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Image Resolution Affects Tracking *in vivo* Biplanar X-ray Images of the Human Foot During Dynamic Motion

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Summary

Dynamic *in vivo* tracking of foot bone motion is challenging due to occlusions of the many small, close-packed bones. In this study, we investigated image resolution of dynamic biplanar videoradiography data and whether it affects the performance of bone tracking when using CT-derived models. Downsampling the dynamic images caused the largest tracking improvement, model upsampling and high-resolution images did not, when compared to manual rotoscoping.

Introduction

Measuring the *in vivo* six-degree-of-freedom motions of foot bones is a known challenge. Biplanar Videoradiography (BVR) is a promising approach to resolve these complex motions [2]. BVR tracking of long bones (e.g., femur, tibia) have cited accuracies of < 0.1 mm and 0.1°, but it is unknown if similar accuracies can be expected for foot images due to the complications caused by bony occlusions. Current approaches in markerless tracking use manual tracking (scientific rotoscoping) or perform global optimization that matches a digitally reconstructed radiograph to the calibrated X-ray images. The automated approaches are promising, but many parameters can be adjusted. For example, it is common practice to downsample the X-ray images to better match the resolution of the partial volume (PV).

The purpose of this study was to determine the accuracy of tracking the talus during hopping using manual rotoscoping and simulated annealing. We also tested whether downsampling the images improved accuracy. Finally, we assessed the accuracy of tracking with a PV created from a 3D surface file. We tested the accuracy against a rare dyanamic dataset where the participant had previously implanted tantalum beads in many of his foot bones.

Methods

After IRB approval and informed consent, we acquired CT images (0.44x0.44x0.625) of an individual with 0.8 mm tantalum beads that were previously surgically implanted in their tibia, fibula, talus, calcaneus, medial cuneiform, cuboid, and first metatarsal. The volumes were segmented using Mimics 19.0 (Materialize Inc., Leuven, BE) to identify the 3D coordinates of the bead centres, create 3D surfaces of the bones, and two PVs: one of the whole bone, the other of only the inner and outer cortex. BVR data of the same individual was obtained performing a hopping task (2048x2048 px @ 250 Hz). BVR bead locations were identified using XMALab [1]. The bead-based transforms were considered ground truth.

Using the bead coordinates, each respective image set was post-processed using a custom Adobe® Photoshop® script to remove the beads. This process generated an equivalent beadless dataset for rotoscoping without any visible markers.

Manual rotoscoping produced positional errors (rms ± sd) of 1.09 ± 0.24 mm and angular errors of 0.71 ± 0.32°, 4.25 ± 3.57°, and 2.70 ± 2.15° in X, Y, and Z, respectively.

The beadless hopping data was tracked using DSX (C-Motion Inc., Germantown, MD) to generate CT-to-BVR transforms for the talus, which was compared to the bead-based transforms. Using the built-in simulated annealing pose optimization of DSX, three workflows were performed for each CT model for a total of six: registration using downsampled 1024x1024 px images, full-resolution images (2048x2048 px), and the full-resolution images with an upsampled model to match the full-resolution image pixel size. Each workflow was run for 10000 iterations per frame with a search space of 3 mm and 3° using scientific rotoscoping as the initial guess.

Results and Discussion

Downsampling the images and tracking with the full PV led to significant performance increases: position improved 35% and angles by 30%, on average (Table 1). Tracking did not improve for the upsampled workflow. The cortex-only model did not improve tracking compared to manual rotoscoping.

Conclusions

Matching the dynamic images to the native resolution of the CT model and using the full PV leads to better automated markerless tracking. Based on these findings, we recommend using the full PV and downsampled images to track the talus.

References

[1] Knörlein B. et al. (2016) *J Exp Zool* **219**; p. 3701-3711.
[2] Miranda et al. (2011) *J Biomech* **133**; p. 121002:1-7

Table 1: Accuracy results (rms + sd) for manual rotoscoping and the six workflow conditions as compared to beaded ground truth.

		Manual Rotoscoping	Downsampled, Whole Bone	Downsampled, Cortical	Full-resolution, Whole Bone	Full-resolution, Cortical	Full-resolution, Upsampled Whole Bone	Full-resolution, Upsampled Cortical
Position (mm)		1.09 ± 0.24	0.71 ± 0.27	1.17 ± 0.45	1.62 ± 0.69	1.47 ± 0.68	1.94 ± 0.49	1.60 ± 0.49
Angle (°)	**X**	0.71 ± 0.32	0.55 ± 0.41	0.92 ± 0.58	1.43 ± 1.19	1.15 ± 0.75	0.94 ± 0.95	1.23 ± 0.84
	Y	4.25 ± 3.57	2.08 ± 1.88	2.73 ± 2.31	3.36 ± 2.29	2.79 ± 2.40	4.23 ± 3.17	3.56 ± 2.50
	Z	2.70 ± 2.15	1.85 ± 1.36	2.40 ± 1.87	2.82 ± 2.38	3.13 ± 2.69	2.61 ± 2.36	1.00 ± 0.91