Enhancement of US-CT registration accuracy for spinal surgery

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Background presentation – Advanced Computer-Integrated Surgery (601.656)

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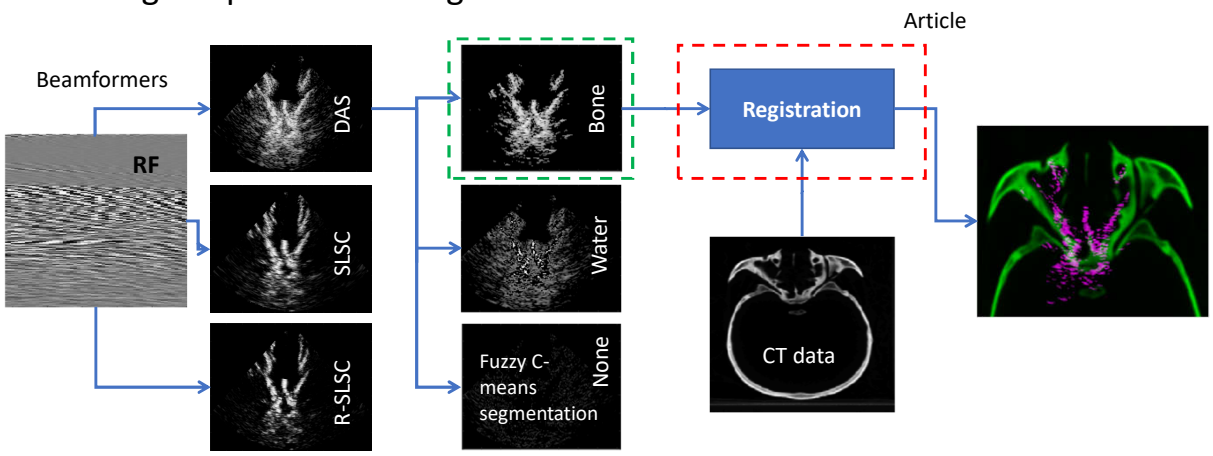
Summary of the project

Goal: Explore methods to improve accuracy of US-CT image registration through improved US image resolution



State of the art

Chosen article

Registration of 3D CT and Ultrasound Datasets of the spine using Bone Structures.

B. Brendel, S. Winter, A. Rick, M. Stockheim, H. Ernert. *Computer Aided Surgery*, vol 7, no 3, pp. 146-155,2002

Why?

- Present a clinical framework of spine samples registration
- Uses conventional volumetric ultrasound images
- Takes into consideration the bone structure for registration

Abstract of the selected paper

Avoid the use of landmarks positioned directly to bone structure by using bone through CT/ 3D ultrasound intensity based registration: maximizing the average gray value of the voxel in the ultrasound dataset covered by the surface.

Key concepts:

1. Very low registration error/displacement (0.5 mm)
2. Robust registration that is low sensitive to rotation
3. Simple algorithm for intensity based registration

Technical Approach

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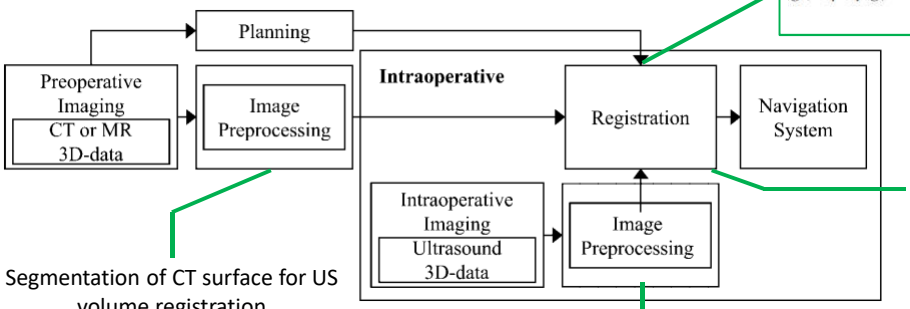
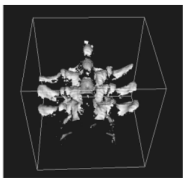
$$\bar{g}(\alpha,\beta,\gamma,\vec{g}) = \frac{1}{N}\sum_{i=1}^{N} UV(\mathbf{A}(\alpha,\beta,\gamma)\cdot\vec{p}_i + \vec{q})$$



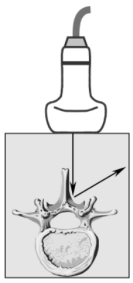
Segmentation of CT surface for US volume registration



Not any noticeable pre processing (just resampling)

Tested with several segmented CT surfaces

- Varying threshold
- Varying the angle of incidence



Technical Approach : CT Segmentation

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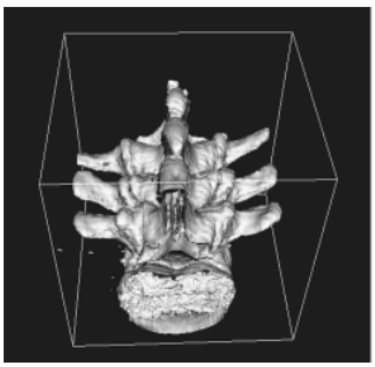
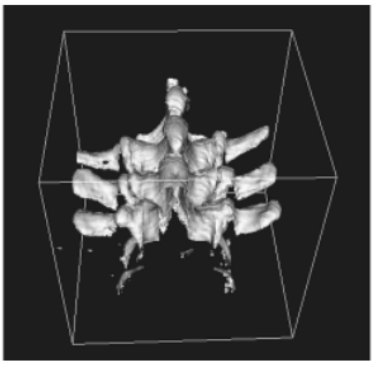
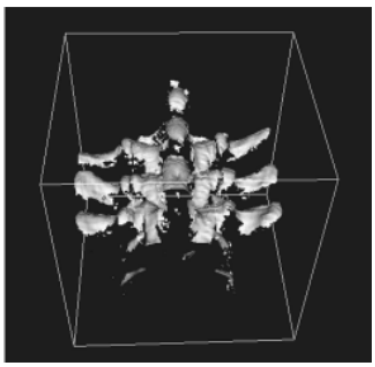


