontario, Canada). The 3D Investigator system was used as a research-grade motion capture system as it has been used for research involving upper limb[46-49] and other motion analyses.[50] A smaller difference in the measurement between the 2 systems would indicate better agreement of the Kinect to the research-grade motion capture system and thus accuracy. The error in the ROM measurement was compared across 9 Kinect sensor locations to examine the extent to which this error changed with varying Kinect sensor locations and to determine if the error in the ROM could be reduced by modifying the Kinect sensor location as compared with the standard location of being horizontally in front of a person. This study intends to contribute to improving Kinect positioning relative to a patient for better measurement accuracy and standardizing a Kinect-based measurement protocol for an upper limb rehabilitation setting, which is a necessary step for implementation in clinical practice.

Methods

Subjects

Ten right-handed healthy subjects (age range, 20-37 years; 5 males and 5 females) participated in this study. The study protocol was approved by the institutional review board, and all subjects signed the informed consent forms.

Procedure

An experiment was conducted to quantify difference in the ROMs for the upper limb joint angles determined using the Kinect as compared with a research-grade motion tracking system of 3D Investigator and to compare the difference across multiple Kinect sensor locations. Subjects were seated with the right forearm resting on a table. On computer-generated cues, subjects were asked to lift their right arm, point their index finger toward a prescribed target, and return to the initial position at a comfortable speed (Fig. 1A), similarly with previous studies.[31,32,37] Twenty-one targets labeled from 1 to 21 were presented on the wall in front of the subject to cover the upper limb workspace in front of a person at or above the shoulder level (Fig. 1A). Subjects' upper limb joint positions were recorded using the Kinect and 3D Investigator systems simultaneously. Each target for each Kinect location was prescribed at least twice. The order of testing the targets was randomized within a Kinect location. The order of testing Kinect locations was randomized across subjects. The consecutive reaching was separated by 5 seconds. Subjects were provided with rest breaks between Kinect location conditions.

Nine Kinect sensor locations were tested. The 9 locations differed by the elevation and azimuth angle of the Kinect sensor relative to the right shoulder (Figs. 1B and 1C): directly in front of the right shoulder at 45° elevation (denoted by $K_{45,0}$ in Fig. 1C), 30° elevation and directly in front of the right shoulder ($K_{30,0}$), 30° elevation and 60° to the left ($K_{30,-60}$) or 60° to the right ($K_{30,60}$), at the shoulder level directly in front of the right shoulder ($K_{0,0}$), 30° to the left ($K_{0,-30}$) or to the right ($K_{0,30}$), or 60° to the left ($K_{0,-60}$) or right ($K_{0,60}$). For all locations, the Kinect sensor was tilted such that the sensor faced the subject's right shoulder. The Kinect sensor was placed 1.5 m away from the right shoulder to ensure that the right shoulder and hand were within the capture range recommended by Kinect specifications[51] while minimizing the distance between Kinect and the subject because the depth accuracy of Kinect decreases with increasing distance.[52] Any shiny or dark objects such as a watch were removed from subjects to prevent interference with Kinect's motion detection.[28,52] The position data for the right shoulder, elbow, and wrist joints in addition to hand in 3-dimensional space were obtained using custom-developed software with Kinect for Windows SDK.

During all reaching tasks, 3D Investigator system recorded positions of the infrared light-emitting markers placed on the subject's upper limb to determine the shoulder, elbow, and wrist joint positions as well as hand position in 3-dimensional space. The markers were placed on the right upper limb: 3 markers on the dorsum of the right hand, 2 markers on the right wrist (medial and lateral), 3 markers on the right forearm, 2 markers on the right elbow (medial and lateral), 3 markers on the right upper arm, and 1