Enhanced Joint Motion Analysis Using an Incremental Angle-Based Finite Helical Axes Method

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Summary

Finite Helical Axes (FHA) are a technique for intuitive visualization of human joints motion. The potential of this representation led to attempts at reducing the numerical error in the calculation of the FHA parameters. A method for error reduction and improved FHA visualization is presented. Preliminary validation on a simple motion suggested better temporal resolution and potential motion pattern detection. This could foster better understanding of joint kinematics in biomechanical and clinical research.

Introduction

Helical axes (HA) are an effective and intuitive technique for representing joint kinematics [1]. Nonetheless, their numerical calculation is prone to errors [2]. Instantaneous Helical Axes (IHA) technique is reliable when the used sensors provide velocity data [3], while Finite Helical Axes (FHA) are more suitable if positional and orientation data are available [3]. To optimize the estimation of FHA parameters, several methods were proposed, such as polynomial fitting and Lie group representations [4]. In this work, an FHA calculation method is proposed, to be applied on medium to high-frequency kinematic data, which relies on angle-based moving increments (miFHA), alongside a visualization technique based on projection of the miFHA on cross-sectional planes.

Methods

A basic flexion movement was performed on a hinge phantom. Rotational (quaternions) and location data were acquired using an electromagnetic tracking system. The data were collected relative to the fixed reference frame of the system at 120Hz. The FHA parameters for the axis associated with the relative pose between each time frame and the previous were first calculated as in [1]. An angle increment step value s (s=5°) was then defined. Next, FHA were extracted stepwise every time an s degrees increment about the FHA was reached, as in [6] (fixed increment FHA, fiFHA). Finally, the new miFHA were extracted by finding, for each time i, the time j at which s degrees of rotation were reached and calculating the FHA between pose at time i and j. For each FHA, fiFHA and miFHA, the Average Helical Axis (AHA) was calculated, and a plane perpendicular to it was generated. The cross-sections of each HA with the plane were found and the mean angle (MA) between each HA and the AHA was calculated.

Results and Discussion

Figure 1 shows the FHA obtained from the flexion motion on the hinge through the three methodologies (FHA, fiFHA and miFHA) and the cross-section of the axes on the AHA plane. Both the fiFHA (MA: 0.33°) and the miFHA (MA: 0.34°)

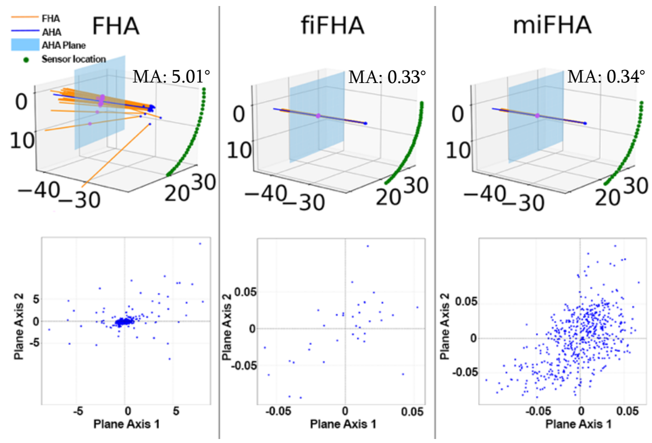

Figure 1: Obtained FHA (top line) and cross-sections on the AHA plane (bottom line) for the flexion motion on the mechanical hinge through the three methods (from left to right: FHA, fiFHA, miFHA). MA = Mean Angle

allowed to reduce the error that is introduced with FHA (MA: 5.01°) in case of stationarity or very little motion, as the MA around a perfect hinge would be 0°. Cross-sections on the AHA plane highlight how the miFHA preserved temporal resolution by associating a HA to each time frame, opposite to the fiFHA. Overall, miFHA enhanced joint motion visualization, by reducing error and maintaining temporal resolution. Cross-sections on the AHA plane could enable detecting specific features in the motion, for example through image recognition algorithms. Further validations of the proposed approach may strengthen its accuracy and validity for motion visualization, with applications in a personalized treatment of musculoskeletal disorders through improved diagnostics [5]. Examples are guiding preoperative planning and prosthesis design [4].

Conclusions

A methodology for enhancing visualization of FHA during motion (miFHA and cross-sections on AHA plane) was proposed. Preliminary validation suggested improved temporal resolution and possibility of motion pattern detection: this could lead to a more precise understanding of joint kinematics, offering a robust foundation for future biomechanical and clinical research.

References

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