Original CT

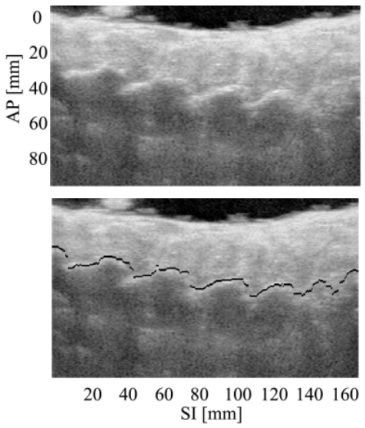


Reached by ultrasound

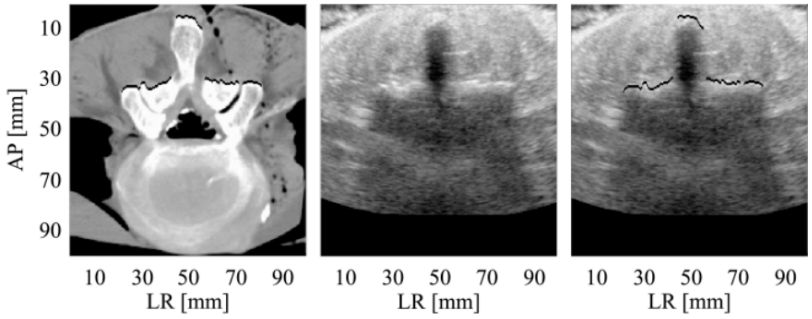


Imaged by ultrasound (Angle of incidence)

Technical Approach : Registration



Lumbar spine



Vertebra

Average gray value

$$\bar{g}(\alpha,\beta,\gamma,\vec{g}) = \frac{1}{N}\sum_{i=1}^{N} UV(\mathbf{A}(\alpha,\beta,\gamma)\cdot\vec{p}_i + \vec{q})$$

Registration results: varying threshold segmentation for CT

Table 1. Deviation of the Registration Results Depending on the Threshold for the Bone Surface Extraction in the CT Dataset

Threshold	Maximal rotational misalignment (whole spine)	Maximal translational misalignment (whole spine)	Maximal rotational misalignment (single vertebra)	Maximal translational misalignment (single vertebra)
100 HU	0.250°	0.5 mm	0.250°	0.5 mm
200 HU*	0.000°	0.0 mm	0.000°	0.0 mm
300 HU	0.500°	0.5 mm	0.125°	0.5 mm
400 HU	0.375°	0.5 mm	0.625°	0.5 mm

* Reference registration.

Not significant

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Registration results: varying incidence angle

Table 2. Deviation of the Registration Results Depending on an Alteration of the Assumed Incidence Angle for the Ultrasound Wave

Alteration of the incidence angle	Maximal rotational misalignment (whole spine)	Maximal translational misalignment (whole spine)	Maximal rotational misalignment (single vertebra)	Maximal translational misalignment (single vertebra)
2°	0.250°	0.5 mm	0.375°	0.5 mm
4°	0.125°	0.5 mm	0.375°	0.5 mm
6°	0.125°	0.5 mm	0.375°	0.5 mm
8°	0.125°	0.5 mm	0.125°	0.5 mm
10°	0.125°	0.5 mm	0.250°	0.5 mm
12°	0.750°	1.5 mm	0.125°	1.0 mm
14°	0.625°	1.5 mm	0.250°	1.0 mm
16°	0.500°	1.5 mm	0.250°	1.0 mm
18°	0.750°	1.5 mm	0.750°	1.5 mm
20°	1.000°	2.0 mm	0.500°	1.5 mm

Not significant

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Good points of the article

- Fast registration: Reported 5 to 10 seconds of registration per vertebra and 50 to 100 seconds for the whole spine
- Low sensitivity in variation of CT registration (around 0.5 mm)
- Mention a curvilinear array and a specific frequency that serves as background imaging parameters for scanning the spine
- Presents a simple fixed registration that is easy to compute

Bad points of the article

- Does not specify the computation time for resampling processes.
- Does not describe the mathematical procedure to segment the CT volume taking into consideration the angle of incident
- Presents a different pattern in the ultrasound for ex-vivo spine sample with soft tissue (acoustic shadow) than a sample with only hard tissue (acoustic echo).
- Does not specify the dynamic range of the whole CT intensity in order to analyze the errors due to different thresholds.

Conclusion – Usefulness to the project

- Segmentation/Registration procedure can be conducted without filtering the US image with Fuzzy C-means segmentation
- It demonstrates the feasibility of registering only part of the CT images that can be reached by the ultrasound
- A wide patter of high intensity could lead to higher registration erros, which can be still corrected with SLSC and robust SLSC.