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Short communication

Evaluation of the global optimisation method within the upper limb kinematics analysis

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Abstract

The aim of this study is to assess the performances of the global optimisation (GO) method (Bone position estimation from skin marker co-ordinates using GO with joint constraints. Journal of Biomechanics 32, 129–134) within the upper limb kinematics analysis. First the model of the upper limb is presented. Then we apply GO method in order to reduce skin movement artefacts that imply relative movement between markers and bones. The performances of the method are then evaluated with the help of simulated movements of the upper limb. Results show a significant reduction of the errors and of the variability due to skin movement.

Keywords: Upper limb kinematics; Optoelectronic system with external markers; Skin movement artefacts; Global optimisation; Simulated movement

1. Introduction

Kinematics measurement techniques with external markers are commonly used within lower limb movement analysis and are more and more applied to the upper limb (Rau et al., 2000). Markers movements relative to the underlying bones are inherent to these techniques and several methods have been proposed to reduce them. Two types of methods can be distinguished: the local or segmental methods which take into account the relative movements of the markers of a cluster attached to a body segment (Chèze et al., 1995; Soderkvist and Wedin, 1993; Spoor and Veldpaus, 1980); the methods which optimise relative segments orientation and position thanks to joint constraints (Biryukova et al., 2000; Lu and O'Connor, 1999; Schmidt et al., 1999). Biryukova et al. propose to optimise joint centres and axis determination but no skin movement artefacts correction is performed during voluntary movements. Schmidt et al. and Lu and O'Connor compensate skin movement artefacts by controlling relative orientation and position of the segments during voluntary movements but the Global Optimisation (GO) method described by Lu and O'Connor (1999) does not demand specific trials to determine the amount of skin movement artefacts to correct. GO method was initially applied to the kinematics analysis of the lower limb. We propose to assess its performances within the upper limb movement analysis thanks to simulated movements and artefacts.

2. Methods

2.1. Model

The upper part of the human body is considered as an articulated system composed of rigid bodies corresponding to the following body segments: trunk, arm, forearm, hand (Roux et al., 2000a, b).

2.1.1. Marker locations

Marker locations are similar to Schmidt et al's protocol (Schmidt et al., 1998, 1999) for the acromion, the forearm, the elbow, the wrist and the hand (Fig. 1).

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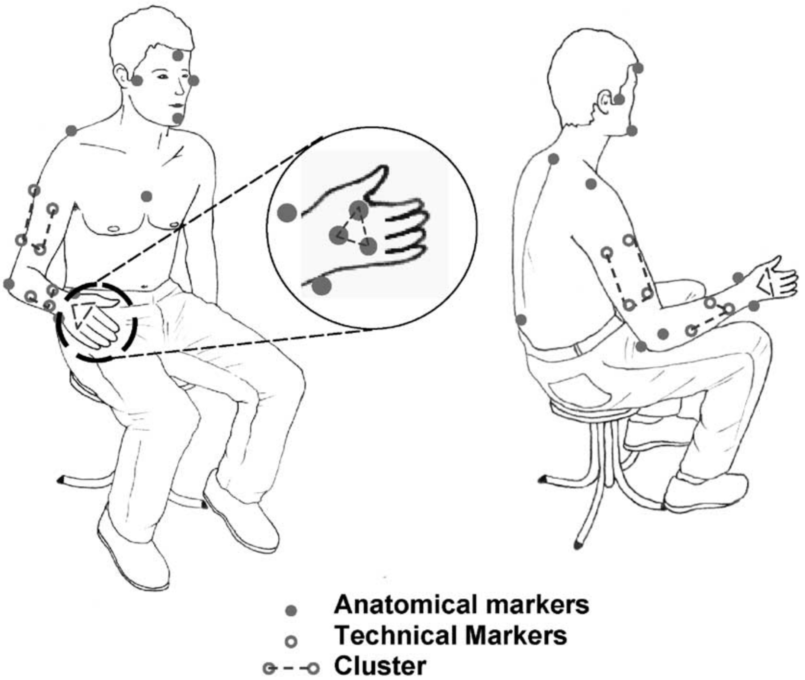

Fig. 1. Marker locations during static trial.

