Initialize globally before acting locally: Enabling Landmark-free 3D US to MRI Registration

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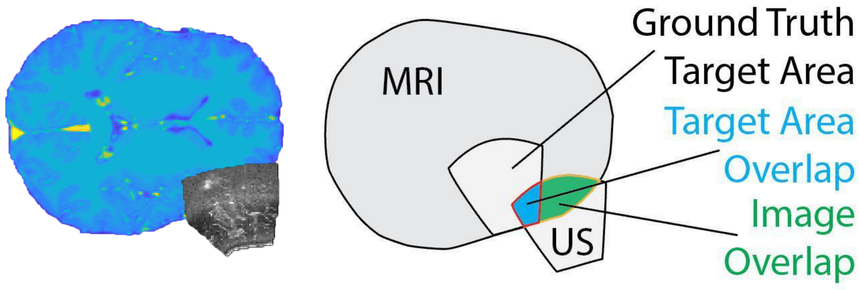
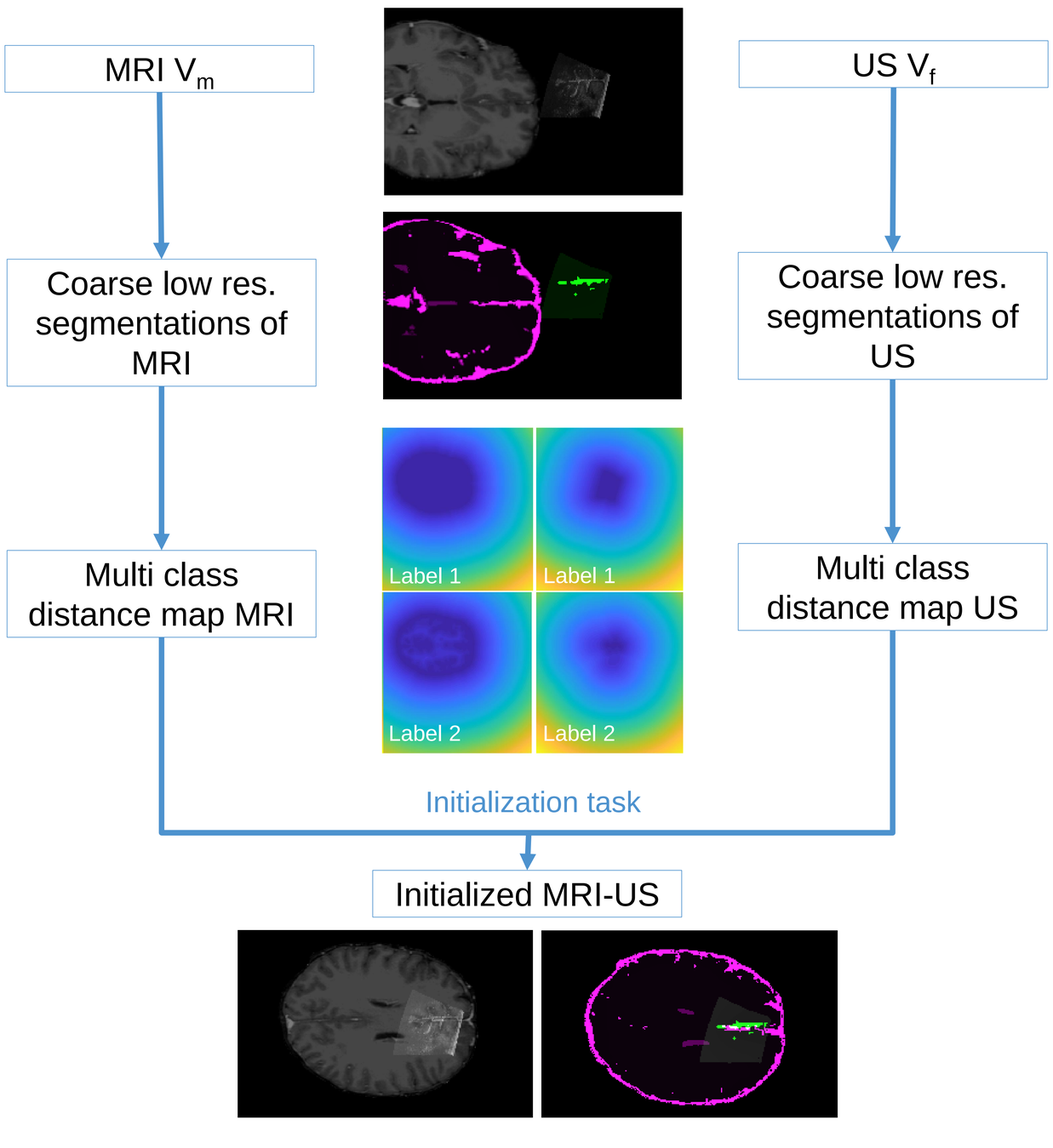
Motivation

- Initialization is crucial for convergence of nonlinear image registration
- US and MRI are often initially only partially overlapping
- US depicts anatomy only partly
- Proper initialization facilitates reliable and precise registration



- Current clinical practice is manual selection of 3D landmarks
- Error prone due to needed mental mapping (lack of orientation and volumetric coverage)
- High inter-observer variation

Methods



Novel initialization procedure that only requires N **low-resolution coarse segmentations**

$$\bigcup_{l=1}^{N} \Omega_{m,l} \subset \Omega_m \qquad \bigcup_{l=1}^{N} \Omega_{f,l} \subset \Omega_f$$

to initialize multi-modal deformable 3D US to MRI registration methods.

