Evaluation of An Experimentally Driven Foot Contact Model

Michele Conconi[1], Alexandre Naaim [2], Nicola Sancisi[1], Raphael Dumas[2], Paul-André Deleu[3]
[1]Deptartement of Industrial Engineering, University of Bologna, Italy
[2]Laboratoire de Biomécanique et Mécanique des Chocs, Univ Eiffel, Univ Lyon 1, Lyon, France
[3]Foot & Ankle institute, Brussels, Belgium

Email: michele.conconi@unibo.it

Summary

A crucial point to enable the use of advanced foot models in musculoskeletal analysis is identifying how ground reaction force (GRF) distributes among the bones. We present and experimentally evaluate a procedure for identifying foot-ground contact regions based on an articulated foot model.

Introduction

An accurate representation of the foot is paramount to increase the fidelity of musculoskeletal models, since the foot represents the interface between the body and the ground. Several multi-segment foot models (MSFM) have been proposed [1] differing in the number of segments, their definition, the associated degrees-of-freedom (DOF), and contact model [2]. MSFM limits, however, the investigation grouping bones and making it impossible to study the motion of individual bones. Recently, we introduced a synergy-based 4-DOF foot model (SBFM) [3] that allows the accurate representation of the kinematics of all the bones as the linear combination of four foot motions. In this paper, we extend the model by introducing a method for identifying contact regions and the associated bones. The approach is developed and evaluated against experimental measures, also comparing SBFM versus MSFM.

Methods

Twenty-four healthy subjects (50±13 years, 73±10 kg, 173±8 cm) walked at a self-selected speed over a 10 m walkway in which a Footscan® pressure plate (0.5m × 0.4m, 4096 sensors) was mounted on an AMTI-force plate (0.5 × 0.4 m). This setup provided continuous calibration of the pressure plate with respect to the force plate. Sixteen retro-reflective markers were placed on the foot and shank according to [4]. An optoelectronic system (8 Micus cameras - Qualysis) tracked kinematic data during walking (200 Hz). The whole setup is reported in [5]. A template foot, including a set of 29 contact spheres built to approximate bones eminences (Fig.1), was scaled on each subject based on foot length. Foot bone kinematics were reconstructed using both a standard MSFM [4] and SBFM. A training set was defined considering the feet of ten subjects at mid-stance. The radii of the spheres were progressively and uniformly increased. The intersection of the spheres with the ground was computed, and the corresponding pressure values measured through Footscan plate were added, estimating the GRF. Optimal radius increment was chosen as the one that minimizes the difference between actual and estimated GRF. Negative pressure was assigned to regions of the Footscan plate not directly loaded, to penalize incorrectly estimated contact areas, with a penalty increasing with the distance from the last loaded pixel. Once the contact model was tuned, the same constant radial increment was applied to all the spheres and subjects. Finally, the GRF was estimated for both foot models and all subjects, over the entire gait cycle.

Results and Discussion

Both MSFM and SBFM had an optimum radius increment of 10 mm. However, SBFM resulted in a smaller errors, denoting a more physiological identification of the contact areas. This suggest that SBFM may identify better which bones are in contact and where this contact take place. In future work, the model will be further tuned, introducing an elastic model to compensate for these intrinsic differences induced by to the discrete nature of the spherical approximation of the contact.

Conclusions

The proposed SBFM can be employed in the standard musculoskeletal analysis, allowing for the investigation of the foot dynamics, as well as in forward dynamics models.

References

[1] Leardini A et al. (2019). *Gait&Pos.*, **69**: 50-59.
[2] Saraiva L et al. (2022), *Mech.Mach. Theory*, **177**,105046.
[3] Conconi M et al. (2024). *Proc. ESB Congress, Edinburg*.
[4] Leardini A et al. (2007). *Gait&Pos.*, **25**: 453-462.
[5] Deleu P A et al. (2021). *Gait&Pos.*, **84**: 308-314.

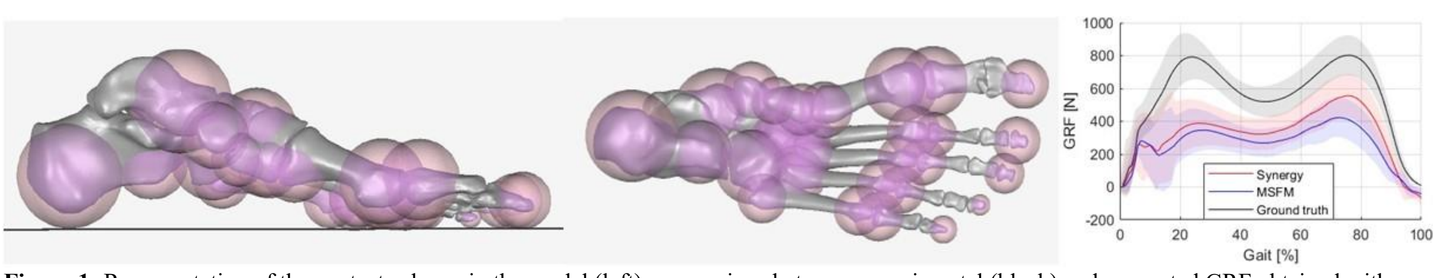

Figure 1: Representation of the contact spheres in the model (left); comparison between experimental (black) and computed GRF obtained with MSFM (blue) and SBFM (red) (right).