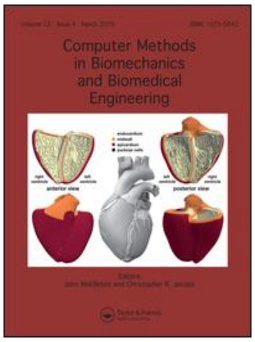

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Validity of 3D reconstruction of a new tool for postural assessmentbased on a single optical camera

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KEYWORDS 3D reconstruction; DLT; low-cost; posture

1. Introduction

Several techniques for balance assessment coexist, either for clinical or research purposes (Yeung et al. 2014; Boulet et al. 2016; Dinu et al. 2016). The gold standard remains measurements of the Center of Pressure (CoP) coordinates using a force plate. From the CoP data, several models for Center of Mass (CoM) reconstruction have been developed. However, these do not take into consideration body segments posture and their influence on the CoM during quiet standing. For these reasons, many authors have developed direct CoM modeling using various technologies (Vicon® (Boulet et al. 2016), inertial sensors (Dinu et al. 2016), thermal imaging (Clark et al. 2012; Yeung et al. 2014), 3D camera (Placidi et al. 2014), multiple camera setting (Corazza and Andriacchi 2009), etc.). The issue of the technological cost and its impact on the clinical accessibility has brought a will to develop low-cost tools.

In this context, our goal is to develop a protocol allowing a 3D modeling of body segments and the CoM using Direct Linear Transformation (DLT method, based on Abdel-Aziz & Karara's equations (Abdel-Aziz and Karara 1971)). The aim of this study is to estimate accuracy and reliability of static 3D reconstruction based on a single low-cost camera and mirrors.

2. Methods

2.1 Experimental setup and equipment

Images were acquired using a smartphone digital camera in automatic settings (lens Sony IMX 214 Exmor Rs, 35 mm equivalent full frame; 12Mpx 4:3, 3968x2976px). This choice of lens quality and resolution makes for an affordable and accessible optical tool, and is consistent with nowadays common technology. The camera was facing two 2×1 m mirrors at a constant distance; the total necessary volume in the room for the entire setup was $3 \times 2 \times 2$ m.

A 24 markers calibration cage has been designed using four plumb lines equipped each with 6 cylindrical markers of 6×6 mm. The coordinates of each marker has been precisely established in a three-dimensional reference frame (O x y z). The setup and number of markers was established according to Challis et al. findings regarding DLT calibration (Challis and Kerwin 1992) to limit the camera lens distortion.

A control tool equipped with 17 control markers (similar to the calibration markers) has been designed to evaluate the pertinence and accuracy of our reconstruction protocol. The tool's design is three-dimensional and the control markers are randomly positioned (*cf.* Figure 1).

2.2 Experimental protocol

Each component x, y, z of the coordinates of the calibration and control markers – hereafter referred to as 'metric measurements' – were measured using a measuring tape relatively to a predetermined origin marker (0, 0, 0); the precision is 0.5 cm. Pixel coordinates of the calibration cage and control tool were then manually determined using a motion analysis freeware (Kinovea, https://www.kinovea.org). Using MatLab, we ran a calibration and reconstruction algorithms based on DLT equations. The entire calibration process takes less than 20 minutes of time.

The sample standard deviation of the differences between metric and DLT values was calculated using Root Mean Squared Error (RMSE) method. This calculation as well as the statistical analysis described below was applied to all components (x, y, z) confounded, reflecting the overall accuracy (Kwon and Fiaud 2002).

2.3 Statistical analysis

A Bland-Altman plot (Bland and Altman 2010) as well as a two-way mixed-effects single measures Intraclass Correlation Coefficient ($ICC_{(3-1)}$ with $\alpha = 005$) were used to compare metric and DLT values.

