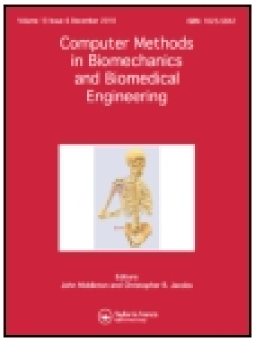

Computer Methods in Biomechanics and Biomedical Engineering

ISSN: 1025-5842 (Print) 1476-8259 (Online) Journal homepage: https://www.tandfonline.com/loi/gcmb20

A new method for determining the location of the instantaneous axis of rotation during human movements

B. Bru & V. Pasqui

Computer Methods in Biomechanics and Biomedical Engineering
Vol. 12, No. S1, August 2009, 65–67

A new method for determining the location of the instantaneous axis of rotation during human movements

B. Bru[a,b]* and V. Pasqui[a,b]

[a]*ISIR, Université Pierre et Marie Curie, Paris, France;* [b]*UMR 7222, Pyramide tour 55, 4 place Jussieu, Paris, France*

Keywords: instantaneous axis of rotation; angular velocity; rotation matrix

1. Introduction

An accurate location of the instantaneous axis of rotation (IAR) between body segments is of primary importance for biomechanical applications, in particular for accurate estimation of muscle forces/torques. Among the numerous studies that addressed this issue, the International Society of Biomechanics recommended the instantaneous helical axis method, which considers that the transition from one position to another for the same solid can be obtained by a rotation around an axis followed by a translation along this axis. Nevertheless, this has the serious drawback of being very sensitive to low angular velocity (Ehrig et al. 2006).

The present study proposes a new method for the determination of the IAR during human movements. Our specific aim is to provide an easy-to-implement method, suitable for all types of movement and whatever the angular velocity of motion.

2. Methods

The mathematical formulation of the method will be tested firstly by way of simulations and then within the context of human movements.

2.1 Mathematical formulation of the method

Suppose an absolutely rigid body S. There is an axis Δ such as $\Delta = (P, \vec{\Omega})$, where the rigid body S turns and translates relatively to a fixed frame R_0 among this axis as illustrated in Figure 1.

Let P be a point fixed on Δ, then

$$\vec{V}_{(P\in S/R_0)} = \lambda\cdot\vec{\Omega}_{S/R_0} \tag{1}$$

with

$$\vec{V}_{(A\in S/R_0)} = \vec{V}_{(P\in S/R_0)} + \vec{\Omega}_{S/R_0} \wedge P\vec{A}. \tag{2}$$

Our method consists of the determination of the location of Δ, which represents the IAR.

Multiply (1) by $\vec{\Omega}_{S/R_0}$; then (1) becomes

$$\vec{\Omega}_{S/R_0} \wedge \vec{V}_{(A\in S/R_0)} = \vec{\Omega}_{S/R_0} \wedge (\vec{V}_{(P\in S/R_0)} \wedge \overrightarrow{PA}) \tag{3}$$

with $\vec{\Omega}_{S/R_0} \wedge \vec{V}_{(P\in S/R_0)} = \vec{0}$ because $\vec{\Omega}_{S/R_0}$ and $\vec{V}_{P\in S/R_0}$ are collinear, as it is written in (1).

In (3), $\overrightarrow{PA} = \overrightarrow{PA} + \overrightarrow{A'A}$, where A' is the orthogonal projection of A, we obtain

$$\overrightarrow{AA'} = \frac{\vec{V}_{(A\in S/R_0)} \wedge \vec{\Omega}_{S/R_0}}{(\vec{\Omega}_{S/R_0})^2}. \tag{4}$$

Apply this to the relative movement between two rigid bodies $S1$ and $S2$. $A_i \in S1$ and $B_j \in S2$ are certain fixed points on the system and A_i^* and B_j^* are, respectively, the orthogonal projections of A_i and B_j points on the IAR between the two bodies as illustrated in Figure 2. For this example, the Equation (3) becomes

$$\begin{cases} \overrightarrow{A_iA_i^*} = \frac{\vec{V}_{(A_i\in S1/S2)}\wedge\vec{\Omega}_{S1/S2}}{(\vec{\Omega}_{S1/S2})^2} \\ \overrightarrow{B_jB_j^*} = \frac{\vec{V}_{(B_jS2/S1)}\wedge\vec{\Omega}_{S2/S1}}{(\vec{\Omega}_{S2/S1})^2} \end{cases} \tag{5}$$

$\vec{V}_{(A_i\in S1/S2)}$ could be known using composition of movement

$$\vec{V}_{(A_i\in S1/S2)} = \vec{V}_{(A_i\in S1/R_0)} - \vec{V}_{(A_i\in S2/R_0)}$$

*Corresponding author. Email: bru@isir.fr

ISSN 1025-5842 print/ISSN 1476-8259 online

DOI: 10.1080/10255840903077139
http://www.informaworld.com

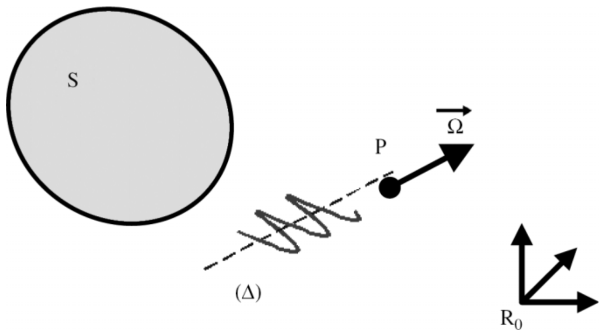

Figure 1. Relative movement between a solid S and a fixed frame R_0 around an axis.