Euclidean distance transform Φ applied to each class individually,

$$\Phi_{m,l} = \Phi(\chi(\Omega_{m,l})) \qquad \Phi_{f,l} = \Phi(\chi(\Omega_{f,l}))$$

resulting in distance maps, where χ denotes the characteristic function.

This leads to a **minimization problem** where p = 1,2 and $T \in SE(3)$ the rigid transformation

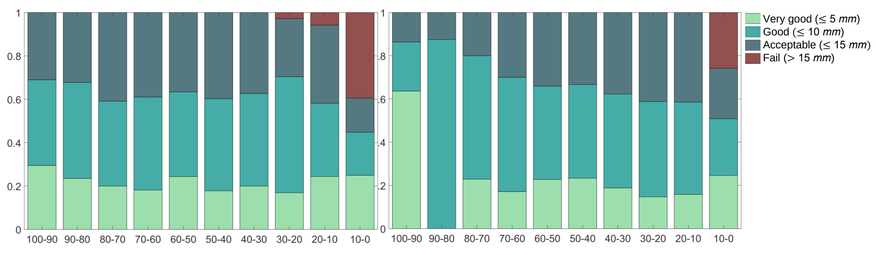
$$\min_{T \in SE(3)} \sum_{l=1}^{N} \int_{\Omega_f} \left| \left(\Phi_{m,l} \circ T\right)(x) - \Phi_{f,l}(x) \right|^p dx$$

Modified gradient descent scheme is employed, with p_i denoting the optimized rotation angle or translation parameter, δ_i the partial derivative of the minimization problem, τ positive step size, p_{max} regulates maximum parameter update

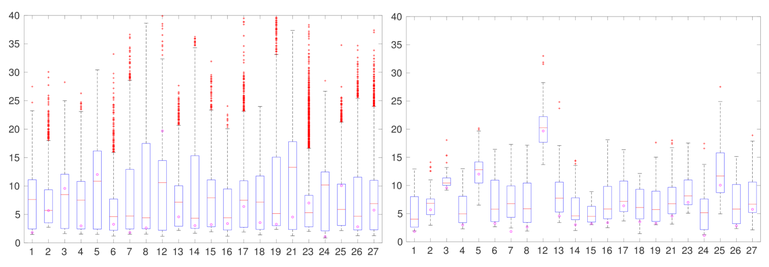
$$p_{i+1} = p_i - \tau \mathrm{sign}(\delta_i) \min\{|\delta_i|, p_{\max}\}$$

Results and Conclusions

- Evaluation on RESECT[3] dataset with two labels (foreground and superficial structures)
- Initizialisation considered a success if position is within capture range of state-of-the-art registration methods[2] ($TRE_{mean} \leq 15\ mm$)



Robustness test Fraction of experiments falling into quality category considering percentage of overlap for image overlap (left) and target area overlap right image (right)



Comparison to manual landmark selection Errors for initialization with four random landmarks selected from available landmark pairs disturbed with Gaussian noise (left) in comparison to errors for our initialization (right)

- Presented method can overcome error prone manual landmark selection
- Initialization robust regarding target area overlap and image overlap
- Can potentially lead to simplified clinical routine and more robust results in 3D image registration

References:
[1] Viergever, M.A., Maintz, J.A., Klein, S., Murphy, K., Staring, M., Pluim, J.P.: A survey of medical image registration–under review. Medical image analysis 33 (2016)
[2] Fuerst, B., Wein, W., Müller, M., Navab, N.: Automatic ultrasound–mri registration for neurosurgery using the 2d and 3d lc2 metric. Medical image analysis 18(8)(2014)
[3] Xiao, Y., Fortin, M., Unsgård, G., Rivaz, H., Reinertsen, I.: Retrospective evaluation of cerebral tumors (resect): a clinical database of pre-operative mri and intra-operative ultrasound in low-grade glioma surgeries. Medical physics (2017)
[4] Slavcheva, M., Kehl, W., Navab, N., Ilic, S.: Sdf-2-sdf: Highly accurate 3d object reconstruction. In: European Conference on Computer Vision, Springer (2016)
[5] Fischl, B., Salat, D.H., Busa, E., Albert, M., Dieterich, M., Haselgrove, C., Van Der Kouwe, A., Killiany, R., Kennedy, D., Klaveness, S., et al.: Whole brain segmentation: automated labeling of neuroanatomical structures in the human brain. Neuron 33 (3) (2002)
[6] Grady, L.: Random walks for image segmentation. IEEE transactions on pattern analysis and machine intelligence 28 (11) (2006)

EDEN2020 Enhanced Delivery Ecosystem for Neurosurgery in 2020
This project has received funding from the European Union's Horizon 2020 research and innovation program EDEN2020 under grant agreement No 688279 as well as the GPU grant program from NVIDIA Corporation.