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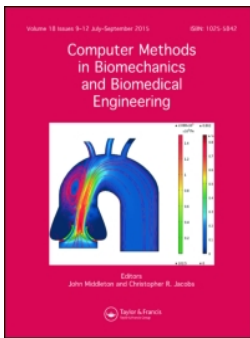
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Estimation of body segment inertia parameters from 3D body scanner images: a semi-automatic method dedicated to human movement analysis applications

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KEYWORDS Body segment inertia parameters; body scanner; human movement

1. Introduction

Estimation of Body Segment Inertia Parameters (BSIP) is a necessary step to perform dynamic analysis of human movement. As BSIPs cannot be directly measured, they are usually estimated using regressions derived from anthropometric tables (AT, e.g. Dumas et al. 2007). However, these tables are usually not adapted to atypical populations (children, elderly, obese, individuals with prostheses, etc.) that are classically of interest. Another option consists in estimating segments' volumes and in deriving their BSIPs using assumptions on their density (usually a constant uniform density). This option is of growing interest as the developments of low-cost 3D scanners yield to simple and accessible ways to obtain 3D body shapes (e.g. Peyer et al. 2015). However, there are still some issues to transform the measured external envelop into 3D shapes for each segment that are relevant for the human movement analysis, i.e. segmented and projected into local coordinate systems (LCS) according to anatomical definition and landmarks (e.g. Wu et al., 2005). Thus, this study aims at proposing a semi-automatic method (i.e. with minimal manual intervention) to estimate relevant BSIP from body scanner images. It is specifically dedicated to be used in the context a human movement analysis framework.

2. Methods

2.1 Experimental data

Nine subjects took part to this experiment: 6 males and 3 females (35 ± 10 y.o., 171 ± 10 cm and 84 ± 7 kg). The experiment consisted of a classical human motion capture experiment, to which a bodyscanning session was added. Subjects were equipped with 51 reflective skin markers, most of which located on specific anatomical landmarks. Once equipped, subjects were installed in a standard standing posture in a 3D body scanner (SYMCADTM

II by Telmat, Renneson, 2012) to obtain their external shape. It provided a textured mesh with a density of about a point every 3 mm (about 160000 nodes). Subjects then performed several motions and 3D trajectories of markers were collected using an optoelectronic system (Vicon). Only the data from a 10 second static trial were used in this study. The body scanner part of the experiment added no more than one minute to the classical procedure (installation in the body scanner cabin + acquisition). Experiments were approved by the national ethical committee.

2.2 Data processing

BSIP were estimated using two different approaches. At first, BSIP were estimated using anthropometric tables (Dumas et al. 2007) and 3D coordinates of markers located on anatomical landmarks measured during the static posture trial. Then a volumetric approach was used. It consisted in obtaining a personalized and structured mesh of the body segments, and estimating their inertia parameter by assuming a constant density (see Figure 1). The first part of the method was adapted from Beurier et al (2015). Beforehand a template mesh was created with the help of MakeHuman and Blender softwares. It was based on a 50th percentile anthropometry and was made of about 9000 nodes and 18000 triangles. Its posture was similar to the one taken by the subjects in the Body scanner. Nodes corresponding to 15 anatomical landmarks were identified. This mesh is further segmented in body segments, according to anatomical definitions used in AT (Dumas et al., 2007). Then, each individual raw mesh from the body scanner was post-treated. At first, nodes corresponding to the 15 anatomical landmarks of the template (a subset of the reflective markers located on subject's skin, i.e. easily identifiable), were manually identified. Then the raw mesh was cleaned and filtered using Meshlab's scripts to limit the number of point, remove duplicate vertices

