PARAMETERIZATION OF JOINT KINEMATICS USING QUATERNIONS

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INTRODUCTION

Several methods exist to parameterize 3D segment orientation of a multijoint system. Any method of attitude characterization requires coordinate data of a minimum of three non-collinear points located on each body segment during the movement (tracking markers). The method used to acquire the kinematic data and characterize the motion must be consistent with the research question and insensitive to the error introduced during the motion detection process. Choosing an appropriate method for a given research question depends on its performance in the following areas: immediate physical meaning, ease of calculations, singularities, smooth transition around 180°, and ability to describe sequential rotations [1].

In this study, we investigated the ability of the quaternion parameterization of rigid body orientation to characterize lower extremity joint kinematics during 3D human movements using experimental data.

A quaternion is an extension of complex numbers of the form:

$$\mathbf{q} = [\cos\theta, \cdot (\sin\theta \cdot n_1, \sin\theta \cdot n_2, \sin\theta \cdot n_3]^T$$

The four parameters represent the rotation of a rigid body about a unit vector **n** by an angle 2θ [2]. Quaternions are advantageous because the addition of a fourth parameter avoids the singularities inherent in the Euler parameterization, the implementation is algebraic, and successive rotations are handled as an addition operation. Further, the axis/angle information embedded in the quaternion can be used to quantify out of plane motion and changes in the axis of rotation within a joint during movements.

METHODS

Footwork skills were performed by a skilled athlete in accordance with the Institutional Review Board. Three non-collinear markers were mounted onto orthoplast and attached to the lateral aspect of the thigh and shank over a neoprene sleeve to minimize marker movement. Sagittal and frontal plane kinematics were recorded during the task using digital video (200 Hz, NAC C2S, Burbank, CA). Tracking markers and joint centers were manually digitized for the entire task (Peak Performance Inc, Englewood, CO). Bony landmarks were digitized for one frame to calibrate segment reference systems. 3D coordinate data for all points was acquired using direct linear transformation. Raw coordinate data was filtered using quintic splines and exported into Matlab.

Quaternions were calculated for both segments at each time step [3]. The shank and thigh quaternions were then used to calculate the knee angle. To validate the quaternion algorithm, these knee angles were compared to knee angles calculated using the digitized joint center coordinates (Figure 1).

RESULTS AND DISCUSSION

Comparison of the joint angles calculated using digitized joint centers versus quaternions demonstrated the ability of the quaternion to accurately parameterize segment configuration. The RMS error for the knee angle calculated with the knee and hip quaternions was 2.53° By increasing the number of tracking markers on each segment to four or five, this RMS error is likely to be reduced.

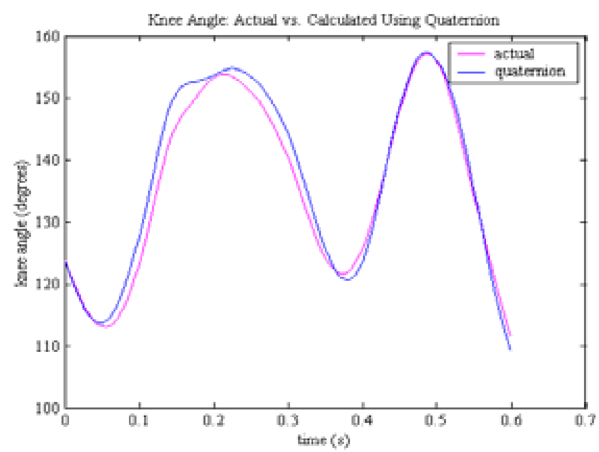

Figure 1. Comparison of knee angle computed using 3D coordinate data and knee angle determined using quaternion parameterization.

These results demonstrate that the quaternion parameterization of segment configuration can be used to characterize knee motion during foot work skills as performed in this study.

CONCLUSIONS

The quaternion parameterization of rigid body orientation was found to be a reasonable method for characterizing lower extremity joint kinematics during 3D human movements. This parameterization provides advantages over alternative methods (Euler angles, screw method) because it provides biomechanically relevant information, is easy to implement, and avoids singularities. The axis/angle information embedded in the quaternions for each segment can be used to validate assumptions about joint characteristics and to quantify out of plane motion between adjacent segments.

REFERENCES

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