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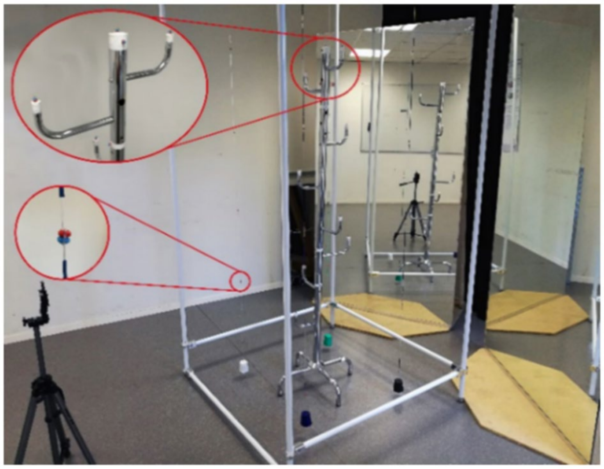

Figure 1. Experimental setup and equipment.

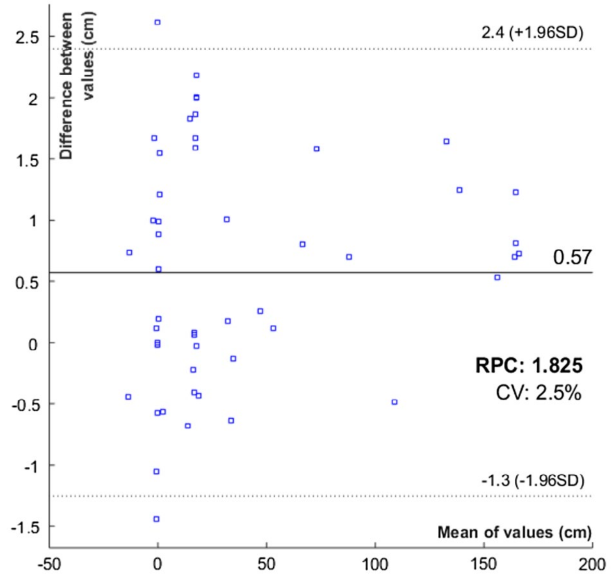

Figure 2 Bland-Altman plot, difference against test measurement with 95% limits of agreement (--- lines).

3. Results and discussion

The ICC reveals excellent reliability (r = 0.9999, 95%CI = 0.9997; 0.9999). The RMSE was 1.09 cm. The Bland-Altman plot is presented in Figure 2 and shows a good agreement between metric and DLT method. A mean difference of 0.57 is observed ($p < 0.0001$, 95%CI = 0.06; 1.09), which could reveal an undervaluation in the metric measurements or an overvaluation in the DLT measurements.

Many authors working on optical 3D-modeling have used CoP measurements as a standard for validity and reliability assessment (Corazza and Andriacchi 2009; Placidi et al. 2014; Boulet et al. 2016). Dinu et al. (2016) and Clark et al. (2012) found similar results to our own assessing respectively inertial sensors (r > 0.99, $p < 0.001$) and a Microsoft Kinect™ (r > 0.90 for the majority of measurements) to a Vicon system. Comparing Microsoft Kinect™ to a Vicon system in balance control tasks, Yeung et al. (2014) obtained a RMSE of 0.401 cm and an excellent correlation score (r = 0.92–0.95).

4. Conclusions

The results of this preliminary study are very satisfactory regarding accuracy in static measurement. The metric values level of precision (0.5 cm) is very likely responsible for the slight discrepancies observed through our analysis. The modeling based on DLT reconstruction relies on image resolution and lens distortion; our current setup allows for a 1 cm level of precision. The calibration process is fast (less than 20 min) and the entire setup costs less than 500$.

The following steps in our research is to establish the validity of our tool with human subjects compared to a standard (Vicon® optoelectronic system), both in static and dynamic measurements.

The aim is to confirm the validity, reproducibility and accuracy of our tool for a quick, accessible and affordable postural assessment.

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