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# ERRORS IN USING TWO DIMENSIONAL METHODS TO MEASURE MOTION ABOUT AN OFFSET REVOLUTE

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## INTRODUCTION

Two dimensional measurement of human joint motion involves the analysis of three dimensional displacements in an observer selected measurement plane. Accurate marker placement and alignment of joint motion plane with the observer plane are difficult. Nonetheless, alignment of the two planes is essential if one is to accurately record and understand the joint mechanism as well as the movement about it.

In nature, joint axes can exist at any orientation and location relative to an arbitrarily chosen global reference frame. An arbitrary axis is any axis that is not coincident with a reference coordinate. We calculate the errors that result from measuring joint motion about an arbitrary axis using two dimensional methods.

## REVIEW AND THEORY

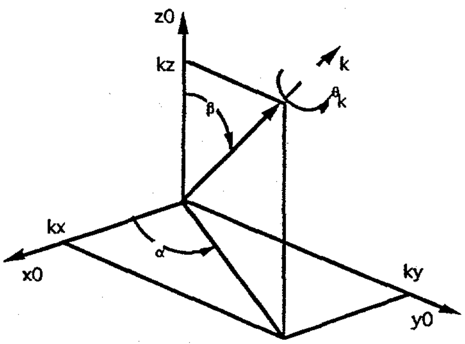
Kinematic and anatomic analyses of a number of human joints have suggested that they move about fixed revolutes that are not parallel to the anatomic reference planes (Hollister, et al. 1991, Hollister, et al. 1993, Inman 1976, London 1981). Analysis of kinematic data has traditionally been done using planar analysis (Reuleaux 1876) in an anatomic reference planes (Frankel et al. 1976, Sudan and Auderkerke 1979) This method of describing motion is subject to error (Panjabi et al. 1982, Sudan and Auderkerke 1979) and intra-observer variability. Furthermore, these methods for describing motion do not relate directly to the kinematic mechanism of the joint itself.

## PROCEDURES AND RESULTS

Rotations of a body moving about an arbitrary axis in a reference frame are determined by the axis' $\alpha$ and $\beta$ angles of offset from the reference frame and the $\theta_k$ angle of rotation about the arbitrary axis, k (Fig. 1).

Displacements of a body moving about an arbitrary axis in a reference frame are determined by the axis' $\alpha$ and $\beta$ angles, the $\theta_k$ angle of rotation, r, the distance of the body from the axis of rotation, and d, the distance from the axis to the reference frame (Fig. 2).

When the arbitrary axis, k, is coincident with the reference z-axis (d, $\alpha$, $\beta = 0$) and with $r = 1$, the x and y positions of the point trace out cosine and sine waves, respectively, and the z position remains at zero for varying $\theta_k$. For perfect alignment, but with $r \neq 1$, the amplitude of the cosine and sine curves is scaled accordingly. When the arbitrary axis is parallel to the reference z-axis, but is translated by non-zero $x_k$, $y_k$, and/or $z_k$, the corresponding measured x, y, and z trajectories are shifted by $x_k$, $y_k$, and $z_k$, respectively (Fig. 3).




$$R_{k\theta} = \begin{bmatrix} k_x^2 v_\theta + c_\theta & k_x k_y v_\theta - k_z s_\theta & k_x k_z v_\theta + k_y s_\theta \\ k_x k_y v_\theta + k_z s_\theta & k_y^2 v_\theta + c_\theta & k_y k_z v_\theta - k_x s_\theta \\ k_x k_z v_\theta - k_y s_\theta & k_y k_z v_\theta + k_x s_\theta & k_z^2 v_\theta + c_\theta \end{bmatrix}$$

where $v_\theta = 1 - c_\theta$

**Figure 1: Rotation about an arbitrary axis.**

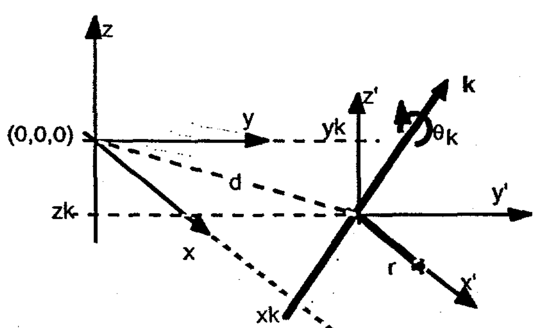



**Figure 2: Rotation, $\theta_k$, about an arbitrary axis, k, with translation (by amounts $x_k$, $y_k$, $z_k$) from the reference frame, x, y, z. The distance of the arbitrary axis is given by: $d = (x_k^2 + y_k^2 + z_k^2)^{1/2}$. The point moved about the arbitrary frame is a distance, r, from the arbitrary axis.**

With the arbitrary axis offset from the reference frame's axes, but still passing through the origin (d = 0), the xyz trajectories vary significantly with the offset angles, $\alpha$ and $\beta$ (Fig. 4). The trajectories can be made to vary qualitatively as well as quantitatively depending on the choice of $\alpha$ and $\beta$. The resulting planar projections used in 2D motion analysis methods can, therefore, also varied at will, with means to recover the complete trajectory unless the offset angles relating the plane of motion to the observer plane are known.

