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Intraoperative brain shift compensation using a hybrid mixture model

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Introduction

- Intraoperative *brain shift* affects the accuracy of neurosurgical guidance significantly
- Conventional image-guided navigation systems do not compensate for soft tissue deformation
- C-Arm computed tomography (CT) is not well studied for *brain shift* compensation [1]

➢ Investigate the use of **C-arm CT for brain shift compensation**
➢ Propose a **vessel centerlines based registration framework**
➢ Perform phantom and **first clinical study**

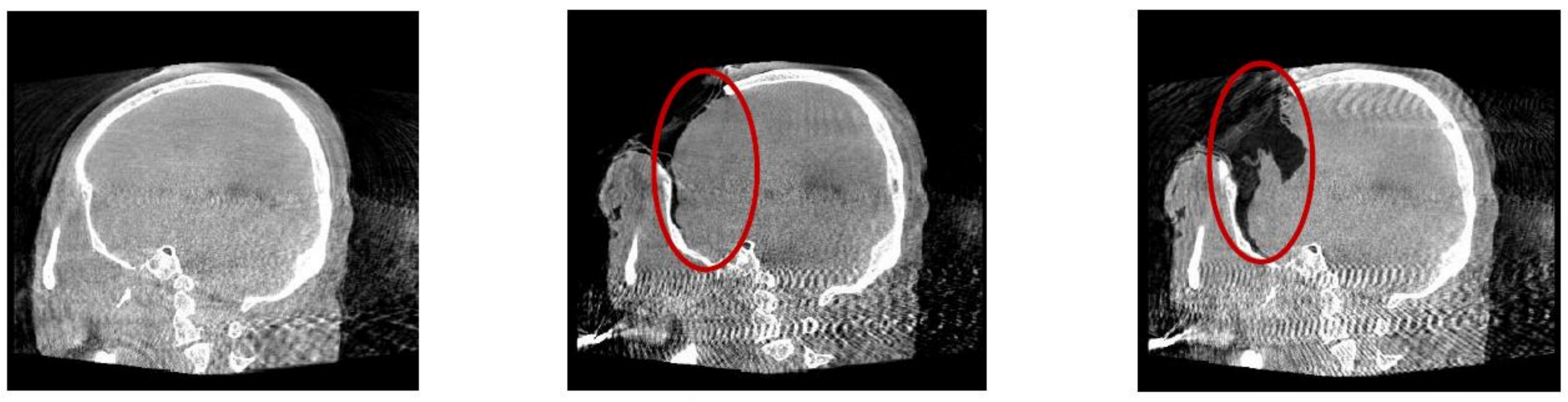


Figure 1: Intraoperative brain shift acquired with C-arm CT scanner in collaborating clinic.

Material and Methods

Hybrid mixture model (HdMM):

- Consider vessel centerlines as 6D hybrid points

Student´s t-distribution — Watson distribution

$$\log(\mathbf{T} \mid \mathcal{T}, \Theta_p, \Theta_d) = \sum_{i=1}^{N} \log \sum_{j=1}^{M} \pi_j \underbrace{\mathcal{S}(\mathbf{x}_i \mid \mathcal{T}\boldsymbol{\mu}_j, \nu_j, \sigma^2)}_{\text{spatial position}} \underbrace{\mathcal{W}(\mathbf{n}_i \mid \mathcal{T}\mathbf{m}_j, \kappa_j)}_{\text{undirected orientation}}$$

Mixture coefficient

- Use Tikonov regularization [2] to constrain the displacement

$$Q(\Theta_p^{t+1} \mid \Theta_p^t) = \sum_{i,j=1}^{N,M} -P_{i,j}^{\star} \frac{||\mathbf{x}_i - (\boldsymbol{\mu}_j + v(\boldsymbol{\mu}_j))||^2}{2\sigma^2} + \underbrace{\frac{\lambda}{2} \mathrm{Tr}\{\mathbf{W}^T \mathbf{G} \mathbf{W}\}}_{\text{smoothness}}$$

Brain shift compensation framework :

- A feature based probabilistic registration framework
- Use 3D Digital Subtraction Angiography and 3D Cone Beam CT

