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Development and applications of a software tool for diarthrodial joint analysis

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ABSTRACT

This paper describes a new software environment for advanced analysis of diarthrodial joints. The new tool provides a number of elaboration functions to investigate the joint kinematics, bone anatomy, and ligament and tendon properties. In particular, the shapes and the contact points of the articulating surfaces can be displayed and analysed through 2D user-defined sections and fittings (lines or conics). Ligament behaviour can be evaluated during joint movement, through the computation of elongations, orientations, and fiber strain. Motion trajectories can be also analysed through the calculation of helical axes, instantaneous rotations, and displacements in specific user-chosen coordinate reference frames.

The software has an user-friendly graphical interface to display four-dimensional data (time-space data) obtained from medical images, navigation systems, spatial linkages or digitalizers, and can also generate printable reports and multiple graphs as well as ASCII files that can be imported to spreadsheet programs such as Microsoft Excel.[1]

1. Introduction

The recent development of navigation systems for surgery and orthopaedic treatment and the increased interest in biomechanical modelling require more accurate tools in order to validate model previsions and have a more precise knowledge of joint functions.

Several software tools have been developed for navigation systems, used in computer-assisted surgery and medical treatments in order to reconstruct the relative position of the acquired anatomical structures and to track the position of surgical instruments with respect to the joint, and especially to compute specific features used to plan the surgical intervention [1–4]. These current systems allow only simple and very clinical-oriented computations, such as elongations of ligament fibers, isometry maps or surface contact for ligament reconstructions, knee alignment for total knee prostheses or hip replacements, but lack a more general analysis of the anatomy and function of the joint suitable for unconventional surgical treatment, individual adjustment of the surgery or validation of mathematical models. Otherwise, a more systematic analysis of joints can be found in planning environments and image-processing software packages [5,6], which are mainly aimed at anatomical measurements but neglect joint kinematics. Therefore, a software tool that enables biomechanical investigations of joint both from anatomical and functional point of view, and quantitative analysis of joints for research and validation purposes, is still not freely available.

This study presents a novel software tool, called StudyJoint, specifically developed for an easy and extensive analysis of diarthrodial joints (e.g. human knee, hip, shoulder or elbow), considering both the joint motions and relative anatomical structures. In particular, this tool allows the user to inter-

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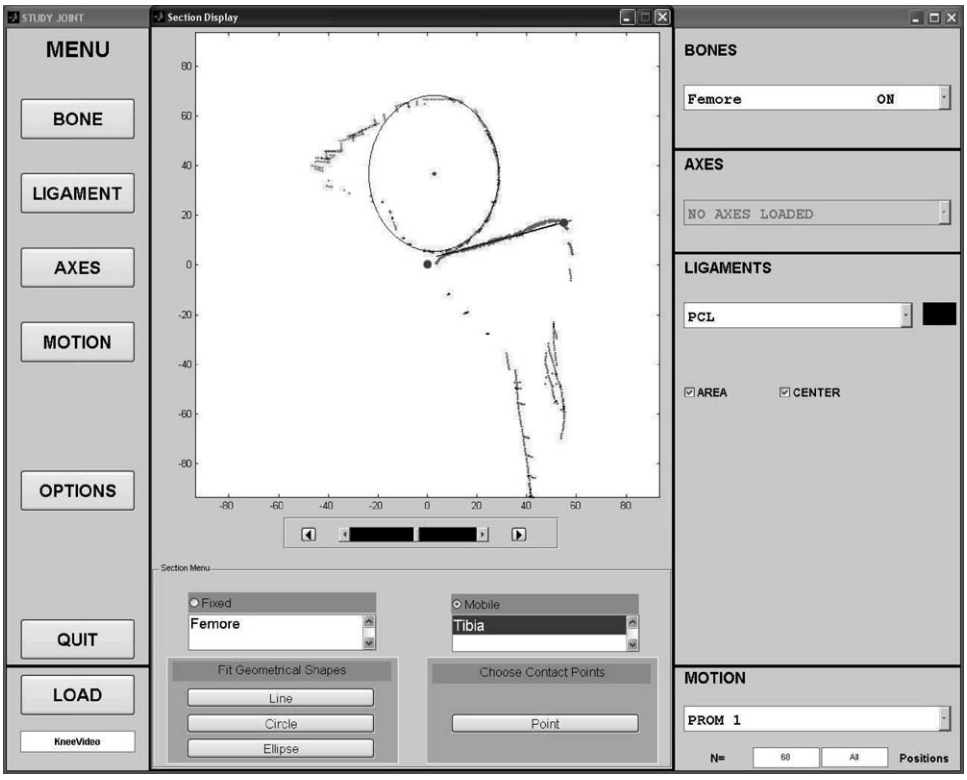

Fig. 1 – Bone section interface: fittings on selected points and 2D window contextual menu are displayed.

act with the acquired data through 3D and 2D visualizations, providing moreover all standard methods for specific investigations on joints.

This software may be particularly useful to validate biomechanical model behaviour over experimental data.

2. Background and requirements

Computer-assisted techniques applied both in clinical and research projects require a deep understanding of the knee functions and features, in order to evaluate the final aim of reconstruction surgery [7–13]. The growing interest in this peculiar joint and the need to generalize this investigation to other human joints [14] led us to extend the primitive separate MATLAB[2] functions and develop a general-purpose environment for standard biomechanical analysis. The aim of our project was to provide physicians, medical experts or researchers involved in clinical or medical applications with a free software for Windows[3] PC with all the classical computations usually performed. For this reason StudyJoint was developed (1) with a user-friendly and easy-to-use interface, (2) with intuitive display of surface data of anatomical structures,and (3) with computational methods classified according to the standard use on the different anatomical structures or motion data.

In this paper the software architecture and features are described in detail and an exemplary case is presented, focusing on a research ambit.

3. Computational methods and algorithms

StudyJoint permits a complete management of 3D image display, including standard features, such as 3D rotations along the three coordinate axes, roll along the camera axis, pan of camera position, and zoom out and zoom in on 3D data.

In bone section management (Fig. 1), surface scattered 3D points are projected onto user-defined planes (considering planes in fixed or mobile reference systems, planes perpendicular to axes, or arbitrary-oriented planes). The obtained profiles can be fitted by lines, circles or ellipses, through standard least-square optimization. Contact points can be defined by mouse clicking and are evaluated as the nearest point on bone projection to the current identified area. Both the fittings and the contact points are tracked in the slides through the motion.

Two functions are available for the ligaments: (1) the ligament or fiber *elongations* (absolute or percentage), evaluated through the tracking of the Euler distance of insertions; and (2) the ligament or fiber *orientations* (Fig. 2), evaluated as the angle between the vector identifying ligament direction and a specific plane (coordinate plane or also the plane fitting ligament insertions).

The computation on motion data includes the decomposition of the relative motion between fixed and mobile reference

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[3] Windows is a registered trademark of Microsoft Corporation.