Inverse dynamics for 3D upper limb movements.

A critical evaluation from electromagnetic 6D data obtained in quadriplegic patients.

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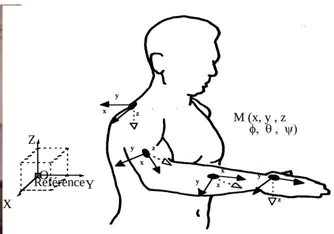
Objectives

C6 quadriplegic patients lose the ability to use their triceps, but the arm flexors remain intact. However, they are still able to extend the elbow. We assumed that the triceps is more likely to be used to ensure elbow stiffness than to provide an active elbow extensor torque.

To test this hypothesis we proposed to calculate active and interaction torques at the elbow through inverse dynamic. Here, we address the first step of this work, which is to develop a 3D inverse dynamics model of the upper limb and to test its validity on previous recordings.

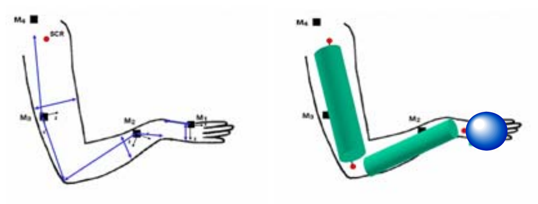
Pointing Task and Electromagnetic recording



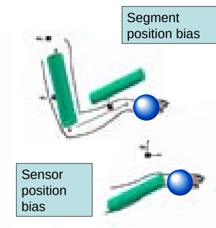
Task : the task was to free 3D pointing movements (torso fixed) in 6 directions of a plane. [1,2]

Recording : Four electromagnetics sensors (Fastrak Polhemus) attached to the acromion, the posterior face of the arm the posterior face of the forearm and the dorsum of the hand. 6D data : 3 position coordinates, 3 Euler angles. Sampling frequency 30 Hz. [3]

Inverse dynamic model and Sensitivity Analysis



Inverse dynamic model



Sensitivity analysis

Inverse dynamic model : rigid bodies based model [4] Shoulder centre of rotation was kinematically calculated [3], Segment extremities reconstructed from known anatomical relationship with sensor. Fixed elbow centre of rotation born by upper arm sensor. Moments were calculated using Newton-Euler recursive method.

Sensitivity analysis : Bias in inertial parameters were introduced to simulate reconstruction errors (Both centre of mass position errors and segment orientation errors). Bias in sensors' coordinates were introduced to simulate skin movement artefacts (Both position errors and Euler angles errors : minus and plus 1, 5, 10 cm and minus and plus 5, 15, 45 degrees respectively). We carried sensitivity analysis for two subjects in two pointing directions.

Results and discussion : moments can reliably be calculated.

Total elbow moment's sensitivity to sensor coordinates biases :

The time profile of total moment was qualitatively preserved whatever the perturbed sensor and whether it was attitude or positions errors, and even for high degrees of errors (10 cm or 45°). Total moment profile was only qualitatively perturbed for errors of plus or minus 45° in arm sensor attitude (Fig. 1). Biases in sensors'coordinates were the most crucial, and most of all on the upper-arm sensor which "carry" elbow centre of rotation (Fig. 2A)

Total moment's sensitivity to segmental biases :

The time profile of total moment was qualitatively preserved whatever the perturbed segment and whether it was orientation or position errors, even for high degrees of errors (10 cm or 45°). Results were as expected by Newton Euler method (No upper-arm influence, No Hand orientation influence -spherical) (Fig. 2B)

This results suggests that electromagnetic sensors and inverse dynamics models could be used to analyse unconstrained 3D redundant movements of the upper limb.

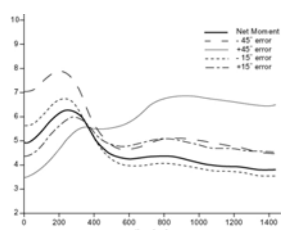


Figure 1. Time profile of elbow total moment (N.m). Variations with bias in attitude of upper arm sensor. *(Control subject, direction 0°)*

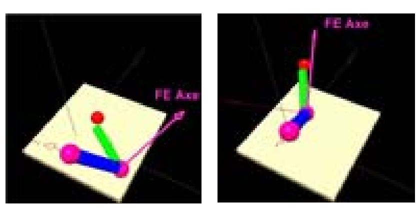


Figure 3. Calculated flexion axe during movement

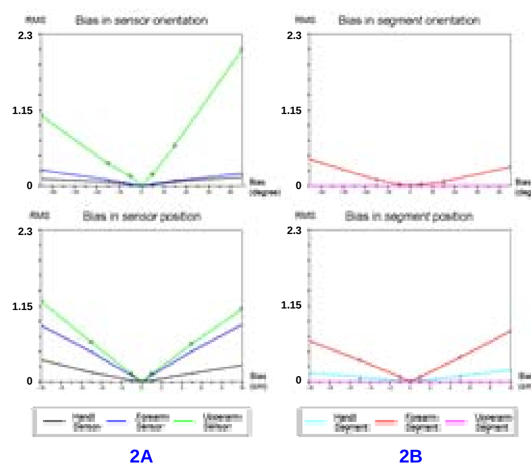


Figure 2. Rms error (N.m) of elbow total moment as a function of biases. *(Control subject, direction 0°)*

However, there was a artefact external rotation of forearm around the upper arm longitudinal axis. The calculated flexion-extension axis (borne by the upper-arm) does not stay perpendicular to the plane of the real flexion-extension movement (Fig 3). This was verified in the recordings obtained in 10 subjects. As a result, we could not decompose total moment on the three elbow joint axis.

This could result either from internal rotation of the upper arm sensor relative to the bone due to skin sliding or from an error in the reconstruction of the forearm axis, since forearm axis and prono-supination axis are not in the same direction.

To Improve the protocol…

- *More relevant centre of rotation :* **Increased sampling frequency.**
- *Improving Model Reconstruction :* **Mapping of Bony landmarks.**
- *To dissociate Forearm Prono-suppination and Elbow flexion extension* : **use of an additional sensor on forearm.**
- *Skin Artefacts :* **Use of casts, Assessment of skin artefact.**

Conclusion

Inverse dynamic Moments calculation should be strong enough to allow solid interpretation.

There is a need to develop assessment protocols and tools for electromagnetic motion analysis devices.

The hypothesis that Triceps Brachialis provides elbow stiffness but no active torque is still to be explored, but remains likely as in [5] for 2D movements.

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