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A survey of formal methods for determining functional joint axes

Rainald M. Ehrig[b], William R. Taylor[a], Georg N. Duda[a,*], Markus O. Heller[a]

[a]Center for Musculoskeletal Surgery, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, D-13353 Berlin, Germany
[b]Zuse Institute Berlin (ZIB), Berlin, Germany

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Abstract

Axes of rotation e.g. at the knee, are often generated from clinical gait analysis data to be used in the assessment of kinematic abnormalities, the diagnosis of disease, or the ongoing monitoring of a patient's condition. They are additionally used in musculoskeletal models to aid in the description of joint and segment kinematics for patient specific analyses. Currently available methods to describe joint axes from segment marker positions share the problem that when one segment is transformed into the coordinate system of another, artefacts associated with motion of the markers relative to the bone can become magnified. In an attempt to address this problem, a symmetrical axis of rotation approach (SARA) is presented here to determine a unique axis of rotation that can consider the movement of two dynamic body segments simultaneously, and then compared its performance in a survey against a number of previously proposed techniques.

Using a generated virtual joint, with superimposed marker error conditions to represent skin movement artefacts, fitting methods (geometric axis fit, cylinder axis fit, algebraic axis fit) and transformation techniques (axis transformation technique, mean helical axis, Schwartz approach) were classified and compared with the SARA. Nearly all approaches were able to estimate the axis of rotation to within an RMS error of 0.1 cm at large ranges of motion (90°). Although the geometric axis fit produced the least RMS error of approximately 1.2 cm at lower ranges of motion (5°) with a stationary axis, the SARA and Axis Transformation Technique outperformed all other approaches under the most demanding marker artefact conditions for all ranges of motion. The cylinder and algebraic axis fit approaches were unable to compute competitive AoR estimates. Whilst these initial results using the SARA are promising and are fast enough to be determined "on-line", the technique must now be proven in a clinical environment.

Keywords: Axis of rotation

1. Introduction

Clinical gait analysis is capable of assisting in the assessment and diagnosis of kinematic irregularities that may be unobservable even to a skilled clinician (Andriacchi et al., 1998; Cappozzo et al., 2005). Musculoskeletal analyses (Heller et al., 2001; Stansfield et al., 2003) can determine the internal loading conditions during functional load bearing, using the kinematics delivered from such non-invasive clinical gait analyses (Reinbolt et al., 2005), and can therefore aid in assessing treatment options. The ability to perform patient specific analyses, however, is limited by the accuracy of reconstructing the joint kinematics (Lu and O'Connor, 1999), a process that often requires determining an accurate axis of rotation (AoR). Furthermore, some joints such as e.g. the knee, have a much more complex pattern of motion and require a more detailed description than can be provided by joint centres alone and determining an AoR can provide a time-dependent anatomical reference to rotational motion. Moreover, in the orthopaedic and biomechanical literature, the function of the knee has often been characterised by a flexion axis (Churchill et al., 1998; Li et al., 2002; Most et al., 2004; Piazza et al., 2004; Asano et al., 2005) and hence procedures that are able to identify these axes are required.

The non-invasive determination of body segment motion is usually performed by directly measuring reflective marker positions using infra-red optical measurement

*Corresponding author. Tel.: +49 30 450 559079;
fax: +49 30 450 559969.
E-mail addresses: bill.taylor@charite.de (W.R. Taylor), georg.duda@charite.de (G.N. Duda).

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