ARTICLE IN PRESS

Measurement xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Effects of the calibration procedure on the metrological performances of stereophotogrammetric systems for human movement analysis

Roberto Di Marco [a,b,*], Stefano Rossi [c], Enrico Castelli [d], Fabrizio Patanè [e], Claudia Mazzà [b,f], Paolo Cappa [a,d]

[a] Department of Mechanical and Aerospace Engineering, 'Sapienza' University of Rome, via Eudossiana, 18, Roma 00184, Italy
[b] Department of Mechanical Engineering, The University of Sheffield, Sir Frederick Mappin Building, Mappin Street, Sheffield S1 3JD, UK
[c] Department of Economics and Management, Industrial Engineering (DEIM), University of Tuscia, Via del Paradiso, 47, 01100 Viterbo, Italy
[d] Laboratory of Movement Analysis and Robotics (MARlab), Children Hospital 'Bambino Gesù', via della torre di Palidoro, 00050 Passoscuro, Rome, Italy
[e] School of Mechanical Engineering, 'Niccolò Cusano' University, Via Don Carlo Gnocchi, 3, 00166 Rome, Italy
[f] INSIGNEO Institute for In Silico Medicine, The University of Sheffield, The Pam Liversidge Building, Sir Frederick Mappin Building, Mappin Street, Sheffield S1 3JD, UK

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Accuracy
Calibration
Stereophotogrammetry
Human movement analysis

ABSTRACT

This paper proposes a methodology for evaluating the effect of different stereophotogrammetric system calibration procedures on the calculation of marker-based kinematics information. The methodology, based on calibrating the system using data recorded from capture volumes of different sizes and in trials of different durations, was applied to two different systems. The calibration data were used to reconstruct the static and dynamic position and orientation in space of a rigid wand carrying markers in known positions. The inaccuracies in the reconstruction of distances and angles from the wand markers were independent on the calibration data, with average errors lower than 1.7 mm and 0.7°, respectively. Similar results were obtained from human gait data, with the highest variations observed in the transverse plane kinematics and in the foot segment, suggesting that successful calibration procedures of different durations and performed in different volumes did not affect the metrological performance of the investigated systems.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

In the past decades, movement analysis techniques have been increasingly used to study human/animal motion [1–4]. Besides emerging techniques based on MIMU systems [5–8] and markerless approaches [9–12], the majority of the human movement analysis techniques are based on the measurement of three-dimensional position of active or passive markers attached to the body skin, as obtained using a stereophotogrammetric approach. These markers are used to track the three-dimensional pose of the subject's bones, to which they are uniquely associated through a procedure called anatomical calibration [1]. Once the pose of a bone is known, the joint kinematics, i.e. the relative orientation between adjacent bones, are estimated and used to quantify movement alterations and limitations and to plan and evaluate a patient's treatment.

Although stereophotogrammetric systems (SS) are routinely used in research and clinical practice, relevant data suffer from a number of inaccuracy sources that could hin-

* Corresponding author at: Department of Mechanical and Aerospace Engineering, 'Sapienza' University of Rome, Via Eudossiana 18, 00184 Rome, Italy. Tel.: +39 06 44585207.

E-mail address: roberto.dimarco@uniroma1.it (R. Di Marco).

http://dx.doi.org/10.1016/j.measurement.2016.01.008
0263-2241/© 2016 The Authors. Published by Elsevier Ltd.
This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Please cite this article in press as: R. Di Marco et al., Effects of the calibration procedure on the metrological performances of stereophotogrammetric systems for human movement analysis, Measurement (2016), http://dx.doi.org/10.1016/j.measurement.2016.01.008