A 2 dimensional method would analyze only 2 of the 3 displacement dimensions. If the plane analyzed is not the motion plane the total displacement will not be measured. Furthermore, displacements in the third dimension will move the segments closer to or farther from the observer and will introduce perspective error in the planar analysis. Both of these factors introduce significant errors for instant center analysis or other 2D methods if the motion plane is not the plane analyzed.

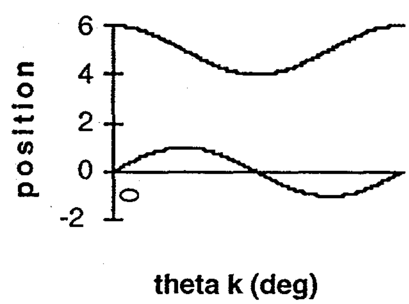



**Figure 3: xyz positions with a shift of $x_k = 5$, for $\theta_k$ varying fro m zero to 90 deg. The z trajectory is zero; the y trajectory traces out the cosine function; the x trajectory traces out an offset sine, centered about $x_k$=5.**

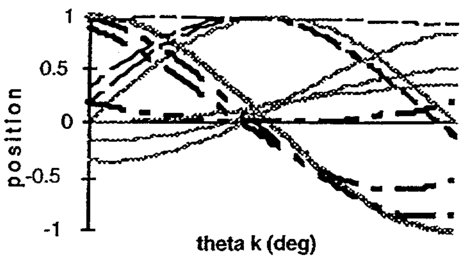



**Figure 4: xyz positions for axes of rotation with varying offset angles, $\alpha$ and $\beta$ (d=0, r=1): shown are x trajectories (thick lines; $\alpha, \beta = 0$, solid; $\alpha,\beta = 10$ and 20 deg, dashed; $\alpha$=80 deg, $\beta = 0$, dashed), y trajectories (thin dashed), and z trajectories (thin, solid).**

One method that is commonly used in kinematic analysis is that of Euler angles. This method, though not inherently 2D, is also affected by varying $\alpha$ and $\beta$ offsets. With zero offsets, the Euler angles correspond with the $\theta_k$ rotations (with variation in only one of the Euler angles). The resulting displacements then occur only in the plane that is perpendicular to the axis corresponding to the non-zero Euler angle, and 2D analysis of the displacements in that plane is appropriate. With rotation about a single arbitrary axis with 10 deg offset, this relationship breaks down: $\alpha$ and $\beta$ offset angles produce rotations about all three Euler coordinates, and the relationships are nonlinear (Fig. 5). Furthermore, the plane of motion, although the displacements still occur in 2D, cannot be simply determined from the Euler angle analysis.

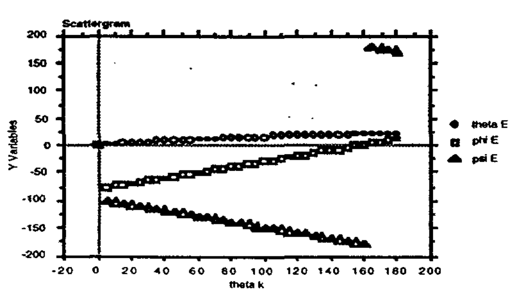



**Figure 5: Euler angle rotations calculated from rotations about an arbitrary axis with $\alpha$ and $\beta = 10$ deg.**

Different results are obtained for different $\alpha$ and $\beta$ offsets. If the motion plane is not the plane studied, the rotations will not be perpendicular to the analyzed plane and will not be directly related to the recorded displacements.

## DISCUSSION

Slight offsets of the measurement plane from the axis of rotation produce significant errors in recording displacements and rotations for motion about the joint axis with 2D methods. We conclude that, if 2D methods are used, the relationship of the reference frame to the axis of rotation must be known in order to perform accurate kinematic measurements.

## REFERENCES

[1] Frankel, VH, and Burstein AH, and Brooks DB: Biomechanics of Internal Derangement of the Knee. J. Bone and Joint Surg. **53-A**: 945-962, 1971.
[2] Hollister A, et al. The Axes of Rotation of the Thumb Carpometacarpal Joint, JOR, **10**:445-460, 1991.
[3] Hollister AM, et al. The axes of rotation of the knee, Clin Orthop, **290**:259-268, 1993.
[4] Inman,VT: The Joints of the Ankle. pp. 45-112, Williams & Wilkins, 1976.
[5] London JT: Kinematics of the Elbow. *J Bone Joint Surg,* **63**-A, 529-35, 1981.
[6] Panjabi MM, Goel VK, and Walter SD: Errors in Kinematic Parameters of a Planar Joint: Guidelines for Optimal Experimental Design. J. Biomechanics. **15**:537-44, 1982.
[7] Reuleaux F: Theoretische Kinematik: Grundzuege einer Theorie des Maschinenwesens, F.Kieveg und Sohn, Brauschweig. 1876.(Translated by A. B. W. Kennedy: The Kinematics of Machinery: Outline of a Theory of Machines.) London, Macmillin, 1960
[8] Soudan K and Auderkercke RV: Methods, Difficulties and Inaccuracies in the Study of Human Joint Mechanics and Pathokinematics by the Instant Axis Concept, Example: The Knee Joint. J. Biomechanics. **12**: 27-33, 1979.

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