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# Errors in Using Two Dimensional Methods for Ergonomic Assessment of Motion in Three Dimensional Space



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# ERRORS IN USING TWO DIMENSIONAL METHODS FOR ERGONOMIC ASSESSMENT OF MOTION IN THREE DIMENSIONAL SPACE

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## INTRODUCTION

Wrist posture and rapid wrist movements are risk factors for work related musculoskeletal disorders (Kilbom, 1994, Silverstein et al., 1987) Measurement studies frequently involve optoelectronic methods in which markers are place on the subject's hand and wrist and the trajectories of the markers are tracked in three dimensional space. A goal of wrist posture measurements is to quantitatively establish wrist posture orientation. Accuracy and fidelity of the measurement data with respect to kinematic mechanisms are essential in wrist motion studies. Fidelity with the physical kinematic mechanism can be limited by the choice of kinematic modeling techniques and the representation of motion.

Frequently, ergonomic studies involving wrist kinematics make use of two dimensional measurement and analysis techniques. 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.

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

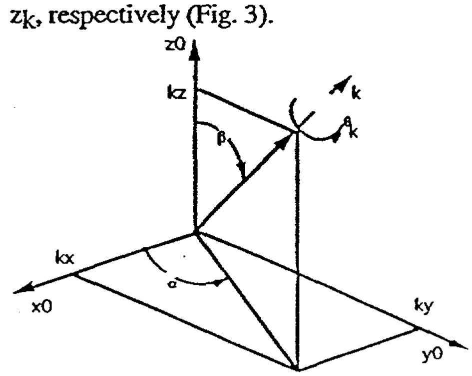
Kinematic and anatomic analyses of a number of human joints have suggested that they move about fixed revolutes that are not parallel to the anatomic reference planes (Hollister, et al. 1991, Hollister, et al. 1993, Inman, 1976, London, 1981). Analysis of kinematic data has traditionally been done using 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.

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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 $\beta$.

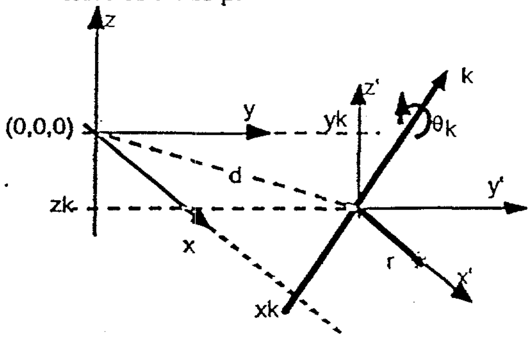


**Figure 2: Rotation, $\theta_k$, about an arbitrary axis, k, with translation (by amounts $x_k$, $y_k$, $z_k$) from the reference frame, x, y, z. The distance of the arbitrary axis is given by: $d = (x_k^2 + y_k^2 + z_k^2)^{1/2}$. The point moved about the arbitrary frame is a distance, r, from the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

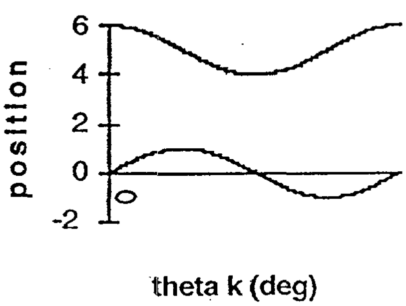


**Figure 3: xyz positions with a shift of $x_k = 5$, for $\theta_k$ varying fro m zero to 90 deg. The z trajectory is zero; the y trajectory traces out the cosine function; the x trajectory traces out an offset sine, centered about $x_k$=5.**

A 2 dimensional method would analyse only 2 of the 3 displacement dimensions. If the plane analysed 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.

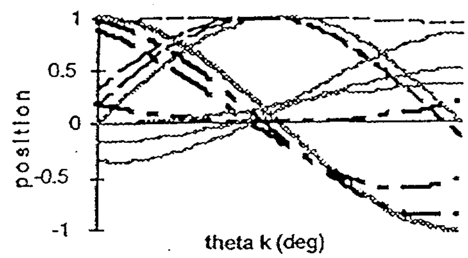


**Figure 4: xyz positions for axes of rotation with varying offset angles, $\alpha$ and $\beta$ ($d$=0, $r$=1): shown are x trajectories (thick lines; $\alpha$, $\beta$ = 0, solid; $\alpha$,$\beta$ = 10 and 20 deg, dashed; $\alpha$=80 deg, $\beta$ = 0, dashed), y trajectories (thin dashed), and z trajectories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

## 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 2 D methods. We conclude that the relationship of the reference frame to the axis of rotation must be known in order to perform accurate kinematic measurements.

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