HIERARCHICAL REGISTRATION BASED ON PATCH-SSMs

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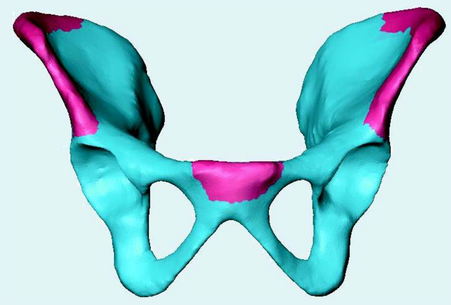

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Abstract

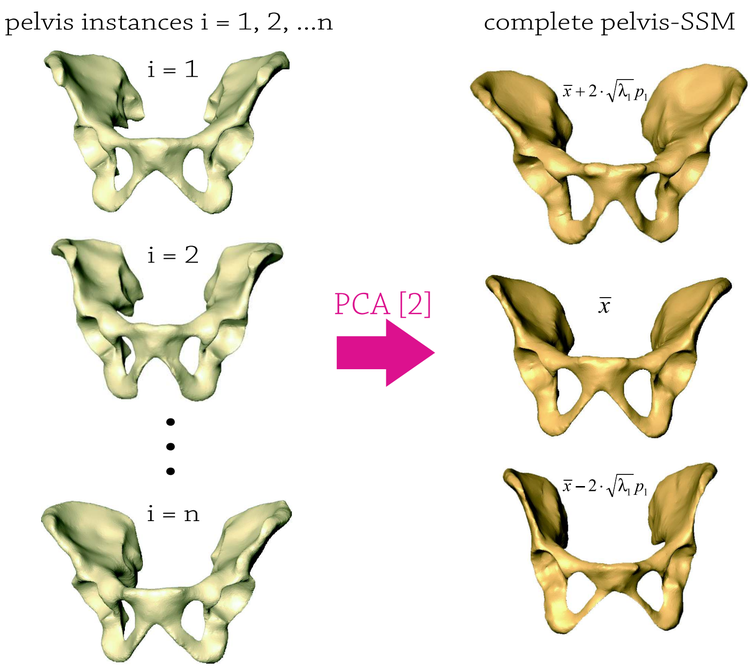
The extrapolation of sparse point cloud data by statistical shape models is a common problem. In the present case, a patient-specific model of the pelvis needs to be reconstructed based on sparse 3D point-cloud data derived from B-mode ultrasound images. In order to solve this problem, we propose a hierarchical registration method based on patch statistical shape models (SSMs), which iteratively compensates the speed of sound variation for different propagation distances of the ultrasound beam. We validated our new method with several phantom studies and one cadaver trial.

Clinical Background

In the field of computer assisted orthopaedic surgery (CAOS), the precise measurement of the pelvic orientation is inevitable for an accurate prosthesis placement during total hip arthroplasty. The pelvic orientation is normally determined with respect to the anterior pelvic plane (APP), which is defined based on specific pelvic landmarks (bilateral anterior superior iliac spines + pubis symphysis). In order to intraoperatively determine these landmarks, B-mode ultrasound (US) potentially provides an efficient means.

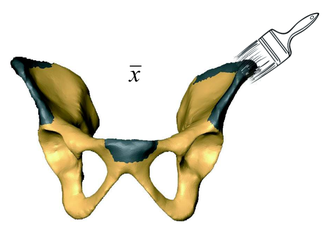
Patch-SSM Construction

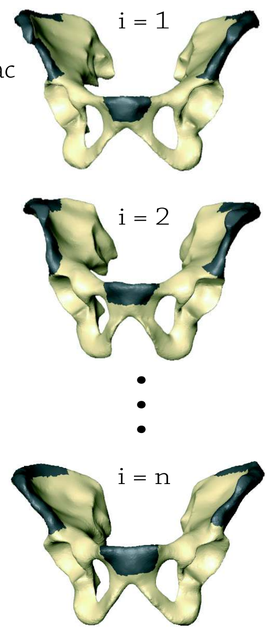
Non-Rigid Registration [1]



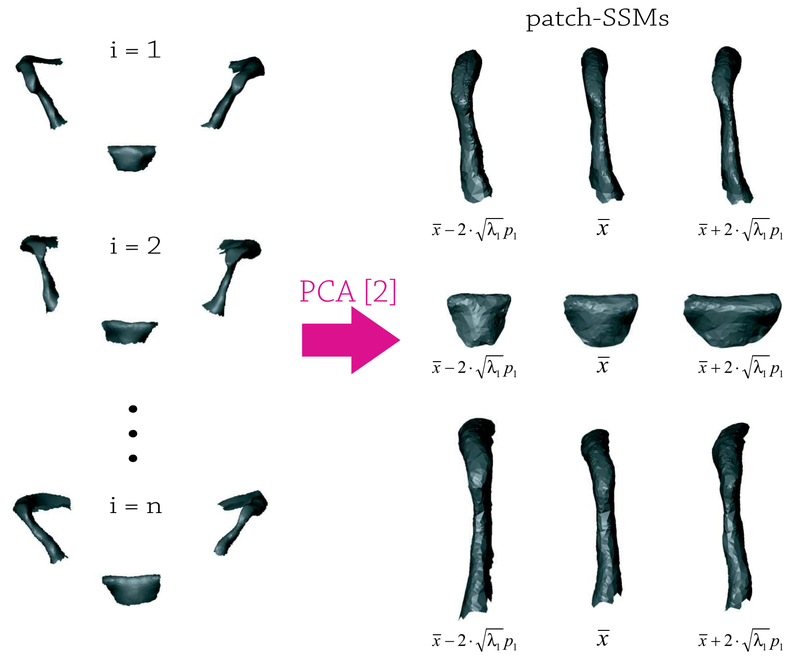
Patch Region Determination

- Iliac spine, left: Anterior superior iliac spine (ASIS) + Anterior inferior iliac spine (AIIS)
- Pubis symphysis
- Iliac spine, right: ASIS + AIIS



