FUNCTIONALLY INTERPRETABLE LOCAL COORDINATE SYSTEMS USING INERTIAL MAGNETIC SENSORS

W.H.K. de Vries[1,2], H.E.J. Veeger[1], C.T.M. Baten[2], F.C.T. van der Helm[1]

[1] Biomechanical Engineering, Faculty of Mechanical, Maritime & Materials Engineering, Delft University of Technology, Netherlands.
[2]Roessingh Research & Development, Enschede, Netherlands. E-mail: w.devries@rrd.nl

INTRODUCTION

To generate input for a biomechanical model of the upper extremity from inertial magnetic sensors, local frames of reference for each segment need to be determined. The sensors deliver orientation estimations based on acceleration, angular velocity and magnetometer data, but no 3D position information. The option of building the local reference frames based upon functional axes of rotation is addressed. When performing a series of well-defined, isolated, uni-axial rotations of a segment, the angular velocity vectors can be used as an estimator for the orientation of the axis around which the segment rotates. With two of these vectors, e.g. thoracal flexion and torsion, a local frame of reference can be defined according eq.1.

METHODS

Five subjects were equipped with sensors (MT-X, Xsens, Netherlands) on thorax, humerus, forearm, and hand. An optoelectronic system (Vicon, 6 MX13 cameras) served as reference system. Reflective markers were attached to sensors and on Bony Landmarks (BLM) conform the ISB proposal [1]. Prior to subject measurements, both systems were aligned, to enable all data to be expressed in the same global reference system. Subjects were asked to perform the following movements, five repetitions each, after 5 seconds of stance in the anatomical reference position:

$$z = \frac{\omega_{axial}}{\|\omega_{axial}\|},\ y_{temp} = \frac{\omega_{F-E}}{\|\omega_{F-E}\|}$$

$$x = cross(y_{temp}, z)$$

$$y = cross(z, x),\ y = \frac{y}{\|y\|}$$

$$R_{thor} = [x \quad y \quad z]$$

Equation 1; definition of local frame of reference with functional axes.

- Trunk: flexion- retroflexion, lateral flexion, and torsion;
- Humerus: ab-adduction, flexion-anteflexion, endo-exo rotation;
- Forearm: elbow flexion-extension, pro-supination;
- Hand: ulnar-radial deviation, palmar-dorsal flexion.

This protocol was repeated 3 times by two experimentors each, resulting in six trials per movement.
Per segment, the functional axes with the lowest variation were chosen to construct local coordinate systems, and compared to the reference, segment orientation based on BLM.

RESULTS AND DISCUSSION

The method was well repeatable. The mean variation of the determination of functional axes over subjects was the lowest for ‘trunk flexion’ and ‘gravity vector’ for the thorax, 2.0º and 2.9º resp. Humeral ‘endo-exo rotation’ and ‘elbow flexion’ showed a mean variation over subjects of 1.6º and 2.8º; Forearm pro-supination and elbow flexion showed 1.3º and 3.8º. For the hand the variation was higher from 2.9º for dorsal flexion to 5.5º for radial ulnar deviation.

Subsequently, for each segment, local frames of reference were constructed with the named functional axes (having the lowest variation, and thus highest repeatability). Segment orientations obtained by the functional method were compared to those obtained by the BLM method, see figure 1 for a visualisation. This difference was expressed as smallest angle between the individual X, Y, and Z-axes of the local frames of reference (Table 1).

Table 1, Orientation difference between methods (in º)

	X	Y	Z
Thorax	6	4	5
Humerus	8	6	7
Forearm	16	17	5
Hand	12	10	15

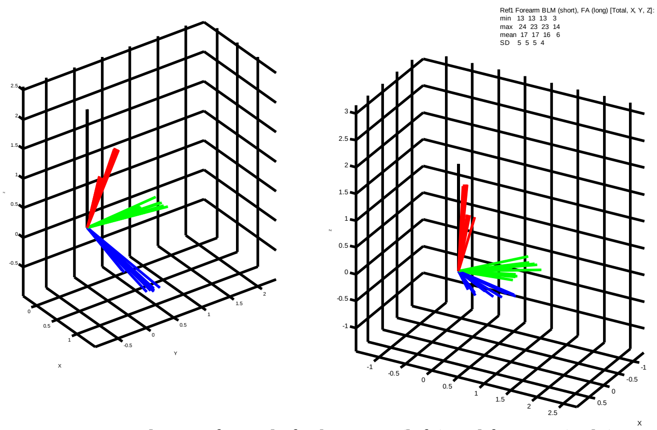

Figure 1, compilation of 6 trials for humerus (left,) and forearm (right), short bundles are axis from ‘BLM method’, long bundles from ‘functional method’.

DISCUSSION & CONCLUSIONS

For most segments at least two functional axes can be found with a repeatability error of 2º to 3º. Comparison with a Vicon based BLM method showed differences of up to 8º for thorax and humerus, and averaged over subjects, up to 17º for the flexion axis of the forearm. Further analysis has to reveal if there is a tendency which can be ‘corrected’ for. The determination of a scapular frame of reference with a sensor is not trivial; prescribed scapular movement is not under voluntary control; alignment with the thorax reference frame will lead to an unacceptable offset. Estimation of scapular orientation by means of regression equations is still the best alternative.

REFERENCES

[1] Ge Wu, F van der Helm, HEJ Veeger, et al, ISB recommendation on definitions of joint coordinate systems… Part II, *Journal of Biomechanics* **38** (2005) 981–992