and property of rigid body

$$\vec{V}_{(A_i \in S2/R_0)} = \vec{V}_{(B_j \in S2/R_0)} + \vec{\Omega}_{S2/R_0} \wedge \overrightarrow{B_jA_i}.$$

Applying the same computation for $\vec{V}_{(B_j \in S2/S1)}$, (5) becomes

$$\begin{cases} \overrightarrow{A_iA_i^*} = \dfrac{(\vec{V}_{(A_i \in S1/R_0)} - \vec{V}_{(B_j \in S1/R_0)} - \vec{\Omega}_{S2/R_0} \wedge \overrightarrow{B_jA_i}) \wedge \vec{\Omega}_{S1/S2}}{(\vec{\Omega}_{S1/S2})^2} \\ \overrightarrow{B_jB_j^*} = \dfrac{(\vec{V}_{(B_j \in S2/R_0)} - \vec{V}_{(A_i \in S2/R_0)} - \vec{\Omega}_{S1/R_0} \wedge \overrightarrow{A_iB_j}) \wedge \vec{\Omega}_{S2/S1}}{(\vec{\Omega}_{S2/S1})^2} \end{cases}$$

We easily obtain the coordinates of each A_i^* and B_j^* points. All A_i^* and B_j^* points should be aligned between each other and allow the location of the IAR. In order to check the align of this points, the coordinates of the A_i^* and B_j^* points were fitted by linear regression.

2.2 *Simulations*

The ability of the proposed method to provide accurate location of the IAR was first evaluated through simulations by considering the case of the motion of two homogeneous rigid bodies linked by frictionless hinges. The relative

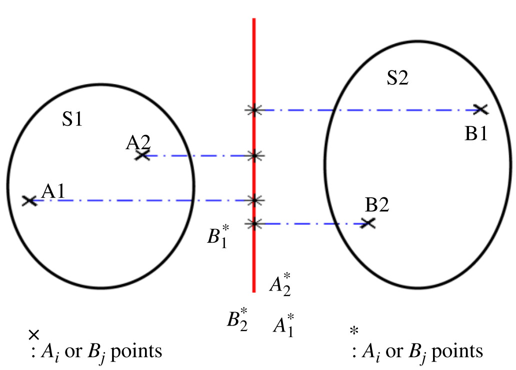

Figure 2. Relative movement between two rigid bodies $S1$ and $S2$.

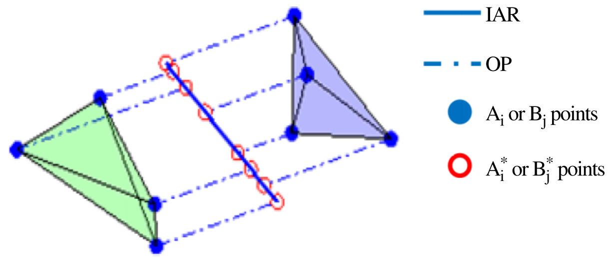

Figure 3. Determination of the IAR.

motion of these two bodies with a random trajectory and at different angular velocity were simulated on Matlab.

2.3 *Experimental analysis*

A three cx1 units Codamotion system (Charnwood Dynamics Ltd, Leicestershire, Rothley, UK) was used to collect kinematic data at 400 Hz during wrist flexion–extension movements performed at different speeds (slow, normal fast). Eight active markers (four on the hand and four on the forearm) were placed on the body.

3. Results and discussion

3.1 *Simulation results*

Figure 3 represents the location of the IAR fitted by linear regression at one instant of the simulation. The mean determination coefficients ($R2$) obtained between the coordinates x and y, then x and z and then y and z of the and points (Table 1) indicated very high accuracy of the proposed method for the computation of the location of the IAR. As expected from the new formulation of our method, results showed that this method is not sensitive to low angular velocity.

3.2 *Experimental results*

The mean determination coefficients ($R2$) obtained between the coordinates x and y, then x and z and then y and z of the A_i^* and B_j^* points (Table 1) show that each point is not totally aligned between them. Even if the alignment of A_i^* and B_j^* points is not perfect, the method provides a good estimation of the location of the IAR without sensitivity to low angular velocity. Current work will lead to an improvement of the experimental results.

Table 1. Determination coefficient.

	(x,y)	(x,z)	(y,z)
$R2$ simulation	1 ± 0	1 ± 0	1 ± 0
$R2$ experimental	0.89 ± 0.4	0.88 ± 0.3	0.91 ± 0.6

4. Conclusions

The present study proposes a new method to determine the location of the IAR during human movements. Simulations results demonstrated its easiness to implement with low computational requirements and its high accuracy with low sensitivity to angular velocity. Despite limitations that are presently addressed, the experimental results are encouraging and will find direct applications for biomechanical modelling and for identification of inertia parameters.

Reference

Ehrig RM, Taylor WR, Duda GN, Heller MO. 2006. A survey of formal methods for determining the centre of rotation of ball joints. J Biomech. 39:2798–2809.