



HAL
open science

Estimation of Musculoskeletal Features by Infering Femur from Thigh Skin

Oulimata Gueye, Guillaume Dardenne, Jocelyne Troccaz, Valérie Burdin

► **To cite this version:**

Oulimata Gueye, Guillaume Dardenne, Jocelyne Troccaz, Valérie Burdin. Estimation of Musculoskeletal Features by Infering Femur from Thigh Skin. Computer-Assisted Orthopedic Surgery 2024, Jun 2024, Groningen, Netherlands. hal-04804975

HAL Id: hal-04804975

<https://hal.science/hal-04804975v1>

Submitted on 26 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Estimation of Musculoskeletal Features by Inferring Femur from Thigh Skin

Oulimata Gueye^{1,2}, Guillaume Dardenne², Jocelyne Troccaz³, and Valérie Burdin^{1,2}

¹ **IMT Atlantique**, Institut Mines-Télécom, Brest;
oulimata.gueye@imt-atlantique.fr

² **INSERM**, LaTIM UMR 1101, Brest;

³ **Univ. Grenoble Alpes**, Grenoble INP, TIMC, CNRS, Grenoble

Abstract

Musculoskeletal disorders (MSDs) pose a significant healthcare challenge. This study addresses diagnostic limitations by proposing a novel algorithm able to estimate key anatomical features of the bone from skin surface. The clinical application concerns the mechanical axis of the femur from thigh skin. Leveraging 50 angioscanner thigh-femur pairs, we pioneer a robust Statistical Shape Model (SSM) capturing correlations between skin and underlying femur bone. Femur inference from a known thigh, uses a Bayesian approach and, demonstrates promising results. Despite non-homogeneous meshes and no prior femur knowledge, our approach outperforms current markerless methods, suggesting its potential as a potential non-invasive musculoskeletal parameter estimation tool for surgery applications.

1 Introduction

This research aims to address the intricate inference of femur features from the surrounding thigh region, introducing a novel approach grounded in a SSM.

In the field of existing diagnostic methodologies, prevalent techniques such as medical imaging and optical markers have been pivotal but present inherent limitations. Conventional medical imaging, despite offering valuable anatomical insights, is plagued by high costs, cumbersome navigation, and radiation risks [1]. Optical markers used for instance in motion analysis provide a non-invasive alternative, but face challenges due to high costs and dependence on complex navigation systems, restricting broad clinical application [2].

Presently, methods aiming to estimate bone structure based on external skin features are not suitable for clinical use but are rather designed for animated applications [3, 4]. The only clinically oriented method, developed by Alireza et al. [5], involves estimating the femoral mechanical axis using precisely placed virtual markers on the thigh skin. However, this method has limitations due to a need for controlled registration process.

In this context, our research seeks to narrow the current disparity by specifically formalising the correlation between the femur and thigh. Our main objective is to predict the femur based on the thigh, with a subsequent focus on deriving clinically relevant anatomical features of the femur as its mechanical axis.

To do so, we first build a SSM to learn correlations between femur and skin, then we use Markov Chain Monte Carlo (MCMC) method to make the inference.

2 Materials and Methods

2.1 Dataset and Preprocessing

We use 25 angioscanner, generating a dataset of 50 femur-thigh pairs. A quadratic decimation was performed in all the meshes to reduce complexity while preserving anatomy. We introduced a novel variable, “Depth”, representing the distance between femur points and each corresponding point on the thigh computed along the normal to the local femur surface (Figure 1-Part 1).

2.2 Statistical Shape Model Construction

We formalise the femur-thigh correlations through a 4D-SSM. A statistical model represents variability and similarity of similar objects within a dataset. The model combines the mean object with main variations, representing weighted contributions of important features such as length, curvature and width [6]. A SSM learns the variations of a dataset and is able to generate various similar objects (Figure 1-Part 2).

Accurate statistical shape modeling relies on mesh alignment and correspondence. Our iterative process included both rigid and non-rigid alignments, resulting in an augmented femurs dataset comprising in-correspondence femurs and their depths. Leveraging the Gaussian Process Morphable Models (GPMs)[7] method within the SCALISMO framework¹, we successfully created a continuous model capturing shape variability in the dataset. In our knowledge, the proposed 4D-SSM is the first SSM modeling correlations between a shape and its underlying bone.

2.3 Femur prediction

Given a known thigh, our algorithm predicts a femur shape using MCMC with the Metropolis-Hastings algorithm, a well-established method for drawing samples and approximating posterior distributions. This iterative process guides the generated samples towards convergence, evaluating a likelihood function to reach the target distribution. Figure 1-part 3) draws samples from the 4D-SSM, approximating femur shape based on the known thigh. The likelihood is computed by assessing the surface mean distance between the generated thigh samples and the target thigh. The selected sample, aligning most closely with the target, provides the predicted associated femur.

A proper initialization is crucial for the algorithm convergence. We achieve this by rigidly registering the mean model shape’s thigh with the target thigh using the Iterative Closest Points (ICP) algorithm (see Figure 1-Part 4). However, non-homogeneous thigh segmentation poses challenges for ICP, leading to inaccuracies in mapping specific regions. This discrepancy impacts femur length during MCMC likelihood evaluation, resulting in a predicted femur that captures the shape well but exhibits error in length matching. To address this, we introduce a double registration approach, focusing on thigh extremities. By separately cropping and registering upper and lower parts, we improve length matching of the predicted femur.

