QUICK AND EFFICIENT SUBJECT-SPECIFIC FINITE ELEMENT MODELING OF THE FOOT USING MESH MORPHING

Woo-Suck HAN(han@emse.fr), Nicolas KROUPA, Baptiste PIERRAT
Jérôme MOLIMARD
EMSE

Abstract

INTRODUCTION

Biomechanical modelling of the foot in association with motion capture is a promising technique to study the motions of the internal structures. In the literature, both aspects are treated with diversity; modelling is mostly done with finite element (FE) models e.g. [1,2]. Foot motion capture is done through multiple techniques, from external (stereo-correlation, motion capture) to internal (weight bearing computed tomography scan, X-Ray fluoroscopy).
The aim of this study is to model soft tissue deformation within the foot in various loading conditions. We present here a 3D FE modeling, with a dedicated protocol for patient specific studies including automatic ligaments positioning method and boundary conditions set from bone motion capture during loaded CT Scans.

MATERIAL AND METHODS

A generic, source geometry of the bones with their ligament attachment sites is hand built from the Visible Human Project data. This geometry contains 28 bones with the insertion points of the 87 ligaments. A subject-specific, target geometry is constructed using classic semi-automatic segmentation and 3D reconstruction from CT scan on an unloaded cadaveric foot, to obtain a mesh for each of the 28 bones. Each source bone is registered and then deformed through normal projection and mesh-morphing, to match its corresponding target bone, allowing positioning of the source ligaments attachment site on the target bone. The mesh-morphing uses a radial basis function (rbf) [3] and landmarks defined automatically through a normal projection mapping between target and source.
The subject specific displacement-controlled FE model is built with the integration of the target bone geometries, the ligaments seen as cable elements joining attachments sites, the surrounding soft tissues (muscle, fat and skin) as one homogeneous material.
Experimentally, the subject feet underwent a series of loading configurations in a CT scan: flat, plantar-flexion, dorsal-flexion, inversion and eversion. The positions of the bones geometry, previously built, are optimized for find their placement on the loaded configuration by using SLSQP minimization [4].
The FE solver calculates the soft tissue deformation and ground interactions using bone displacements as boundary conditions. Finally, the soft tissues constitutive parameters are identified by minimization of the global load.

RESULTS

The mesh-morphing technique successfully reproduces the target bone geometry with a mean distance between the target and morphed meshes of 0.06 mm with a standard deviation of 0.09 mm; this complete method takes 10 min on a regular workstation. The method gives a reasonable bone shape even if the CT scan segmentation does not provide the complete bone contour information. The ligament placements follow the source geometry assumptions and does not require target image ligament segmentation or user positioning.
Finally, the FE simulation coefficient of determination among the ground reaction force is 0.986 and simulated pressure maps have a RMSE of 0.152 MPa when compared to measured field.

DISCUSSION

The proposed technique has some limitations. Ligament positions are found by pure geometric deformation and cannot account for subject-specific particularities. Geometrical and material aspects of the anatomical components are simplified in the FE model with the homogenization of the different soft tissues and the line representation of the ligaments.
This simplification and standardization allow us to accelerate the generation time of a subject-specific model while keeping closed simulated results to soft tissue external interaction measures. Future work will take advantage of the proposed method to study larger foot sample and their interaction with their environment (device, shoe, insole and sole).

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Biography

Mr Woo-Suck HAN is professor at Ecole des Mines de Saint-Etienne in France since 1989. BSc in 1981 and MSc in 1983 in Aeronautical engineering at Seoul National University. PhD in 1989 at Institut National Polytechnique de Lorraine in Mechanical engineering. He is actually working in Biomechanics, in particular on medical devices to identify their therapeutic effects and to design them better. He is distinguished as Knight of the "Ordre des Palmes Académiques" by French government in 2012.