A THEORETICAL MODEL FOR THE SHOULDER GIRDLE APPLICATIONS IN SPORT

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INTRODUCTION

The shoulder is one of the most intriguing structures of the human body. Its most salient feature is its large range of motion. The major part of this motion originates in the glenohumeral joint, which joins the scapula and the humerus.

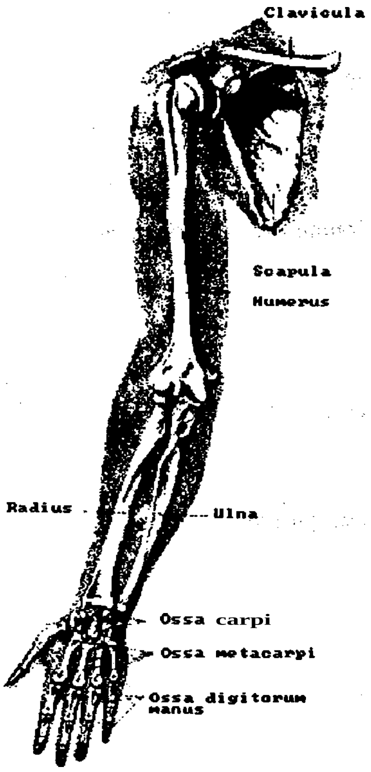

Fig. 1 Human Shoulder Girdle

About one third of the mobility of the shoulder as a whole, however, is due to the mobility of the shoulder girdle, the mechanism of clavicle and scapula (Fig. 1). The clavicle is connected to the front of the thorax in the sternoclavicular joint and through the costoclavicular ligament. and to the scapula at the acromioclavicular joint and through the trapezoid and conoid ligaments. In normal situations the medial rim of the scapula slides over the back of the thorax; this is called the scapulothoracic gliding plane and can be considered as a pseudojoint.

The mechanism is actuated by muscles, which can be anatomically subdivided into three classes: thoracoscapular muscles, thoracohumeral muscles and scapulohumeral muscles. In contrast to the lower extremity, not many biomechanical models of the shoulder have been formulated both for kinematic and dynamic studies. This is mainly due to the fact that shoulder movements are essentially three-dimensional, while the lower limb can in fair approximation be regarded as a planar mechanism (however see Thunisse, 1993).

METHODS & DISCUSSIONS

The motion equations of the system are comparable to the Lagrangian approach; there are as many dynamical equation as generalized coordinates (either position coordinates or deformation modes). In the kinematical step the position coordinates of the next position are computed from the actual position coordinates and the changes in the generalized coordinates, using a second order Taylor expansion:

$$\bar{x}_{i+1}=\bar{x}_i+\frac{\partial\bar{x}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}\Delta(\bar{x}^{(m)},\bar{e}^{(m)})+\frac{1}{2}\frac{\partial^2\bar{x}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})^2}\Delta(\bar{x}^{(m)},A\bar{e}^{(m)})^2 \quad (A01)$$

where $\partial\ddot{x}/\partial(\ddot{x}^{(m)},\ddot{e}^{(m)})$ and $\partial^2\ddot{x}/\partial(\ddot{x}^{(m)},\ddot{e}^{(m)})^2$ **are** the first and second derivatives of the position coordinates to the generalized coordinates (first and second order geometric transfer function) respectively. These matrices are not **instantaneously** available, but can be computed according to the following method. The deformation vectore e in terms of the position coordinates x is known in analytical form from the deformation descriptions of the elements of which the total mechanism consists:

$$\bar{e} = D(\bar{x}) \quad (A02)$$

The derivative to the generalized **coordinates** can be formulated as follows:

$$\frac{\partial\bar{e}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}=\frac{\partial\bar{e}}{\partial\bar{x}}\bullet\frac{\partial\bar{x}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})} \quad (A03)$$

The matrix $\partial\bar{e}/\partial\bar{x}$ is available in analytical **form.** By partitioning the vectors e and x :

$\bar{x}^{(0)}$ – vector of fixed support coordinates;
$\bar{x}^{(c)}$ = vector of dependent nodal coordinates;
$\bar{x}^{(m)}$ = vector of global generalized coordinates;
$\bar{e}^{(0)}$ = vector of fixed prescribed deformation mode coordinates;
$\bar{e}^{(c)}$ – vector of relative generalized coordinates;
$\bar{e}^{(m)}$ – vector of dependent deformation mode coordinates.

the matrices $\partial e/(\ddot{x}^{(m)},\ddot{e}^{(m)})$ **and** $\partial\ddot{x}/\partial(\ddot{x}^{(m)},\ddot{e}^{(m)})$ **can** be simplified:

$$\frac{\partial e}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}=\begin{bmatrix} 0 & 0 \\ 0 & 1 \\ \multicolumn{2}{c}{\frac{\partial\bar{e}^{(c)}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}} \end{bmatrix} \quad (A04)$$

$$\frac{\partial\bar{x}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}=\begin{bmatrix} 0 & 0 \\ \multicolumn{2}{c}{\frac{\partial\bar{x}^{(c)}}{\partial(\bar{x}^{(m)},\bar{e}^{(m)})}} \\ 1 & 0 \end{bmatrix} \quad (A05)$$

