AUTOMATIC CALCULATION OF PERSONAL BODY SEGMENT PARAMETERS WITH A MICROSOFT KINECT DEVICE

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The purpose of this study was to introduce an automatic method for calculating personal body segment parameters (BSPs). In this automatic method, a Microsoft Kinect device was used to capture depth frames for measuring joint locations. The open source software, MakeHuman, was used for generating 3D human models by referring using the joint location data captured from the depth frames. Segmental meshes were obtained from the generated 3D human models and personal BSPs could be calculated automatically. The tests showed that the developed method can complete all of the processes without manual digitizing, anatomical landmark detection and medical scanner operation. Further research should be conducted to establish the accuracy of the segmental masses, centres of mass and moments of inertia acquired from the developed methods.

KEY WORDS: Body Segment Parameters, Microsoft Kinect, Automation

INTRODUCTION: Personal body segment parameters (BSPs) including segmental masses, centres of mass and moments of inertia are essential data for many sport biomechanics studies to conduct accurate kinetic and kinematic analyses (Abe, Yokozawa, Takamatsu, Enomoto, & Okada, 2010; Deffeyes & Sanders, 2005). Several methods such as medical imaging techniques, geometric modelling methods, and experimental techniques have been developed for obtaining personal BSPs. Using these methods can provide more accurate data than using mathematical formulas to predict BSPs from a small number of anthropometric measurements (e.g. stature and body mass) and avoid time-consuming manual anthropometric data collection procedures (Chen, Hsieh, Lu, & Tseng, 2011). However, all of these methods contain some limitations which mean that researchers cannot obtain accurate personal BSP easily. The hardware of medical scanning methods (including 3D photonic scanning) is expensive (Chen et al., 2011). Certificated or well-trained operators are also needed for operating the medical scanners and to ensure high reliability of BSP data. Errors are associated with the post-processing tasks for 3D mesh editing (Ma et al., 2011) or manual digitising in the processes of geometry modelling methods (Sanders et al., 2015). The experimental techniques usually need complex and time-consuming measurement procedures for acquiring complete BSPs. For instance, researchers need to measure segmental girths for each segment and conduct motion capture tests and collect force plate data with several postures (Chen et al., 2011).

Davidson, Wilson, Wilson, and Chalmers (2008) conducted marker-based motion capture to measure the joint positions and used a 3D modelling program to build personal 3D human models for BSP calculation by referring to the joint positions. Although this method can avoid manual digitizing and time-consuming tests, expertise in anatomical landmark detection is needed for placing makers in correct positions. A Microsoft Kinect device can capture the 'depth frames' and the corresponding software can detect the joints without manual digitizing or marker placing as shown in Figure 1 (a, b ,c, d). Thus, a Microsoft Kinect device provides the potential to replace the marker-based system for measuring the location of joint position. This reduces the requirement of technical expertise in anatomical landmark detection. Furthermore, a Microsoft Kinect device is portable and cost-effective, which might increase the convenience for biomechanists to measure personal BSP data. Nevertheless, no method has been developed for using a Microsoft Kinect device to obtain personal BSPs. Therefore, the purpose of this study was to introduce an automatic method for BSP calculation with a Microsoft Kinect device. Evaluation tests were also conducted to understand the accuracy of the developed methods and examine whether the developed method can obtain BSPs automatically.

