Somphong Phommahavong, Dominik Haas, Jing Yu, Sabine Krüger-Ziolek, Knut Möller, and Jörn Kretschmer*

Evaluating the microsoft kinect skeleton joint tracking as a tool for home-based physiotherapy

Abstract: In physiotherapy, rehabilitation outcome is majorly dependent on the patient to continue exercises at home. To support a continuous and correct execution of exercises composed by the physiotherapist it is important that the patient stays motivated. With the emergence of game consoles such as Nintendo Wii, PlayStation Eye or Microsoft Kinect that employ special controllers or camera based motion recognition as means of user input those technologies have also been found to be interesting for other real-life applications such as providing individual physiotherapy exercises and an encouraging rehabilitation routine. Due to the intended use of those motion tracking systems in a computer-game environment it remains questionable if the accuracy of the skeleton joint tracking hardware and algorithms is sufficient for physiotherapy applications. We present a basic evaluation of the joint tracking accuracy where angles between various body extremities calculated by a Kinect system were compared with a high resolution motion capture system. Results show promising results with tracking deviations between 2.7° and 14.2° with a mean of the absolute deviations of 8.7°.

Keywords: Physiotherapy; motion tracking; Microsoft Kinect

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1 Introduction

In physiotherapy, mechanical force and movements are applied by a specialized therapist to prevent and cure injuries. The therapy consists of specific treatments applied by the therapist and of exercises executed by the patient. Therapeutic exercise programs are composed by the therapist to fit the unique needs of an individual patient. Besides manual therapy and exercises applied during appointments with the therapist, the patient is usually instructed to perform additional exercises at home to support the rehabilitation process. In order to achieve satisfying results, the patient has to perform the prescribed exercises on a daily basis at home. There, without the physiotherapist nearby, the patient might find the exercises demotivating and dull [1]. Additionally, to prevent unnecessary strain to the body joints, possibly leading to further injuries, the patient needs to pay close attention to both the body posture and the range of motions, repeating the exercises the exact same way as shown by the therapist [2].

Game consoles employing various ways of user interaction have nowadays been established as a form of home-based exercise. Systems such as Nintendo Wii (Nintendo AG, Kyoto, Japan), PlayStation Eye (Sony Computer Entertainment Inc., Tokyo, Japan) or Microsoft Kinect (Microsoft Corporation, Redmond, USA) allow the user to interact with a computer game by either using a special controller with acceleration and tilt sensors (Wii) or through motion recognition (Eye, Kinect). Various games aiming at mimicking motions during sports such as tennis, skateboarding or boxing allow users to work out in the home environment.

Using such rather low-cost motion tracking systems as a way to support medical rehab and home-based physiotherapy has been the fundamental idea of various systems, some of which are already commercially available on the market [3]. They use the user-computer interaction to provide individualized exercises and an encouraging rehabilitation routine. The Microsoft Kinect camera system comprises two infrared depth sensors with a defined distance from each other. Using both signals together with triangulation allows determining the three-dimensional coordinates of various body joints. Previous studies have shown a good concurrent validity when compared to data recorded with a marker based 3D camera system [4, 5]. Others have shown that the accuracy of the Kinect sensors depend on the posture, where standing posture lead to better outcomes than sitting postures [6]. Thus, the question remains that if, due to its focus on being used in a computer game environment, where the exact tracking of all joints is not the primary goal of the Kinect system, the calculated joint coordinates and the derived joint angles provide suf-

***Corresponding Author: Jörn Kretschmer:** Institute of Technical Medicine, Furtwangen University, Villingen-Schwenningen, Germany, E-mail: krj@hs-furtwangen.de; phone: +49 7720 307 4370, fax: +49 7720 307 4616
Somphong Phommahavong, Dominik Haas, Jing Yu, Sabine Krüger-Ziolek, Knut Möller: Institute of Technical Medicine, Furtwangen University, Villingen-Schwenningen, Germany

ficient accuracy to be used in a physiotherapy setting. We thus present results of a comparison study where angles between various body extremities calculated by a Kinect system were compared to calculations done with the help of a high-resolution motion tracking system.

2 Methods

2.1 Kinect system

The Kinect camera is a compact system, consisting of a VGA camera and a pair of infrared sensors, which serve as depth sensors. The system may be connected to a computer via USB and is usable with various programming languages, e.g. C# (Microsoft Corporation) or C++. The camera is able to track up to six people under normal conditions with two people being active at the same time. Based on the depth information and triangulation it tracks movements of the human extremities by computing the position of various skeleton joints. The origin of the skeleton structure is the hip centre, from which the skeletal tracking algorithm builds the whole skeleton. The position of all joints can be accessed by calling the respective functions provided in the Kinect SDK. In total, the position of 20 joints or body parts are available.