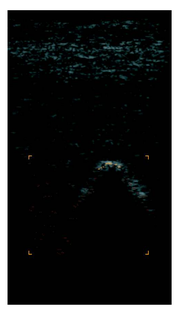


Patch Extraction & Patch-SSM Construction



Ultrasound Acquisition

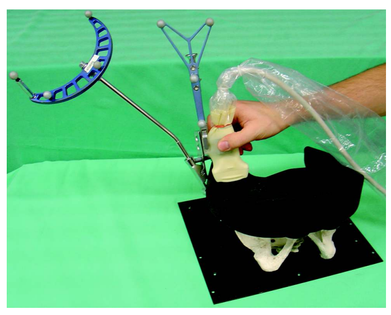
- Navigated ultrasound acquisition and segmentation controlled by PiGalileo system (Smith & Nephew AG, Switzerland)
- Ultrasound probe calibrated using special phantom for a constant speed of sound of 1540 m/s



=> Localization error for tissue types with different speed of sound in scanning direction [3]
=> Scaling factor (mm/pixel) needs to be corrected for exact depth localization of the pelvic landmarks

Experiments

- In-vitro tests using pelvic plastic bone with custom-made soft-tissue simulation attached (ph 1-3)
- One cadaver trial
- Ground truth established by digitization with a tracked pointer
- Results:

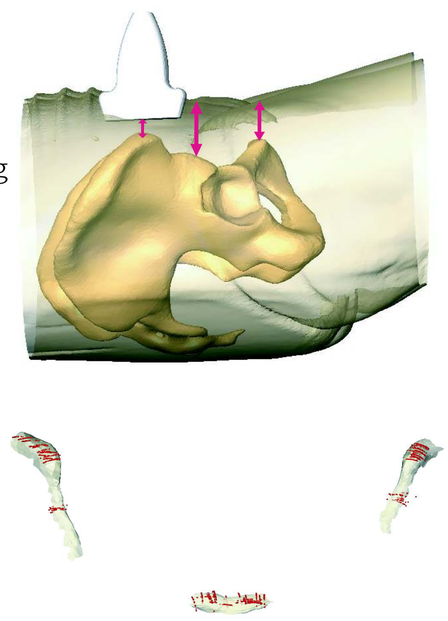


	ph 1	ph 2	ph 3	cadaver
Anteversion [°]:	1.13	0.56	1.24	0.62±0.56
Inclination [°]:	0.93	0.38	1.55	1.67±0.03

Hierarchical Registration

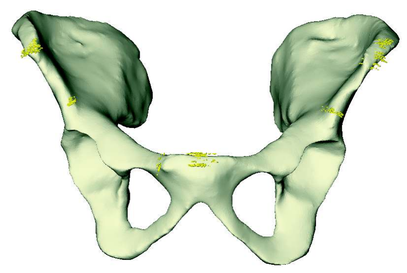
a) Local Registration of patch-SSMs

- Initial alignment of mean patches to assigned 3D point cloud based on centre of gravity, principal axes and least squares fitting
- Compensation of speed of sound difference:
  - × Optimization of scaling factor [3] based on point sets, which are closely located to the skin surface (short propagation distance)
  - × Update of all 3D points based on optimized scale
  - × Rigid registration of mean patches to updated 3D point clouds
  - × Patch-SSMs are instantiated and non-rigidly registered based on Zheng et al. [4] to establish dense correspondences between 3D US-derived points and SSM coordinate system



b) Global Registration of complete pelvis-SSM

- Alignment of complete mean pelvis model to US-derived points based on correspondences, established in a)
- Non-rigidly register complete pelvis-SSM to US points using 3-stage method [4]
- Optimize scale of **all** US-points based on [3]
- Repetition of non-rigid registration between complete pelvis model and US points using [4]



References

[1] Vercauteren, T. et al., LNCS 4792:319-26, 2007
[2] Cootes, T.F. et al., Comput Vis Image Understand 61(2):38-59, 1995
[3] Barratt, D. et al., IEEE Trans. on Med. Imaging 25:313-23, 2006
[4] Zheng, G. et al., LNCS 3852:52-60, 2006
[5] Chan, C. et al., LNCS 3217:397-494, 2004
[6] Foroughi, P. et al., LNCS 5242:871-79, 2008

Discussion

We have developed a novel method, which usess patch-SSMs to incrementally compensate for the speed of sound difference. No existing method (e.g. [5], [6]) presented a solution to compensate for the difference in speed of sound between the calibration and intra-operative use. For the validation of our approach, we conducted two experiments on phantom and cadaver data, showing promising results.

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