Table 1
Definition of the anatomical frames for each body segment

Segment	*X-axis*	*Y*-axis	*Z*-axis
Head	$Y \wedge Z$	Chin → forehead	Left → right temples
Trunk	$Y \wedge Z$	L3 → C7	(L3 → sternum) $\wedge Y$
Shoulder girdle	(L3 → C7) $\wedge Z$	$Z \wedge X$	C7 → acromion
Arm	$Y \wedge Z$	Elbow centre → shoulder centre	(Longitudinal axis of the forearm) $\wedge$ (*Y*-axis of the forearm)
Forearm	$Y \wedge Z$	Wrist centre → elbow centre	(Posterior → anterior styloïd) $\wedge$ Y
Hand	$Y \wedge Z$	Barycentre of the three markers of the hand → marker near the wrist	(Posterior → anterior hand markers) $\wedge Y$

Markers are directly attached to the subject's skin with adhesive tape. Four markers are attached to the arm. To avoid tracking difficulties due to the proximity of cluster markers, only three markers are attached to the forearm and to the hand. The trunk is characterised by markers on C7, on the 3rd lumbar vertebrae (L3) and on the sternum (Fig. 1).

Elbow and wrist markers are only used during a static trial since their positions, near the joints, are very sensitive to skin movements (Cappozzo et al., 1996).

2.1.2. Joint centres

The sphere-fitting method for the determination of the joint rotation centre has proved to be more repeatable than regression methods (Leardini et al., 1999; Stokdijk et al., 2000). It is used to compute the rotation centre of the gleno-humeral joint, denoted shoulder centre, and the centre of the wrist. Circumduction of the shoulder and of the wrist are performed for this purpose.

The elbow centre is the middle between the medial and the lateral elbow markers.

2.1.3. Definition of anatomical frames

According to the static trial, anatomical frames are defined in regards to the ISB recommendations (Wu and Cavanagh, 1995) and are described in Table 1. Euler's angles have been chosen to describe the relative movement of the body segments.

2.1.4. Joint constraints

The elbow and the wrist joints are considered as cardanic joints. The abduction–adduction of the elbow and the pronation–supination of the wrist are forced to be within the interval $[-1^\circ, 1^\circ]$. Dislocation of the multi-link system is prevented by imposing a 2 mm maximal translation between the arm and the forearm and between the forearm and the hand. The $[-1°, 1°]$ interval and the 2 mm translation define joints laxity. No constraint is imposed on the location of the shoulder centre. Indeed the scapular motion cannot be reliably determined with the help of external markers and a motion capture system (Pronk, 1991).

2.2. Global optimisation applied to the upper limb

In order to minimise relative movement between clusters and bones, we apply the GO method presented by Lu and O'Connor (1999). Marker positions at the static trial are free from skin movement artefacts and are taken as reference (Lu and O'Connor, 1999). Moreover, during movement, we consider as negligible the whole displacement of the cluster of the hand relative to the underlying bones.

The weighting matrix W described by Lu and O'Connor is defined with segmental residual errors given by the algorithm of Söderkvist (Soderkvist and Wedin, 1993). An iterative optimisation method is then used to compute the optimal parameters.

2.3. Evaluation of the method

Evaluation of the GO method was carried out with simulated movements.

The static trial of a subject gave the geometrical model. Two movements were simulated: a pure internal–external rotation of the shoulder and a pure pronation–supination of the elbow. Indeed the relative movement between clusters and underlying bones especially affects the evaluation of the axial rotation (Cappozzo et al., 1996; Roux et al., 2000a, b; Schmidt et al., 1999).

2.3.1. External–internal rotation of the shoulder

The movement took the following form: $\mathrm{Rot} = \mathrm{Rot}_{\mathrm{ArmInit}} + \pi/3 \sin(2\pi\, 0.5t)$, *with* $\mathrm{Rot}_{\mathrm{ArmInit}}$ the initial rotation angle, i.e. the angular configuration during the static trial.

The amplitude $\pi/3$ ensured a realistic motion range and the frequency of 0.5 Hz a feasible movement velocity. Movement duration was two seconds, corresponding to one period of the sinusoidal wave, with a 50 Hz sample frequency.

Concerning measurement errors, we imposed a maximal error of 5.5 mm for relative distance between markers. This value is based on the results of Richards (1999). To this end, measurement errors were considered as a random noise with a normal distribution (mean = 0 mm; standard deviation = 0.615 mm). This distribution ensured a maximum position measurement error of 1.59 mm (99% confidence) for each direction and consequently a maximum error of 5.5 mm for the distance between two markers.

The error previously described was assumed to be the worst we could find in our application and was applied to each marker position.

