Beyond the Surface: Predicting Foot Bone Morphology from Skin Measurements

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Summary

By utilizing a combination of non-linear statistical shape modeling and Partial Least Squares regression, the foot bone morphology was predicted from skin surface data. By analyzing a dataset of 43 subjects, the feasibility of this approach was shown, achieving high accuracy in predicting both the shape(<3mm) and position of individual bones. This research provides a foundation for further development of non-invasive methods for assessing foot anatomy.

Introduction

The human foot, a complex weight-bearing structure crucial for locomotion, requires precise anatomical assessment for a wide range of clinical applications. Traditional imaging methods, such as X-rays or MRI scans, while valuable, present limitations, including high costs, potential radiation exposure, and limited accessibility. This study addresses this need by exploring the feasibility of utilizing statistical shape modeling and regression analysis to predict foot bone morphology directly from skin surface measurements.

Methods

The dataset consisted of standing CT data of 43 subjects (age: 38.3±16.7 years, length:1.75±0.12m ,mass: 82.7±19.4kg, sex:17 females, 26 males). A 3D template of the human foot and ankle was constructed, comprising 28 skeletal segments and the surrounding skin (Figure 1).

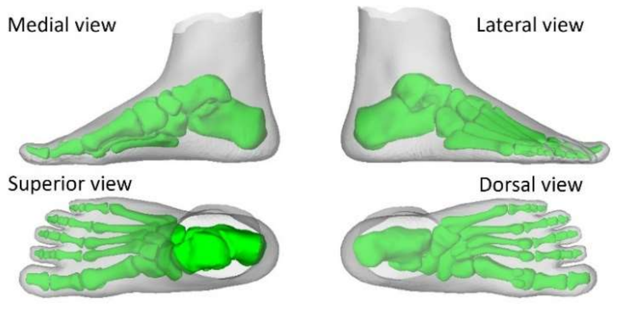

Figure 1: Template model of the feet: 28 bones and skin.

Non-rigid transformations were applied to each individual template component to match with the segmented foot bones and skin surfaces. Subsequently, separate Principal polynomial statistical shape models (SSMs) (order 2) were generated: one for the combined foot bones and another for the skin surface [1]. In each SSM 80% of the variance was retained. Partial Least Squares (PLS) regression models were trained using cross-validation with varying training set sizes [2]. To ensure data independence, both feet from each subject were either pairwise included in the training or test set. 2 PLS regression components were utilized. The accuracy was assessed by predicting bone shapes from their corresponding skin surfaces in the test set and comparing these predictions to the ground truth. More specifically, the errors were decomposed into pose and anatomy errors. The pose error was quantified as the squared Procrustes distance between predicted and ground truth shapes of each individual bone. The anatomy error was determined as the pointwise Root Mean Square Error (RMSE) between individual bones after Procrustes alignment.

Results and Discussion

The median anatomical error for the complete foot varied between 1.00mm and 0.94mm, with the latter achieved using 90% of the data for building the SSMs and training the PLS regression. Figure 2 illustrates the pointwise median anatomical accuracy. The middle and distal phalanges of the third, fourth, and fifth toes displayed the greatest pose errors (0.01-0.03mm), while the fourth and fifth metatarsals demonstrated the highest pose accuracy with errors below 0.001mm.

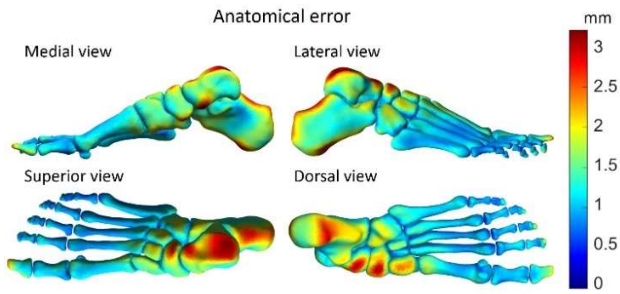

Figure 2: Median point-wise RMSE across 20-fold cross-validation for predicted foot bones compared to ground truth..

To the best of our knowledge, no previous method has predicted a detailed foot morphology from the skin surface.

Conclusions

This study demonstrates the feasibility of predicting foot bone morphology from skin surface measurements using non-linear statistical shape modeling and regression analysis, offering a potentially non-invasive and accessible alternative to traditional imaging techniques for clinical assessments.

References

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