In this expresions the only unknowns are the submatrices $\partial \dddot{e}^{(c)} / (\dddot{x}^{(m)},\dddot{e}^{(m)})$ and $\partial \ddot{x}^{(c)} / (\ddot{x}^{(m)},\ddot{e}^{(m)})$. Because the number of dependent nodal coordinates is equal to the sum of numbers of fixed prescribed deformation mode coordinates and the number of relative generalized coordinates (the number of degrees of freedom), the $\partial e^{(0)} / \partial x^{(c)}, \partial e^{(m)} / \partial x^{(c)}\}^T$ is square, and if the mechanism' is not in a singular position, invertible. Therefore the matrices $\partial e^{(c)} / (\dddot{x}^{(m)},\dddot{e}^{(m)})$ and subsequently $\partial \ddot{x}^{(c)} / (\ddot{x}^{(m)},\ddot{e}^{(m)})$ can **be** calculated:

$$\frac{\partial \bar{x}^{(\,)}}{\partial(\bar{x}^{(\,)},\bar{e}^{(\,)})} = \begin{bmatrix} \dfrac{\partial \bar{e}^{(\,)}}{\partial \bar{x}^{(\,)}} \\ \\ \dfrac{\partial \bar{e}^{(\,)}}{\partial \bar{x}^{(\,)}} \end{bmatrix}^{1} \bullet \begin{bmatrix} \dfrac{\partial \bar{e}^{(\,)}}{\partial \bar{x}^{(\,)}} & 0 \\ & \\ \dfrac{\partial \bar{e}^{(\,)}}{\partial \bar{x}^{(\,)}} & \end{bmatrix} \quad (A0)$$

$$\frac{\bar{e}^{(\,)}}{(\bar{x},\bar{e})} = \frac{\bar{e}^{(\,)}}{\bar{x}^{(\,)}} \frac{\bar{x}^{(\,)}}{(\bar{x}^{(\,)},\bar{e}^{(\,)})} + \frac{\bar{e}^{(\,)}}{\bar{x}^{(\,)}} \frac{\bar{x}^{(\,)}}{(\bar{x}^{(\,)},\bar{e}^{(\,)})} \quad (A0)$$

In a similar manner the second derivative of the position coordinates to the generalized coordinates can be derived, resulting in:

$$\frac{\bar{x}^{(c)}}{(\bar{x}^{(m)},\bar{e}^{(m)})} = \begin{bmatrix} \dfrac{\bar{e}^{(o)}}{\bar{x}^{(c)}} \\ \\ \dfrac{\bar{e}^{(m)}}{\bar{x}^{(c)}} \end{bmatrix}^{-1} \begin{bmatrix} \dfrac{\bar{e}^{(o)}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \dfrac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \dfrac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \\ \\ \dfrac{\bar{e}^{(m)}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \dfrac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \dfrac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \end{bmatrix}$$

$$\frac{\bar{e}^{(c)}}{(\bar{x}^{m},\bar{e}^{m})} = \frac{\bar{e}^{(c)}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \frac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \frac{\bar{x}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \frac{\bar{e}^{(c)}}{\bar{x}^{(c)}} \frac{\bar{x}^{(c)}}{(\bar{x}^{(m)},\bar{e}^{(m)})} \quad (A\,9)$$

After an approximation of the new position of the mechanism has been computed, a **Newton-Raphson** iteration procedure is performed to satisfy the continuity equation in the new position.

Despite its advantages, the **Lagrange** method, many times could lead to not suitable mathematical models from numeric point of view. For this reason, on the presented model, the **Denavit-Hartenberg** matrix formalism was implemented, where the transformation matrix from a reference system to the next reference system has the expresion:

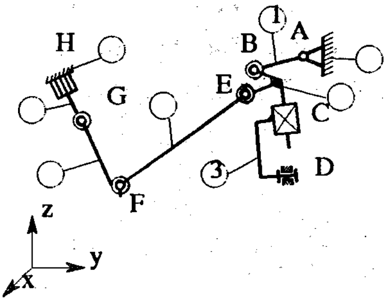

Fig.2 **Mechanical** model for the upper limb

$$A_n = \begin{bmatrix} \cos q_i & -\sin q_i \cos a_i & \sin q_i \sin a_i & a \cos q_i \\ \sin q_i & \cos q_i \cos a_i & -\cos q_i \sin a_i & a_i \sin q_i \\ & \sin a_i & \cos a_i & d_i \\ & & & 1 \end{bmatrix} \quad (\;)$$

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[1] Only the most important were completely mentioned. and the others were previously specified in the text