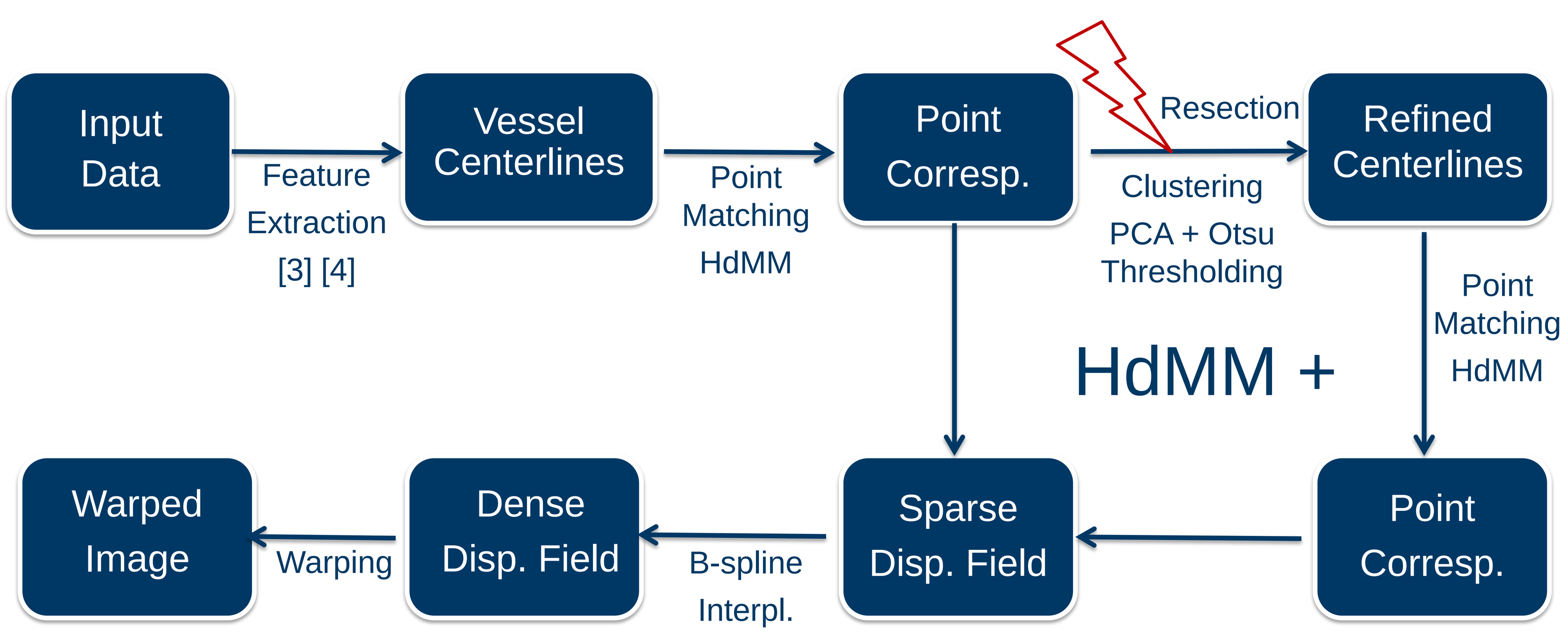
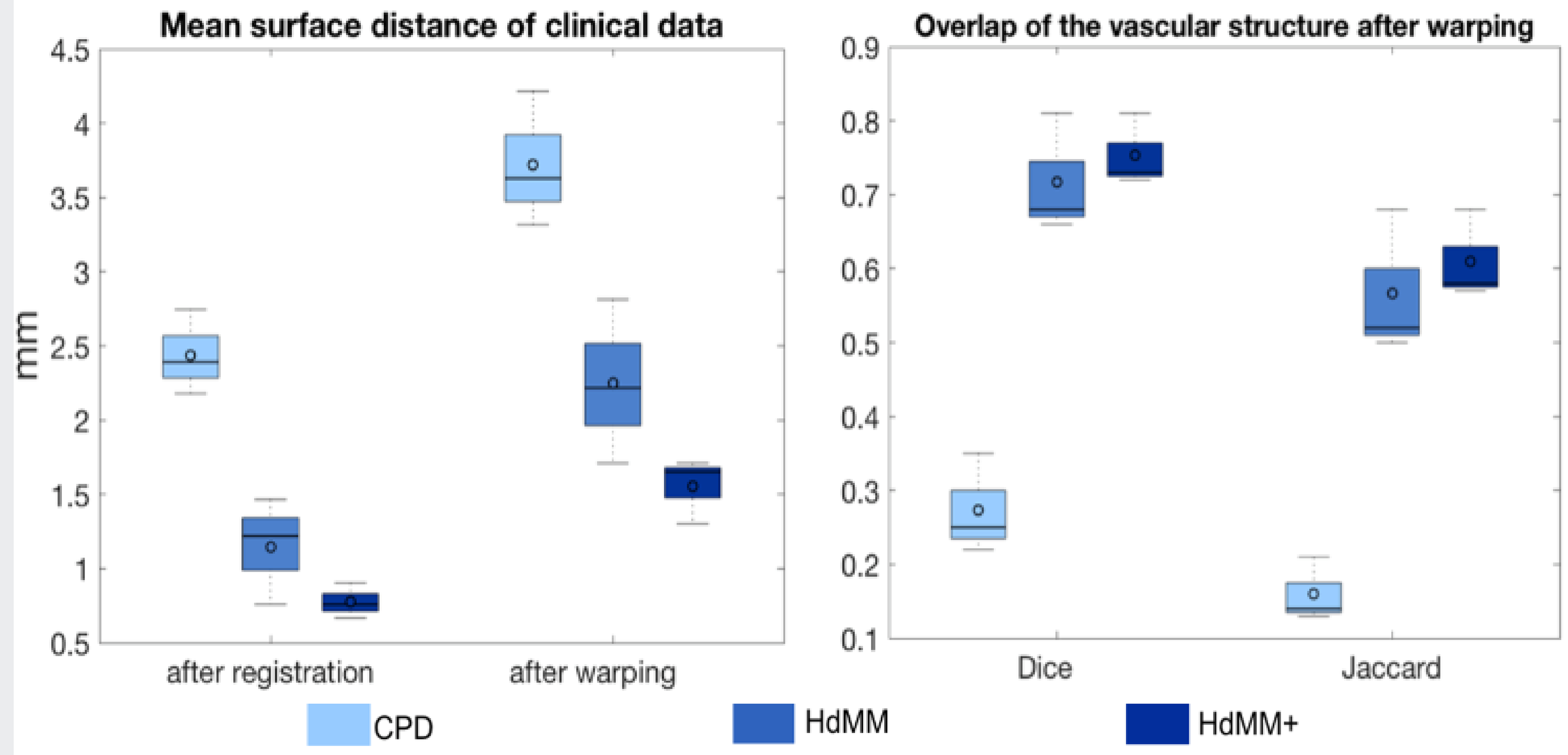
