

CALCULATING THE INVERSION/EVERSION MOTION OF THE FOOT FROM PRESSURE PLATE MEASUREMENTS

F. Hagman, T. Ulicevic, A.A.F van de Ven, S.J.L. van Eijndhoven
Mathematics for Industry, Technische Universiteit Eindhoven
The Netherlands, 5600 MB Eindhoven, Den Dolech 2.

INTRODUCTION

The kinematics of the calcaneus is calculated from the temporal evolution of the local pressures underneath the foot during barefoot walking or running over a pressure plate. The kinematic modeling relies primarily on the rolling of a rigid object over a rigid plate. From the pressure distribution, the Center of Pressure (CoP) and the local radius of curvature of the calcaneus are calculated, where it is assumed that the surface of the calcaneus is part of sphere, locally. At each measurement time point, the contact point between the rigid body and the rigid plate is located at the CoP. Then the location of the CoP together with the radius of the sphere at the CoP in the next time point is calculated.

REVIEW AND THEORY

The calculation of the CoP from pressure measurements or force measurements is a well-known assessment tool in human gait analysis (for example: Fuller, 1999, and Xu et al., 1999). Mostly, the CoP of the whole footprint is calculated, while in this study, the CoP of the heel is considered, only. The CoP time series is used as input for the model, it describes the contact points in time between the rigid body and the rigid plate. The rolling of an arbitrary rigid body over a plate can be described with a difference scheme based on the fundamental law of kinematics. An input of the difference scheme that has to be determined is the angular velocity. This angular velocity is approximated in two ways: one is based on the local description of the calcaneus by a sphere with changing radii in time, and the other one is based on a relationship between the curvature tensor of an arbitrary rigid body and the angular velocity; this is deduced from differential geometry. In the first approximation, we need to determine the different radii of the spheres from the pressure distribution, incorporating results from elasticity theory. For the second approximation, we need to know a mathematical description of the surface of the calcaneus.

The model can be used to derive the position and orientation of the calcaneus from heel impact till foot flat.

PROCEDURES

Local pressure measurements during barefoot walking were measured by means of a Footscan® pressure plate (354Hz, 4 sensors/cm²). The measurements were analyzed with Matlab. Also, the difference scheme based on the sphere approximation with changing radii in time is implemented in Matlab and is given by:

$$\begin{aligned}\underline{x}(t + \Delta t) &= \underline{x}(t) + \Delta t(\underline{v}_0(t) + \underline{A}(t) \times (\underline{x}(t) - \underline{x}_0(t))), \\ \underline{x}_0(t) &= [x_{CoP}(t), y_{CoP}(t), R(t)]^T, \\ \underline{v}_0(t) &= \frac{1}{\Delta t} [x_{CoP}(t + \Delta t) - x_{CoP}(t), y_{CoP}(t + \Delta t) - y_{CoP}(t), 0]^T, \\ \underline{A}(t) &= \frac{1}{R(t) \Delta t} [y_{CoP}(t + \Delta t) - y_{CoP}(t), -x_{CoP}(t + \Delta t) + x_{CoP}(t), 0]^T,\end{aligned}$$

where $\underline{x}(t)$ are the Cartesian coordinates of an arbitrary point of the sphere at time t , $\underline{x}_0(t)$ and $\underline{v}_0(t)$ are respectively the Cartesian coordinates of the center point of the sphere and the velocity of the center of the sphere at time t , $\underline{A}(t)$ are the Cartesian coordinates of the angular velocity of the sphere at time t , $R(t)$ is the radius of the sphere at time t , and $x_{CoP}(t)$ and $y_{CoP}(t)$ are the x and y components of the CoP at time t .

RESULTS

The model describes mathematically the angular velocity of the calcaneus and the motion of arbitrary points of the calcaneus. Subsequently, the model calculates the position and the orientation of the calcaneus in every measurement time point. Since the orientation is known, we are able to calculate the inversion/eversion motion of the calcaneus. Kinematic output from this difference scheme will be presented at the conference.

DISCUSSION

The model describes the possibility to calculate the kinematics of the calcaneus in a theoretical manner. The next, natural step is to validate the model in different ways. One way is to look at the change of the radius of the sphere in time, to see if this constitutes a smooth transition in time and are anatomically "possible". Another way is to validate the kinematics obtained from the pressure plate with the kinematics obtained from a 3D motion capture device.

The validation process can lead to adaptations to the model. An example is to replace the local description of the surface of the calcaneus from a sphere to an ellipsoid, which describes all 3D surfaces locally.

REFERENCES

- Fuller E.A., *J. Am. Podiatr. Med. Assoc.*, *Center pressure and its theoretical relationship to foot pathology*, **89(6)**, 278-291, 1999
 Xu H. et al., *Am. J. Phys. Med. Rehabil.*, *Effect of shoe modifications on center of pressure and in-shoe plantar pressures*, **78(6)**, 516-524, 1999.

ACKNOWLEDGEMENTS

Since this study was done as contract research for the company RSscan International, we want to thank them for their contribution. Also, we want to thank prof. dr. D. De Clercq (University of Ghent), prof.dr. B. Van Gheluwe (University of Brussels), and prof. dr. P. Aerts (University of Antwerp) for their interest and suggestions for this project.