¹<https://scalismo.org/docs/Tutorials/tutorial06>

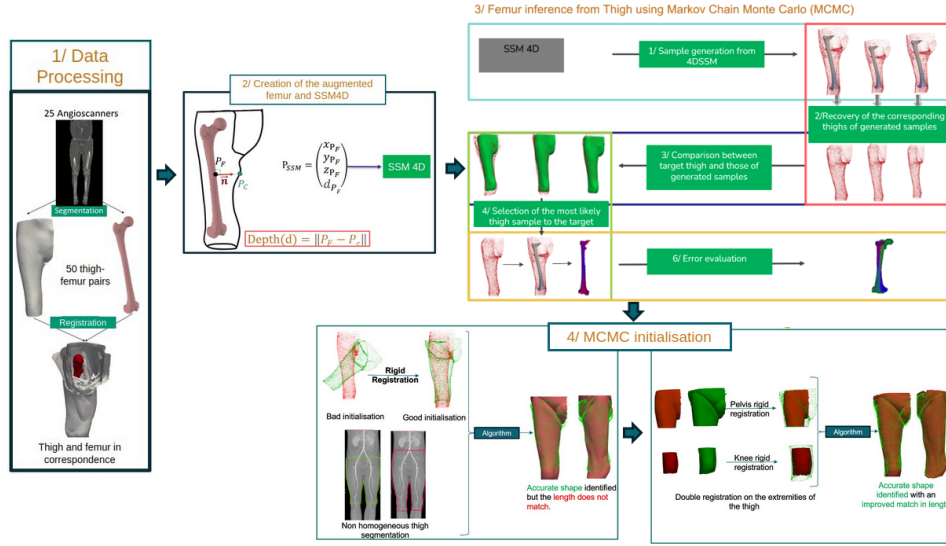


Figure 1: 4D-SSM building and femur inference

3 Results

From 50 femur-thigh pairs, 2 were discarded. The 4D-SSM construction utilized 25 datasets, with 23 retained for evaluation. Figure 2 illustrates femur inference errors.

Our method achieved a Root Mean Square Error (RMSE) of [7-14]mm for femur surface reconstruction, aligning with [5], which reported RMSE values of [7.5-10.5]mm using well-localized skin landmarks for femur surface reconstruction.

4 Discussion

Despite non-homogeneous meshes and a lack of prior femur knowledge, our model performed well. Subsequently, these predicted femurs can be used to evaluate the mechanical axis. Compared to Asvadi’s study, which reports an angle deviation error for the derived mechanical axis of less than 2° , our similar femur prediction suggests an acceptable approximation of the mechanical axis, emphasizing the significance of our advancements in musculoskeletal parameter estimation.

5 Conclusion

In summary, our novel algorithm infers femur bone from thigh skin, outperforming existing methods. Despite challenges, promising results have been obtained. The accuracy regarding the femur prediction from the model suggests an accepted estimation of the mechanical axis compared to the literature. Future enhancements may include addressing gender distinctions and incorporating additional parameters such as Body mass index (BMI).

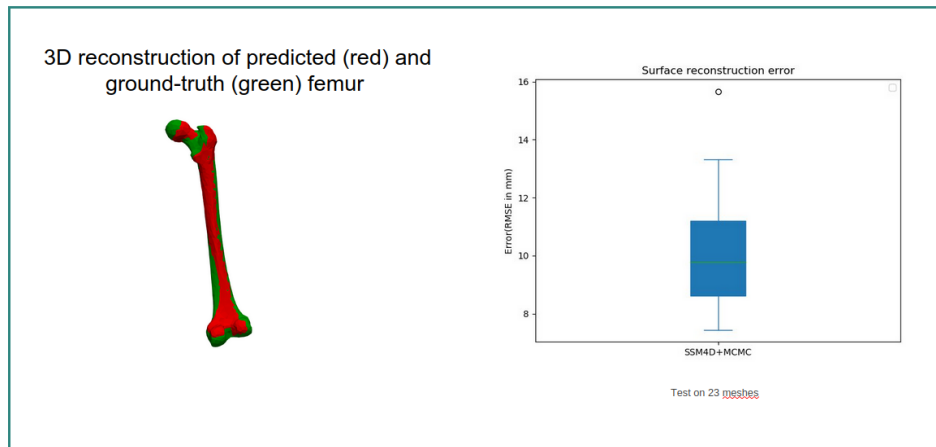


Figure 2: Femur inference errors

References

- [1] David J. Brenner and Hedvig Hricak. Radiation Exposure From Medical Imaging: Time to Regulate? *JAMA*, 304(2):208–209, 07 2010.
- [2] Angela Sorriento, Maria Bianca Porfido, Stefano Mazzoleni, Giuseppe Calvosa, Miria Tenucci, Gastone Ciuti, and Paolo Dario. Optical and electromagnetic tracking systems for biomedical applications: A critical review on potentialities and limitations. *IEEE Reviews in Biomedical Engineering*, 13:212–232, 2020.
- [3] Roland M Kanko, Einar Laende, W Scott Selbie, and Kevin J Deluzio. Inter-session repeatability of markerless motion capture gait kinematics. *Journal of Biomechanics*, 121:110422, 2021.
- [4] Marilyn Keller, Silvia Zuffi, Michael J. Black, and Sergi Pujades. Osso: Obtaining skeletal shape from outside, 2022.
- [5] Alireza Asvadi, Guillaume Dardenne, Jocelyne Troccaz, and Valérie Burdin. Bone surface reconstruction and clinical features estimation from sparse landmarks and statistical shape models: a feasibility study on the femur. *Medical Engineering and Physics*, 95:30–38, 2021.
- [6] Marcel Lüthi, Thomas Gerig, Christoph Jud, and Thomas Vetter. Gaussian process morphable models. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 40(8):1860–1873, 2018.
- [7] Dennis Madsen, Andreas Morel-Forster, Patrick Kahr, Dana Rahbani, Thomas Vetter, and Marcel Lüthi. A closest point proposal for mcmc-based probabilistic surface registration, 2020.