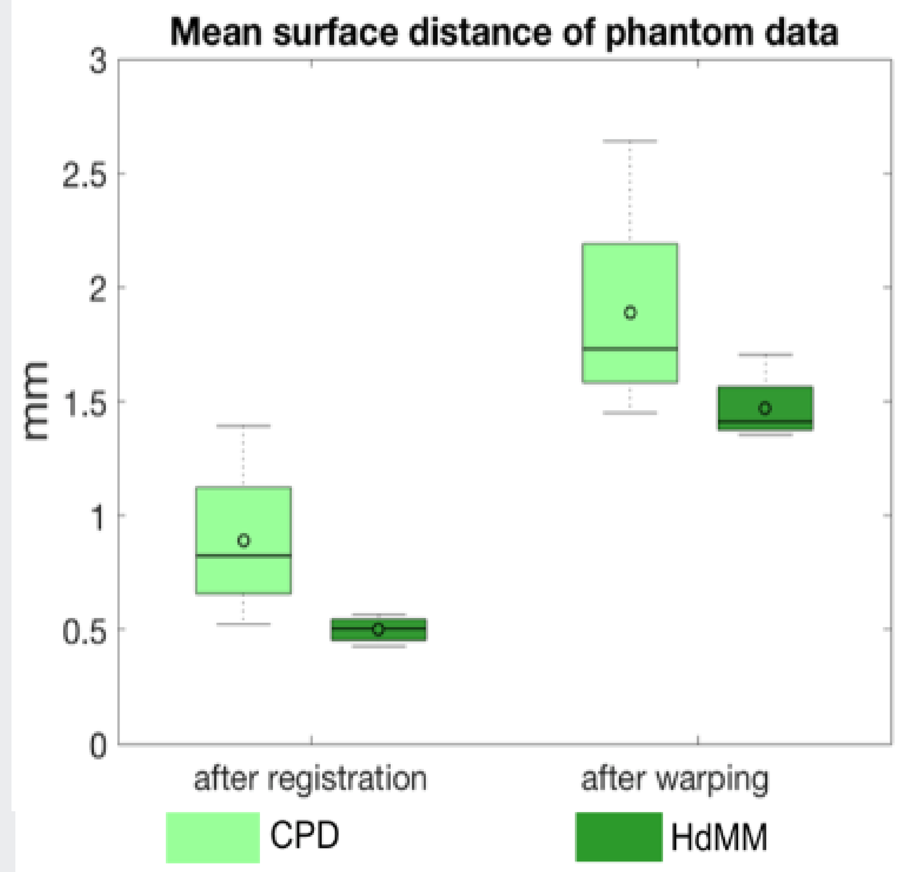