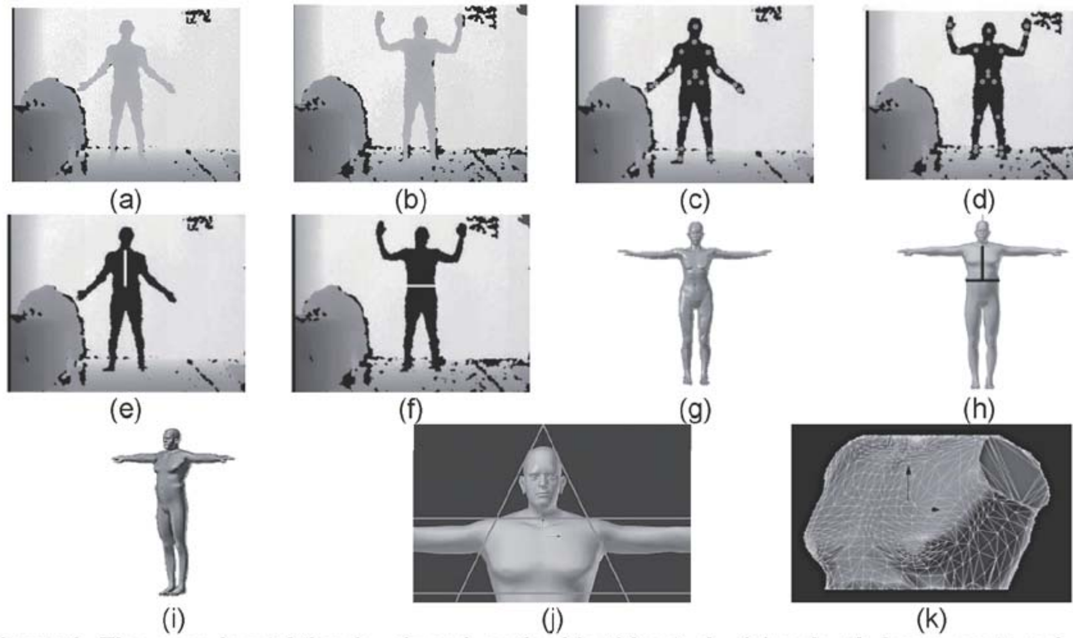

Figure 1: The overview of the developed method in this study. (a) a depth frame captured with natural pose (b) a depth frame captured with psi pose (c, d) the corresponding software can detect the joints without manual digitizing or marker placing from depth frames (e, f) the body dimensions extracted from depth frames (g) the base model of MakeHuman (h) after parameter setting, the body dimensions of the deformed base mesh can fit the body dimensions extracted from depth frames. (i) a generated personal 3D human model (j) the segmental boundaries can be easily identify from generated 3D models (k) the segmental mesh can be used to calculate BSPs.

METHODS:

A Microsoft Kinect device (Version 1) was used to capture depth frames for measuring joint locations. The Microsoft Kinect device captured a participant's depth frames in two poses (natural pose and psi pose) as shown in Figure 1(a, b). Fifteen body dimensions were used to illustrate the joint locations (i.e. relative positions between joints). The definition of body dimensions is listed in Table 1. Neck height, upper arm length, lower arm length, neck breadth and calf breadth were measured with the natural pose. Neck to waist length, waist to hip length, shoulder distance, upper leg height, lower leg height, four torso breadths, thigh breadth were measured with the psi pose. For each pose 30 depth frames were collected, and the body dimensions were extracted from each frame. The medians of the extracted body dimensions were used as the input for human modelling. In addition to 15 medians of extracted body dimensions, three manual measurements, age, gender and stature, were obtained for human modelling.

The open source software, MakeHuman (http://www.makehuman.org/), was used for generating a personal 3D human model. Eighteen MakeHuman parameters including 'stature', 'gender', 'age', 'weight', 'muscle tone', 'neck height', 'upper arm length', 'lower arm length', 'front chest', 'nape to waist', 'waist to hips', 'neck girth', 'bust girth', 'under bust girth', 'waist girth', 'hips girth', 'thigh girth' and 'calf girth' were altered to deform the base model (Figure 1 (g)) such that the body dimensions extracted from the deformed model (Figure 1 (h)) could fit the manual measurements (stature, age, gender) and the body dimensions measured from the depth frames (Figure 1 (e, f)). The 'gender' and 'age' parameter was set by MakeHuman functions and the 'stature' parameters was set by the bisection method. Other parameters were altered by the results of derivative-free optimizations.

Table 1 The Definition of Body Dimension (the joints detected by the correspond software of Microsoft Kinect are marked with single quotation markers).