2.2 Vicon bonita system

To evaluate accuracy of the Kinect motion tracking, we employed a high resolution 3D motion tracking system. The system uses a network of eight infrared video cameras (VICON-Bonita, Vicon, Los Angeles, USA) placed around the test subject and linked by Ethernet cables. Each camera has 68 LEDs located around the lens to emit infrared light which is reflected by hemispherical markers attached to the test subject's body. The detection of the same marker by different cameras allows its location in three-dimensional space through spatial triangulation. Recording of camera data and computation of marker positions was done using the Vicon Nexus Software (Vicon).

2.3 Calculation of extremity lengths and angles

Using the Cartesian coordinates provided by both the Kinect and the Vicon system, the length of extremities and the angles between those can be calculated as described in Eq. 1 and 2. Figure 1 provides an example on how to calculate the angle in which the elbow is abducted.

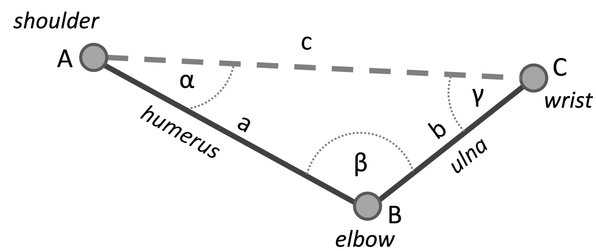

Figure 1: Example on how to calculate the ankle in which the elbow is abducted.

Solving the triangular equation, the elbow angle can be calculated as:

$$\beta = \text{acos}\left(\frac{a^2 + b^2 - c^2}{2ab}\right) \tag{1}$$

with a denoting the length of the humerus (AB), b denoting the length of the ulna (BC) and c being the distance between wrist and shoulder (CA). The length between joints A and B is calculated as:

$$AB = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2} \tag{2}$$

with x, y and z denoting the Cartesian coordinates of joints A and B in three dimensional space.

2.4 Experimental setup and study protocol

Figure 2 provides a schematic overview of the experimental setup. The Vicon cameras were placed on tripods and positioned around the test subject. Tripod height and camera angle were adjusted to provide an optimal vision of the reflective markers. Three equally distanced markers were placed each on the right wrist, elbow, shoulder, hip, knee and ankle of the test subject. Figure 3 shows the markers on the test subject.

The test subject was asked to adduct elbow, shoulder and hip in three different angles each (180°, 135° and 90° for elbow and hip; 90°, 45°and 0° for shoulder) and hold the position for several seconds. Thus, for the elbow the angle between humerus and ulna, for the shoulder the angle between humerus and right body side, for the hip the angle between femur and right body side was calculated. Marker positions were continuously recorded with the Vicon Nexus software and were exported to MATLAB (R2012a, The Mathworks, Natick, USA) to calculate the position of the skeletal joints and the angles between the extremities. The skeletal joint coordinates were estimated at

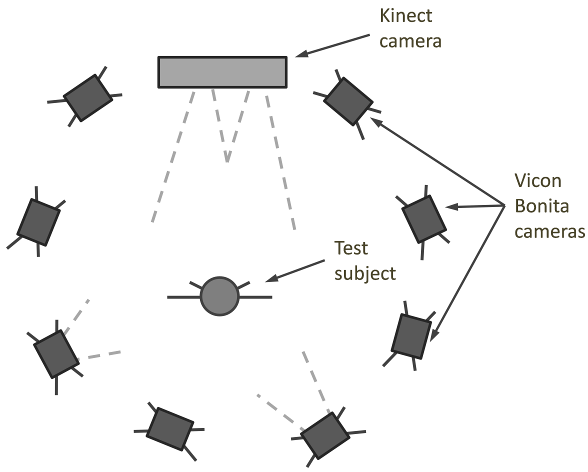

Figure 2: Experimental setup

the centre of the triangular area spanned by the markers. The calculated angles were then averaged over the period in which the test subject was holding the position. The Kinect camera was placed in front of the test subject with a distance of three meters. Skeletal joint coordinates provided by the Kinect camera were extracted using C# and the Kinect SDK. At each of the postures executed by the test subject, a snapshot containing the current joint coordinates was taken.