Figure 2: Pipeline of brain shift compensation framework using a hybrid mixture model

Results and Discussion

- **HdMM/HdMM+** vs. coherent point drift (**CPD**) [2] with phantom and clinical data
- Fixed hyper-parameters for fair comparison





HdMM:
- Reduces initial average MSD
  ➢ From 5.42 ± 1.07mm to 0.5±0.05mm (phantom)
  ➢ From 6.06 ± 0.68mm to 1.15±0.36mm(clinical)
- Outperforms CPD consistently (see **Figure 3**)
- Preserves fine structural details (see **Figure 4**)
- Further improvement achieved with HdMM+

Figure 3: Result of quantitative evaluation following registration phantom and clinical data.

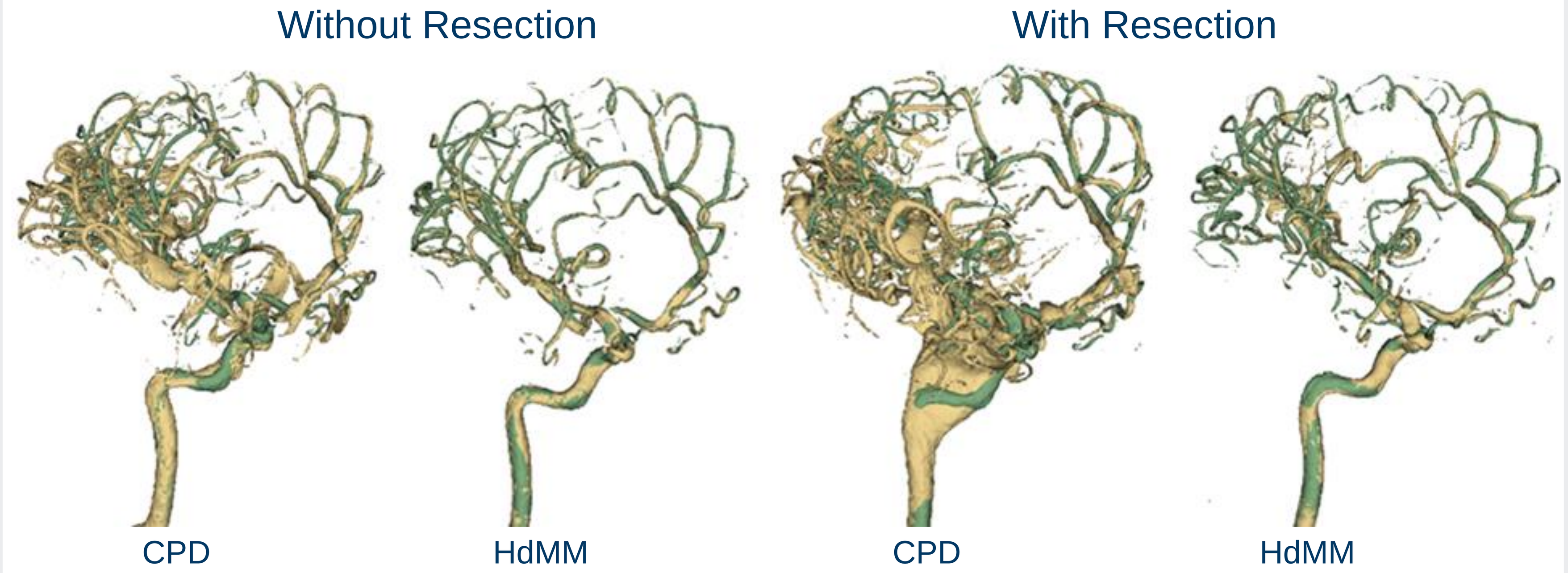


Figure 4: Overlay of 3D cerebral vasculature segmented from the registered preoperative (yellow) DSA image and the target intraoperative image (green).

Conclusion

- Investigated the use of C-Arm CT for intraoperative brain shift compensation
- Proposed a vessel centerline based registration framework
  1) represents centerlines as hybrid point sets
  2) inherently robust against outliers
  3) increases the registration accuracy significantly
- Clinical data evaluated for the first time

References

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