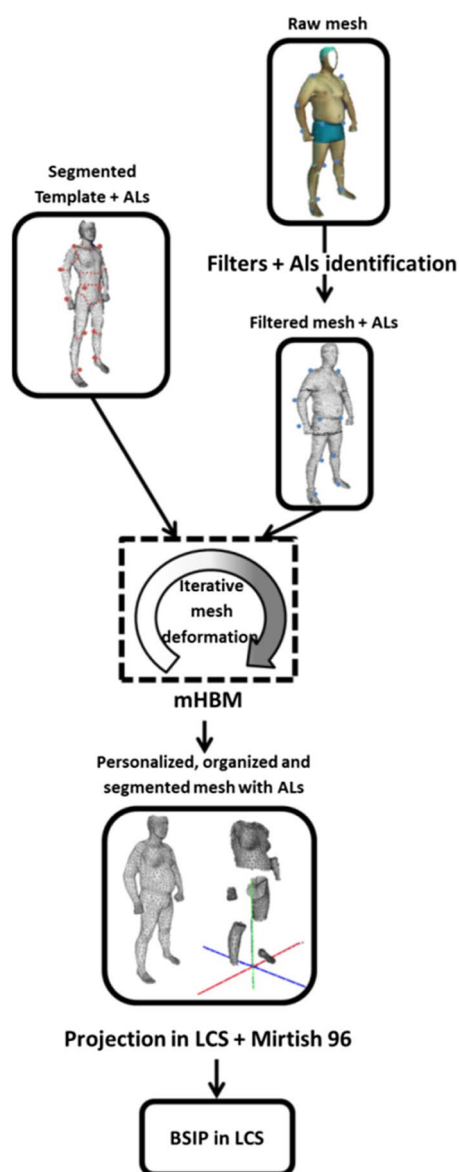


Figure 1 Overview of the volumetric approach to estimate the BSIPs in Local Coordinate Systems

and faces, non-manifoldness... A non-rigid transformation tool (mHBM software, Yamakazi et al., 2013) was then used to deform the template mesh onto the subject's cleaned mesh, ensuring a minimal distance between both mesh and a match between template and target landmarks. It resulted in a structured, segmented and personalized mesh with identified anatomical landmarks. Resulting meshes of body segments were then transferred into their corresponding LCS, defined according to ISB conventions (e.g. Wu et al. 2005), using the anatomical landmarks's nodes. Then, assuming a homogeneous density, BSIP were estimated using Mirtich's algorithm (Mirtich, 1996).

3. Results and discussion

Estimated BSIP by AT or volumetric methods yielded to very similar results. An example is provided for a typical subject in Figure 2. Mean absolute errors on mass distribution

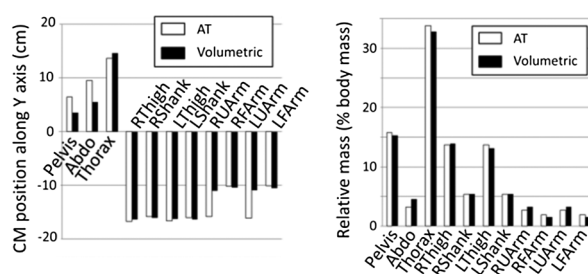


Figure 2 Results for a typical subject: CM along the Y axis (left) and relative mass (right) estimated by AT (white) and volumetric (black) approaches

are below 2% of body weight (maximal error observed for the thorax). Similarly, mean absolute errors on CM location were below 1cm in the frontal and lateral axis (X and Z), and up to 4 cm in the longitudinal axis (Y, maximal error observed for the thorax and abdomen). On average, absolute errors on inertia terms remained below 10^{-1} kg.m².

4. Conclusions

This study provided encouraging results showing that the proposed method leads to a relevant estimation of BSIP from body scanner images. Once the template has been created, the method is largely automated and necessitates only minimal manual intervention (selection of ALs on the body scanner images). This step could be easily automated by automatically detecting of markers corresponding to the ALs on the textured mesh based on their colour or shape. In terms of experimental constraints, it only adds about a minute to the experiment in order to perform the body scan. The method should still be extensively evaluated, in particular on atypical populations.

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