Nomenclature

Abd/Add	abduction/adduction
CMC	coefficient of multiple correlation
ECS	embedded coordinate system
Flx/Ext	flexion/extension
GV	global volume
Int/Ext	internal/external rotation
Inv/Eve	inversion/eversion
Plt/Drs	plantar/dorsiflexion
RF	refinement frames
SS#1	stereophotogrammetric system #1
SS#2	stereophotogrammetric system #2
SS	stereophotogrammetric system
STA	soft tissue artefact
SV-LH	sub-volume left and high
SV-LL	sub-volume left and low
SV-RH	sub-volume right and high
SV-RL	sub-volume right and low

der the sought information. The main sources of inaccuracy are: (i) the soft-tissue artefacts (STA) due to the relative movement between the markers attached on the skin and the underlying bones [13]; (ii) errors in the anatomical calibration due to markers' misplacement [14]; and (iii) instrumental errors [15]. Whereas the first two errors are intrinsic in the use of skin markers, the third one is due to the use of a camera-based approach and it has been found to be dependent on: the number and position of the cameras [16,17], their lens distortion [18], the dimension of the capture volume [19,20] and, last but not least, the algorithms used for the reconstruction of a marker's 3D position [21], i.e. the marker tracking.

The effect of instrumental error on marker tracking have been originally quantified by placing a goniometer equipped with retroreflective markers in different zones of the capture volume [19,22], imposing known static angles and random trajectories to the goniometer and then comparing its outputs with the angles measured with a SS. More recently, a T-pendulum has been used for similar purposes, and it has been shown that increased angular velocities of the body under observation can decrease the accuracy of angle measurements [23]. Shifting the problem closer to the human movement analysis, a 'walking test' was proposed in [24,25]: a subject was asked to walk at a self-selected speed within the capture volume holding an aluminium bar equipped with two markers and eight SSs were tested. They showed that the systems with low noise generally seem to exhibit better performances. Subsequently, the Movement Analysis Laboratory (MAL) test has been proposed [26], which is based on recording the position of a rod carrying a 2-marker cluster, manually rotated around its tip either following a pseudo circle or two orthogonal arches. The MAL test allows to quantify both precision and accuracy associated with SS-based measurements (respectively related to random and systematic errors).

The need to move cameras, the changes in light conditions, or the presence of reflecting objects call for frequent recalibration of a stereophotogrammetric system within the human movement analysis context. As a matter of fact, the SS manufacturers recommend performing a calibration before each session of data collection. This calibration procedure is performed manually by the operator, who usually has to freely move an object within the camera capture volume, and is hence dependent on the modality of its execution. The evaluation of possible errors associated with the calibration procedure of the SS has been the object of a few investigations. In [27,28] two different methodologies to quantify the intrinsic error of the calibration algorithms that reconstruct the marker time histories have been introduced. Despite providing interesting results concerning the quantification of the calibration algorithm errors, they are by definition not useful in quantifying the variations following the need of a system recalibration. More recently, a custom-made robot, which could be used to move a L-frame equipped with retroreflective markers to perform the calibration, has been devised [16]. The authors showed that the use of the robot can significantly improve the accuracy of the calibration. However, the robot was moved within a capture volume ($180 \times 180 \times 150\,mm^3$) that is much smaller than those needed in human movement analysis. Last but not least, the effects that the calibration procedure has on the metrological performances of a SS – to the authors' knowledge – have not been fully exploited.

The aim of this paper is to propose a methodology that can be used to evaluate the effect of different calibration procedures, as executed on data capture from different acquisition volumes and of longer or shorter duration, and to use it to quantify the relevance of the effects that those calibration procedures can have on the estimate of the joint kinematics. The proposed methodology will be applied to two different SSs.

2. Material and methods

2.1. Calibration procedure

Two stereophotogrammetric systems were set up in two centres: an 8-camera Vicon system MX-series (SS#1 installed at the Movement Analysis and Robotics Laboratory 'MARLab' of the Children Hospital 'Bambino Gesù', Palidoro – Rome, Italy) and a 10-camera Vicon system T-series (SS#2 installed at The University of Sheffield, Sheffield – United Kingdom). The data collection was performed with a sampling frequency of 200 Hz and the marker position reconstruction was performed using the software Vicon Nexus 1.8.5 (Vicon Motion Systems, Oxford – UK). It is worth noticing that having a different number of cameras in the two systems does not affect the accuracy of the calibration, since at least six cameras have been used

Download English Version:

https://daneshyari.com/en/article/5006736

Download Persian Version:

https://daneshyari.com/article/5006736

Daneshyari.com