Body dimension	Definition
Neck height	The distance between 'head' and 'neck'.
Upper arm length	The distance between 'right shoulder' and 'right elbow'.
Lower arm length	The distance between 'right elbow' and 'right wrist'.
Neck to waist length	The distance between 'mid spine' and 'neck'.
Waist to hip length	The perpendicular distance from 'mid spine' to the horizontal middle level between 'right hip' and 'left hip'
Shoulder distance	The distance between 'right shoulder' and 'left shoulder'
Upper leg height	The distance between 'right hip' and 'right knee'
Lower leg height	The distance between 'right knee' and 'right ankle'
Neck breadth	The distance across the narrowest horizontal level on the neck segment
Torso breadth 1	The width at the Lv1. Lv1 was defined as the middle level between the horizontals of 'spinespace' and 'neck'.
Torso breadth 2	The width at the middle level between Lv1 and the horizontal of 'spinespace'
Torso breadth 3	The width at the horizontal of 'spinespace'.
Torso breadth 4	The width at the middle level between the horizontals of 'right hip' and 'left hip'
Thigh breadth	The width at the middle level upper leg
Calf breadth	The width at the middle level on the lower leg

After parameter setting, personal 3D human models were generated (Figure1 (i)). Since the generated 3D human models are the deformation from the base models, the segmental boundaries can be identified easily to acquire segmental meshes by indicating the specific vertex orders without any manual digitizing as shown in Figure1(j, k). The BSPs can be calculated by tetrahedron volume techniques (Zhang & Chen, 2001) and the method developed by Mirtich (1996) with the homogeneous density data presented in previous studies (Deffeyes & Sanders, 2005).

Examining the ability for the developed method to accurately assess body mass is considered a first step in the assessment of the potential for the process to assess BSPs. Seventeen healthy male participants were invited to take part in the study (stature: 162.8-189.5cm; body mass: 64.5-97.1kg). Each participant's stature and actual body mass were measured following the International Society for the Advancement of Kinanthropometry protocol (Stewart, Marfell-Jones, Olds, & Ridder, 2011). A Microsoft Kinect device was used to capture 60 depth images in two poses for each participant. The depth images and the manual measurement (stature, gender, and age) were input to estimate participants' segmental masses for calculating whole body masses by our developed method. The actual body masses were compared with the estimations by the relative technical error of measurement (Perini, Oliveira, Ornellas, & Oliveira, 2005) and Bland-Altman analysis.

RESULTS: Our developed method generated personal 3D models from depth frames which were captured from a commodity device for all 17 participants without putting any markers on anatomical landmarks. The BSPs can be calculated from generated 3D human models automatically. The estimated body masses were close to the actual body masses (relative technical error of measurement and root mean square error within 5% and 5kg respectively). The bias and limit of agreement ($\pm$2SD of the difference) between actual masses and estimated masses were 2.64$\pm$8.62kg respectively.

DISCUSSION: An automatic method for BSP calculation with a Microsoft Kinect device was introduced. This method can detect joint locations and avoid the need for technical expertise in specific hardware and software operation (e.g. manual digitizing on 3D meshes). Moreover, the developed method used a commodity device, Microsoft Kinect, which can reduce the cost of hardware. Therefore, Microsoft Kinect devices can be a useful tool for biomechanists to calculate BSPs with fewer limitations than previous methods.

The body mass estimation from the developed method (relative error larger than 5%) was not as good as the elliptical method (Jensen (1978), relative error less than 2%). The possible reason might be that the developed method only used a few body dimensions to build the personal 3D human model. Future improvement should be conducted to extract more body dimensions from depth frames in order to extract accurate BSPs.

It should be noted that the accuracy of elliptical zone method or other methods such as 3D photonic scanning might vary with different operators (Ma et al., 2011; Sanders et al., 2015). One of the major advantages of the proposed Microsoft Kinect-based method is that it can provide operator-independent results for BSP calculation. Nevertheless, this study only quantified whole body mass and not complete BSPs. Therefore, future research should be conducted to establish the accuracy of the developed software for obtaining segmental masses, centres of mass, and moments of inertia.

CONCLUSION: An automatic method for BSP calculation with a Microsoft Kinect device that enables body mass to be calculated within 5% was developed. This method has the potential to yield a full set of BSP data. Further validation research should be conducted to establish the accuracy of the segmental masses, centres of mass, moments of inertia acquired from the developed methods.

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