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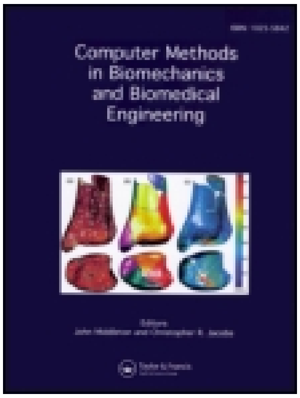

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How to reconstruct athlete movement during outdoor rowing? A pilot study

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How to reconstruct athlete movement during outdoor rowing? A pilot study

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Keywords: sport; biomechanical model; lower limbs; kalman filter; inverse kinematics

1. Introduction

The gold standard in human biomechanics for measuring the three-dimensional (3D) whole-body movement of an athlete is to use an optoelectronic motion capture system and skin markers (Leardini et al. 2005). Skin markers placed on the athlete are directly used to reconstruct the whole-body movement, i.e. to calculate the joint angles, using either a direct, local or global numerical method (Lu and O'Connor 1999).

Although this kind of motion capture system is appropriate for laboratory experiments, its use can be limited for outdoor measurements. This is the case for on-water sport activities, e.g. rowing. The acquisition volume needs to be large to record several cycles. The water will produce important light changes and make the placement of the cameras problematic. Moreover, using optoelectronic motion capture systems represents a non-negligible human and financial cost and can be time consuming. These last features will be problematic when working with athletes and coaches because they want easy-to-use equipment and immediate feedback that is usable during training sessions.

An alternative to optoelectronic motion capture systems can be the use of inertial measurement units (IMUs). Generally, an IMU contains three components (a gyroscope, an accelerometer and a magnetometer) to give the orientation, i.e. the three rotation angles, of the body segment on which it lies (Cutti et al. 2008). However, using about 20 IMUs, i.e. one on each segment, will not meet the above exigencies asked by athletes and coaches. Thus, the final idea will be to place a few IMUs on key body segments and use an appropriate numerical method to obtain the whole-body movement during on-water rowing.

To reach this main objective, a step-by-step approach was chosen. The goal of this first study was to develop numerical methods to reconstruct the 3D movement of the lower limbs. This choice was supported by the idea that the lower limbs would be easier to reconstruct than the upper limbs because their movement is more planar and involved fewer degrees of freedom (dof).

The aim of this study was to assess the kinematic fidelity of reconstructed movements.

2. Methods

The experiments were conducted indoors using a 14-camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 100 Hz. After giving informed consent, one athlete (height: 1.90 m; mass: 83 kg and age: 19 years old) with international level in rowing was enrolled in the study. Between five and seven markers were placed on each body segment. The data, i.e. unfiltered 3D marker trajectories, were collected in three steps. Firstly, a static trial in the anatomical position was collected. Secondly, several trials of joint movements were recorded to estimate the hip, knee and ankle joint centres using a functional approach (Ehrig et al. 2006). Thirdly, the athlete performed a 1-min rowing trial at a constant pace of 20 strokes per minute on a rowing ergometer.

The data recorded from the trials of the two first steps were used to define two biomechanical models. The first model comprised 7 segments and 24 dof to be used to reconstruct the movement using all known marker positions. One local frame was embedded within each segment with the proximal joint centre as origin, except the pelvis that is the root segment of the biomechanical model. The 3D coordinates of each marker were expressed in the segment frame to which they belonged. The second biomechanical model differed from the first model in having reduced dof; the medio-lateral and vertical dof being removed to avoid unrealistic poses of the biomechanical model when reconstructed.

Data from the rowing trial were used to reconstruct the two movements. An extended Kalman filter algorithm associated with the first biomechanical model

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*Corresponding author. Email: vincent.fohanno@univ-nantes.fr reconstructed the LAB movement. The joint kinematics were estimated at each instant using the 3D marker coordinates as input data (Halvorsen et al. 2005). This technique helps to limit joint kinematic discontinuities that could lead to unrealistic poses of the biomechanical model as rowing is a cyclic and smooth movement.

An inverse kinematic algorithm associated with the second biomechanical model was used to reconstruct the OUT movement (Liégeois 1977). This approach is very popular in the robotic field when input data are partially missing. In this study, the following time-varying parameters were used as input data: the 3D angles of the pelvis and shank segments and the longitudinal displacement of the seat–pelvis. The displacement between the pelvis and the seat was assumed to be negligible. The 1st and 5th metatarsals of the biomechanical model were kept in a fixed position during the rowing trial. As this study is a pilot study, no IMUs were used. The IMU angles were directly simulated from the 3D marker coordinates. Cutti et al. (2008) have shown the consistency between the angles obtained from these two methods.

The two movements were compared in terms of segment position and orientation to assess the fidelity of the OUT movement.

3. Results and discussion

Results of the comparison between the two reconstructed movements are given in Table 1. The average errors in position ranged from 8.1 mm for the pelvis to 45.0 mm for the shanks. The average errors in orientation ranged on average from 0.4° for the pelvis to 6.0° for the feet.

The pelvis segment was the first element of the biomechanical model, i.e. the root segment. Furthermore, four input data were related to the pelvis segment, namely the seat–pelvis displacement and the three orientation angles of the pelvis. These characteristics explained the good reconstruction of the pelvis segment of the OUT movement, especially in terms of orientation.

On one hand, the metatarsals were strictly fixed to the footrest for the OUT model. This assumption is an experimental need because the feet will be hidden by the boat shell during on-water rowing. On the other hand, slight movements were permitted for the LAB movement that was reconstructed using markers. The metatarsal markers could move during the rowing trial even though the feet were strapped on the footrest. This explains partly the position and orientation differences of the feet between the two movements (Table 1). The results could be improved (i) by permitting errors on the metatarsal position and/or (ii) by accurately determining a fixed and virtual axis of rotation between the feet and the footrest.

Table 1. Position and orientation differences between OUT and LAB movements (mean ± standard deviation over time).

	Pelvis	Thighs	Shanks	Feet
Position (mm)	8.1 ± 4.8	31.3 ± 9.6	45.0 ± 18.0	19.5 ± 12.3
Orientation (°)	0.4 ± 0.2	3.5 ± 1.0	5.2 ± 1.5	6.0 ± 4.0

No input data were provided to the OUT model for the position of the thighs and shanks. Moreover, the hip and knee were modelled as three-dof joints. Combined together, these features lead to poses of the biomechanical model being found that were too dissimilar to the reference, resulting in larger position differences for these two body segments (Table 1). These results could be improved (i) by using the 3D angles of the thighs instead of those of the shanks as the pelvis position and orientation were faithfully reconstructed and/or (ii) by decreasing the number of dof for the corresponding joints as the movement of the lower limbs is relatively planar when rowing.

4. Conclusions

This study showed that the reconstruction of the lower limbs during a rowing trial was feasible using partial input data, i.e. when some position and/or orientation segments were missing. Large reconstruction errors resulted for the shanks because there were multiple positions that could satisfy a given shank orientation and foot and leg position. Using the thigh orientation and decreasing the dof number could improve the fidelity of the OUT movement.

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