Skin movement artefacts were simulated by a continuous noise model of the form $A \sin(\omega t + \varphi)$ (Chèze et al., 1995, 1998; Lu and O'Connor, 1999). A is the amplitude of the noise, ω its frequency and φ its phase angle. This noise was only applied to the markers of the moving segment, i.e. the arm. A was assumed to be proportional to movement amplitude. This assumption was verified by Schmidt et al. during a pure axial rotation of the forearm (Schmidt et al., 1998, 1999). Given the fact that skin movements are greater near the proximal end of a segment and that displacements of the markers with respect to the underlying bone can reach 40 mm on the lower limb (Cappozzo et al., 1996), A was scaled to be between 0 and 20 mm for the two proximal markers of the arm, and between 0 and 10 mm for the two others. So for the marker m, the amplitude of the noise was of the form: $A_{\mathrm{m}} = B_{\mathrm{m}} |\sin(2\pi\, 0.5t)|$, with $B_{\mathrm{m}} \in \{10, 20\}$.

ω_{m} and φ_{m} are random scaled numbers. ω_{m} was scaled to be between π and 3π, i.e. between 1 and 3 times the frequency of the movement. The lower limit ensured that the minimum signal to noise ratio was observed during the trial. φ_{m} was scaled to be between 0 and 2π (Chèze et al., 1995, 1998; Lu and O'Connor, 1999).

2.3.2. Pronation–supination of the elbow

The same method was applied to simulate a pure pro-supination of the forearm. The simulated movement was of the form $\mathrm{Rot}_{\mathrm{Forearm}} = \mathrm{Rot}_{\mathrm{ForearmInit}} + \pi/3 \sin(2\pi\, 0.5t)$, with $\mathrm{Rot}_{\mathrm{ForearmInit}}$ the initial pro-supination angle that was imposed to be neutral.

Skin movement artefacts were added on the three markers of the forearm. $B_{\mathrm{m}} = 20$ mm for the proximal marker and $B_{\mathrm{m}} = 10$ mm for the two others. In practice, a pro-supination movement is combined with a contraction of the biceps muscle, implying artefacts on the position of the arm markers. So simulated skin movement artefacts were added to these markers too, with a maximum amplitude $B_{\mathrm{m}} = 5$ mm.

3. Results

Thirty simulated trials were performed. They differ in the noise parameters ω_{m} and φ_{m}, that are randomly settled in a given interval previously defined. For each variable and each trial, we computed the root mean square (RMS) of the errors with and without using GO. The average and the standard deviation of the RMS over the 30 trials were computed. Figs. 2 and 3 correspond to the angle errors and Figs. 4 and 5 to the relative translation between adjacent body segments, denoted dislocation.

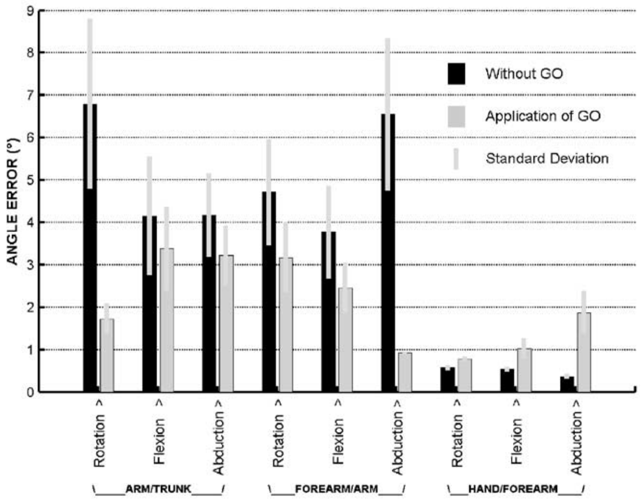

Fig. 2. Mean/standard deviation of RMS error of angles for external–internal rotation.

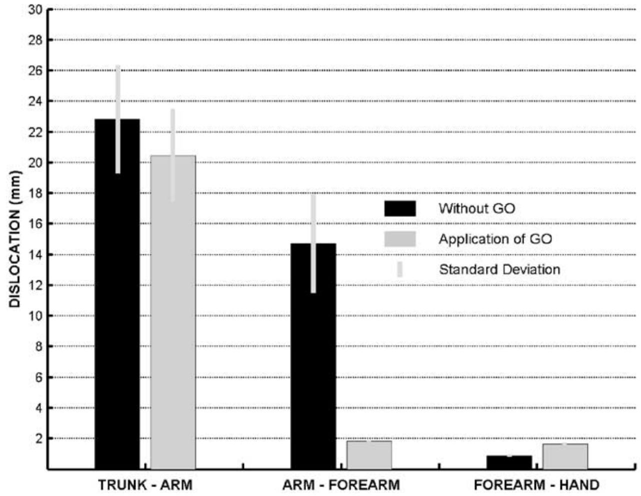

Fig. 3. Mean/standard deviation of RMS of translation between segments for external–internal rotation.