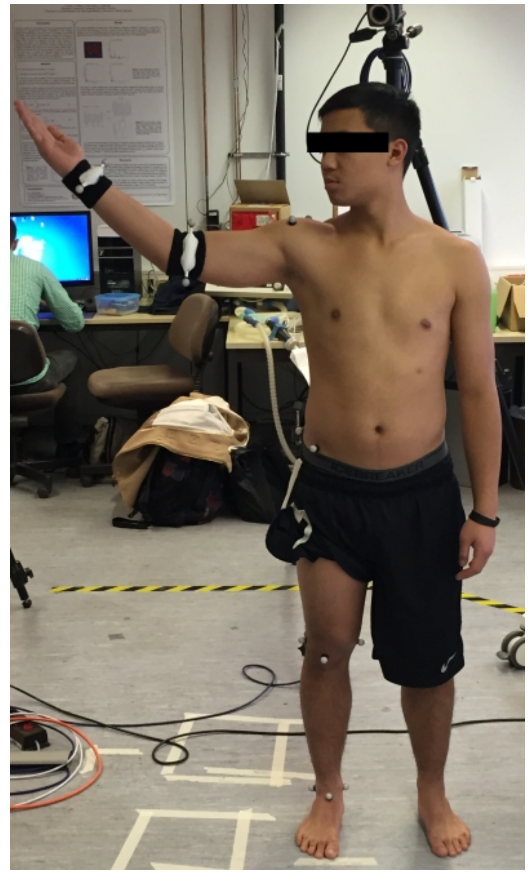

Figure 3: Test subject with reflective markers attached to wrist, elbow, shoulder, hip, knee and ankle joints.

3 Results

Table 1 provides a comparison between angles calculated with the Vicon system and the Kinect system. Angles provided by the Kinect system showed a maximum deviation of 12.6° for the elbow, 10° for the shoulder and 14.2° for the hip. Elbow and hip angles were all overestimated by the Kinect system, while shoulder angles were underestimated. Mean of the absolute deviations was 8.7°.

Table 1: Comparison between angles calculated based on Vicon and Kinect tracking data.

Body angle	Tested angle	Vicon result	Kinect result	Deviation
Elbow	180°	166.8°	170.3°	+3.5°
	135°	128.9°	136°	+7.1°
	90°	93.6°	106.2°	+12.6°
Shoulder	90°	93.5°	83.8°	−10.3°
	45°	47.1°	39.1°	−8°
	0°	15.5°	5.5°	−10°
Hip	180°	172.3°	175°	+2.7°
	135°	144.4°	158.6°	+14.2°
	90°	112.2°	121.7°	+9.5°

4 Discussion

The use of low-cost motion tracking systems with computer game background in a medical environment has been increasing majorly over the last few years. They allow high-quality training support at home without stressing health insurance costs. However, being intended to be used as a tool for gesture recognition, the accuracy might not be sufficient for medical applications.

The presented results show that the Kinect system has a deviation in calculating the angle between two joints of at least 2.7° and up to 14.2°. However, there are several limitations to this study to be mentioned. Firstly, the presented results were acquired with one single test subject. The Kinect system builds the skeleton structure based on the on the outer shape recognized through the dual infrared sensors. Thus, in obese patients, positional accuracy of the skeletal joints might decrease. An extended test with a greater number of test subjects, preferably with different body sizes and shapes would be necessary. Secondly, the joint positions recorded with the Vicon system were defined by three markers equidistantly placed around the skeletal joints of the test subject, thus not necessarily being in accordance with the joint positions calculated with the Kinect system. Additionally, the Vicon markers were placed on the test subject's skin, which at the shoulder and the hip joints might not be accordance with the real joint position. Therefore, the angles calculated in both systems comprise a natural difference. In the Kinect calculations, the hip joints are usually positioned more towards the hip centre compared to the placement of the Vicon markers. Logically, the highest deviation was recorded there. As the compared systems employ different reference coordinates, comparing the position of joints is not possible, thus preventing an analysis on which skeleton joint is tracked with best and which is tracked worst by the Kinect system.

Concluding, we believe that using a motion tracking system such as the Microsoft Kinect may be used as a low-cost solution for home-based physiotherapy as the recorded deviations are – despite the mentioned limitations – within a reasonable range. For professional applications the tracking accuracy might however be not sufficient.

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Author's Statement

Conflict of interest: Authors state no conflict of interest. Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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