Enhancement of Ultrasound / Computed Tomography registration applied to spinal surgery

Computer Integrated Surgery II

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Introduction

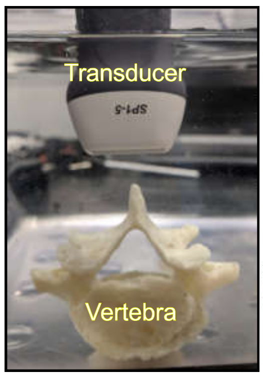
- **Implemented novel beamforming technique**: Locally Weighted Short Lag Spatial Coherence (**LW-SLSC**) to further enhance bone features in the human vertebra.
- This allowed us to **substantially reduce the noise in US bone images** and potentially increase the registration accuracy between ultrasound (US) and computed tomography (CT) images.
- **Ex-vivo** US channel data from a **human vertebra** was beamformed with Delay and Sum (**DAS**), **SLSC** and **LW-SLSC**, measuring **similarity with CT** using gradient correlation **(GC)**

The Problem

- **Registering** preoperative **CT** images with intraoperative **US** is a **challenging task**, due to the poor similarity of reconstructed images.
- Existing CT-US registration **approaches rely on** accurate **segmentation of bone structures in US images**, which are often subject to ultrasound speckle, noise and clutter.

The Solution

- US channel data was acquired for 10 different views of a human vertebra submerged in deionized water using a SP1-5 phased array probe (3.8 MHz center frequency, 65 mm depth, 50 mm focus).
- US images generated with



DAS

$$\tau(x_1,x,z) = \left(z + \sqrt{z^2 + (x-x_1)^2}\right)/c,$$
$$s(x,z) = \int_{x-a}^{x+a} RF(x_1, \tau(x_1,x,z))\, dx_1$$

SLSC

$$\hat{R}(m) = \frac{1}{N-m}\sum_{i=1}^{N-m} \frac{\sum_{n=n_1}^{n_2} s_i(n) s_{i+m}(n)}{\sqrt{\sum_{n=n_1}^{n_2} s_i^2(n) \sum_{n=n_1}^{n_2} s_{i+m}^2(n)}} \qquad R_{sl} = \int_1^M \hat{R}(m)\,dm \approx \sum_{m=1}^{M} \hat{R}(m)$$

LW-SLSC

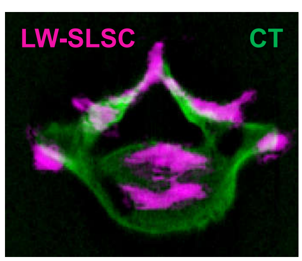
$$\hat{w}_i = \operatorname{argmin}\{\|\mathrm{TV}(w_i K_i)\|^2 + \alpha\,\|\nabla w_i\|^2\}$$

Total Variation | **Optimized weights for calculated summed lags of kernel *i*** | **Kernel *i* of the correlation matrix** | **Preserving high resolution**

- Fixed US/CT registration using Mattes Mutual information
- Similarity comparison metric: **GC**

$$\mathrm{NCC} = \frac{\sum_{(i,j)\in\Omega^T}[A(i,j)-\bar{A}][B^T(i,j)-\bar{B}]}{\sqrt{\sum_{(i,j)\in\Omega^T}[A(i,j)-\bar{A}]^2 \sum_{(i,j)\in\Omega^T}[B^T(i,j)-\bar{B}]^2}}.$$

$$0.5[\mathrm{NCC}(\frac{\partial A(i,j)}{\partial i}, \frac{\partial B(i,j)}{\partial i}) + \mathrm{NCC}(\frac{\partial A(i,j)}{\partial j}, \frac{\partial B(i,j)}{\partial j})]$$



Lessons Learned

- **SLSC and LW-SLSC provide improved bone segmentation** over DAS, with possible applications to improving US-CT registration for spine surgery.
- Gradient correlation is a suitable metric to evaluate similarity