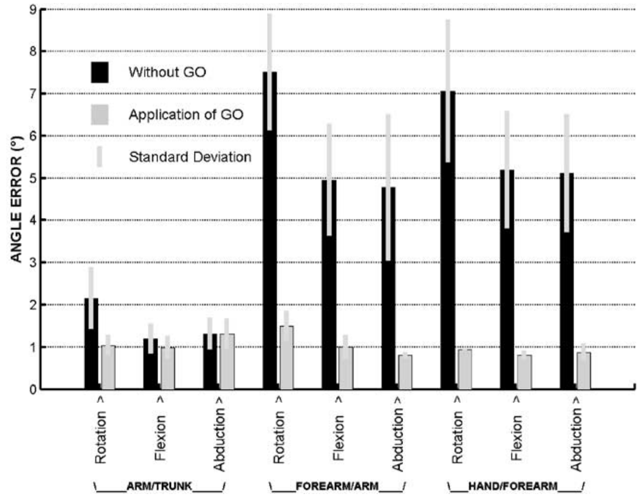

Fig. 4. Mean/standard deviation of RMS error of angles for pro-supination of the elbow.

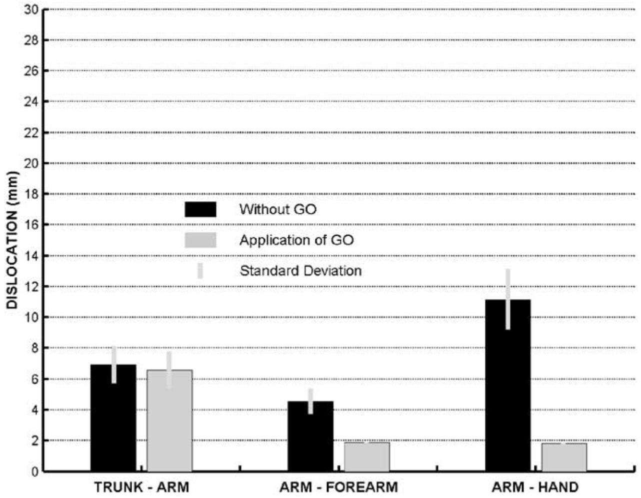

Fig. 5. Mean/standard deviation of RMS of translation between segments for pro-supination of the elbow.

4. Discussion

Only the relative movement between the hand and the forearm during the internal–external rotation of the shoulder present greater errors with the application of the GO method than without it. Moreover, these errors still remain very low in regards to the measurement ones (Richards, 1999).

Errors are significantly compensated for all the other degrees of freedom.

The variability of the results are also significantly reduced with the GO method, except for the flexion-extension and the abduction–adduction of the wrist during internal–external rotation of the shoulder.

In spite of the good results thanks to the application of the GO method, some aspects of the kinematics model are arguable. From an anatomical point of view, the flexion axis of the elbow is not normal to the plane formed by the longitudinal axis of the arm and of the forearm during the static trial. However, according to Wang et al. (1998) this definition can be used to approximate the elbow flexion extension axis in a large motion range of the elbow joint, especially when the forearm is pronated and neutral. By using the joint coordinate system of the elbow, Schmidt et al. (1998, 1999) make the same assumption for the whole movement. The kinematics constraint that imposes the abduction–adduction of the elbow to be within the interval $[-1^\circ, 1^\circ]$ is not verified from an anatomical point of view because of the bony structure of the forearm and of the articular surfaces of the elbow joint. However, simulations show that an abnormal abduction–adduction of the elbow is observed because of the skin movement artefacts, when GO is not applied (Figs. 2 and 4). Consequently, the abduction–adduction of the elbow observed during a voluntary movement and without applying the GO method is due to the skin movement artefacts and does not reflect the real bone movements.

5. Conclusion

This study shows that GO method significantly reduces the errors and the variability introduced by skin movements within the kinematics analysis of the upper limb with external markers. Another advantage of the method is that it does not demand specific trials realisation to previously estimate skin movements artefacts.

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