Publications

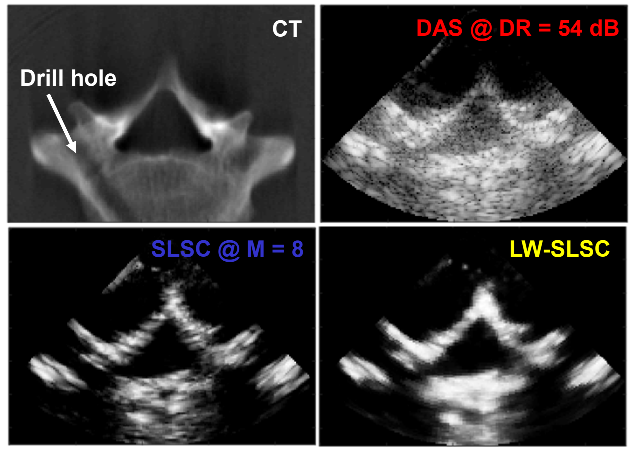
- "Segmenting bone structures in ultrasound images with Locally Weighted SLSC beamforming", *IUS 2018* (*in review*)

Acknowledgements

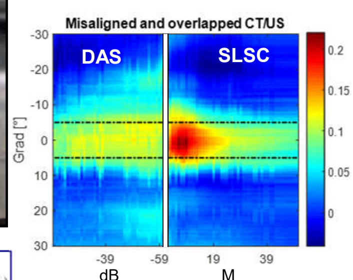
- Thank you to Michelle Graham for assisting me with the acquisition of CT / PA data

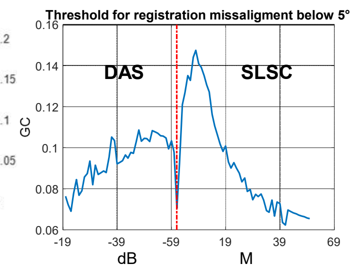
Outcomes and Results

Overall, **SLSC outperforms DAS** for a range of parameters commonly used in the literature (e.g., M=5-25, DR=-50 to -60 dB). An additional **improvement** is observed **with LW-SLSC over SLSC** (e.g., 8.2 dB mean contrast-to-noise ratio increase, 0.10 mean GC increase)

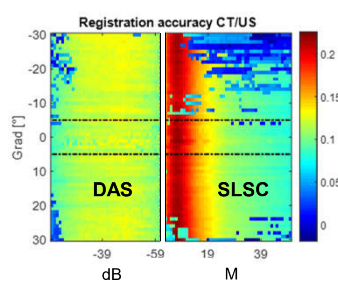


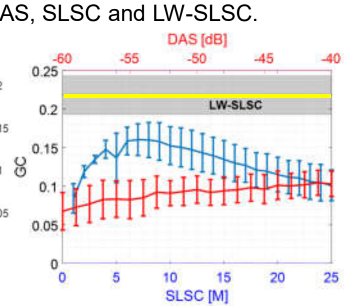
Intentional misalignment shows poor performance beyond ± 5 degree rotation, which corresponds to GC values <0.06





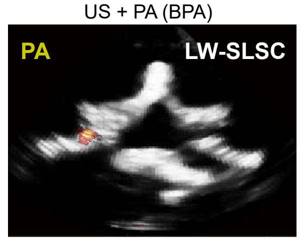
Registration experiment from rotation **showed similar results** (i.e., GC>0.06) with DAS, SLSC and LW-SLSC.



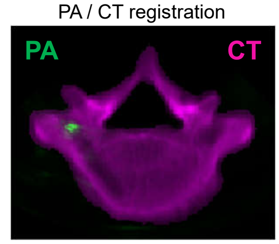


Preliminary results of photoacoustic(**PA**)-CT registration **could aid in tracking of surgical tools** inside the human vertebra

US + PA (BPA)



PA / CT registration



Future Work

- Implementation with **volumetric US/CT data**
- Experiments on ex-vivo human spine with **soft tissue and/or in-vivo samples**.

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