SVoRT: Iterative Transformer for Slice-to-Volume Registration in Fetal Brain MRI

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Introduction

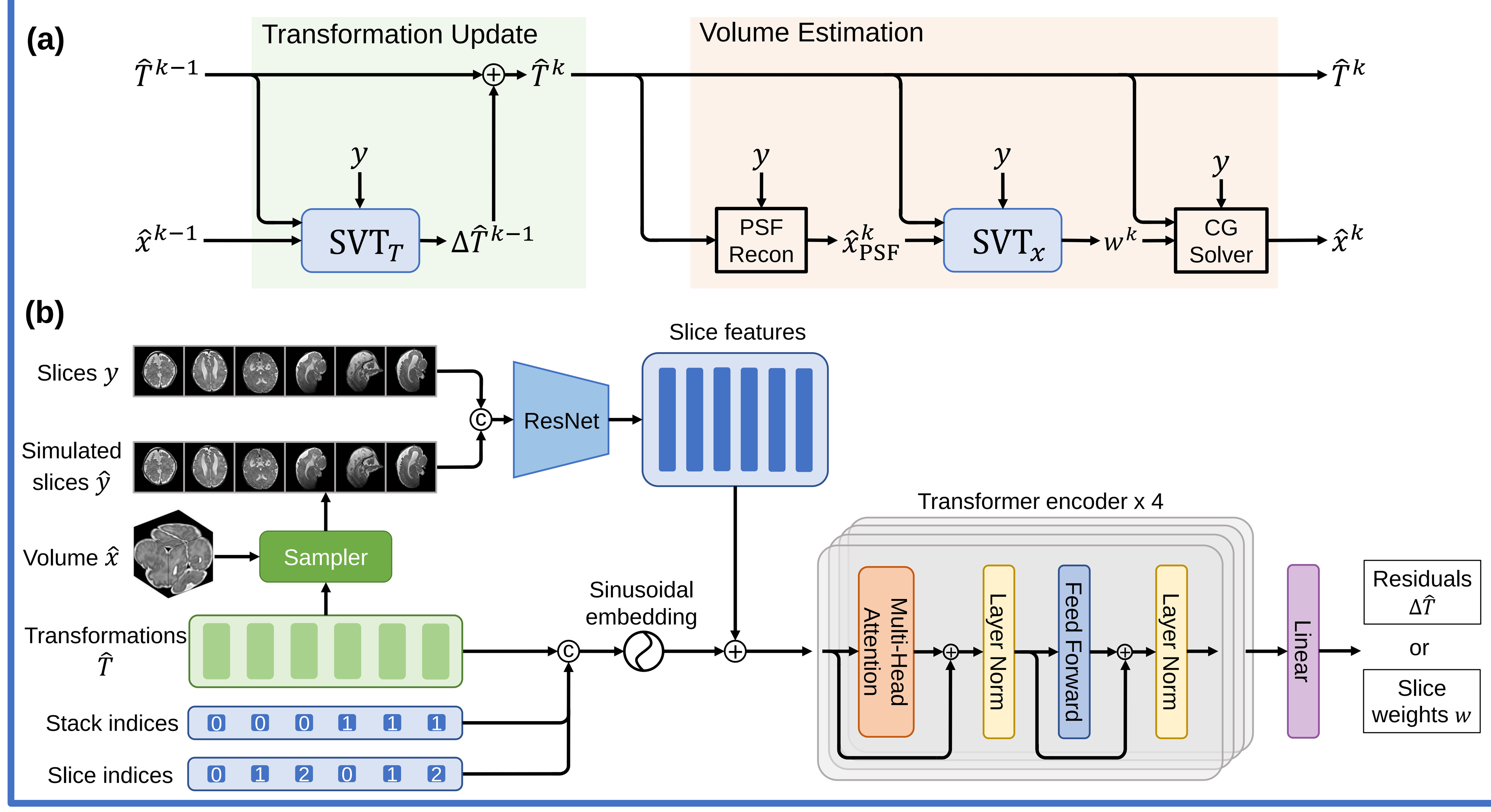
3D reconstruction in fetal brain MRI

- Fetal MRI is vulnerable to subject motion which leads to slice misalignment
- Volumetric reconstruction of fetal brains from multiple stacks of MR slices is sensitive to the initialization of slice-to-volume transformations

Ideas

- Model multiple stacks of slices as a sequence of images and predict rigid transformations of all the slices simultaneously by sharing information across different slices.
- Estimate the underlying 3D volume to provide context for localizing slices in 3D space.
- Update the slice transformations in an iterative manner to progressively improve accuracy.

Method



loss functions

- **Transformation Loss** $\mathcal{L}_T$: L2 loss between the predicted and target anchor points (center, the bottom right and left corners of a plane)
- **Volume Loss** $\mathcal{L}_x$: L1 loss between the estimated and ground truth volumes
- **Total Loss**: $\mathcal{L} = \sum_{k=1}^{K} \mathcal{L}_T^k + \lambda \sum_{k=1}^{K} \mathcal{L}_x^k$

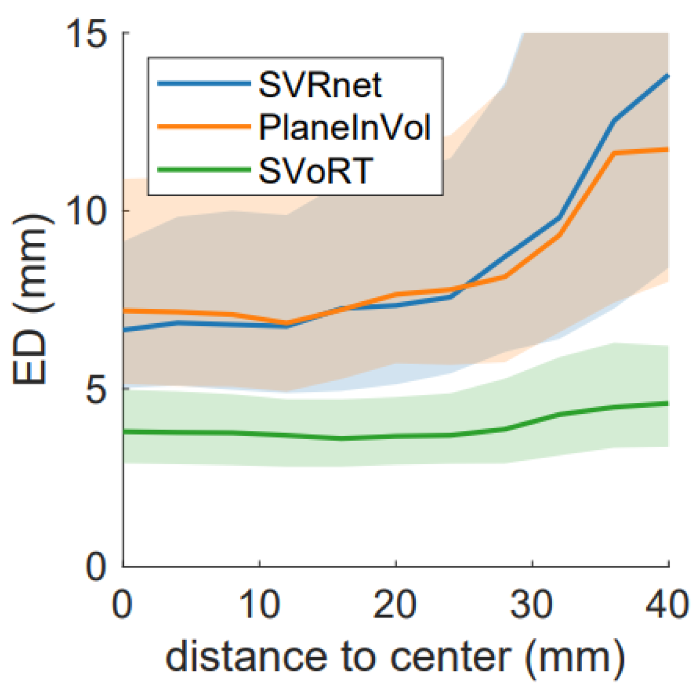
Dataset

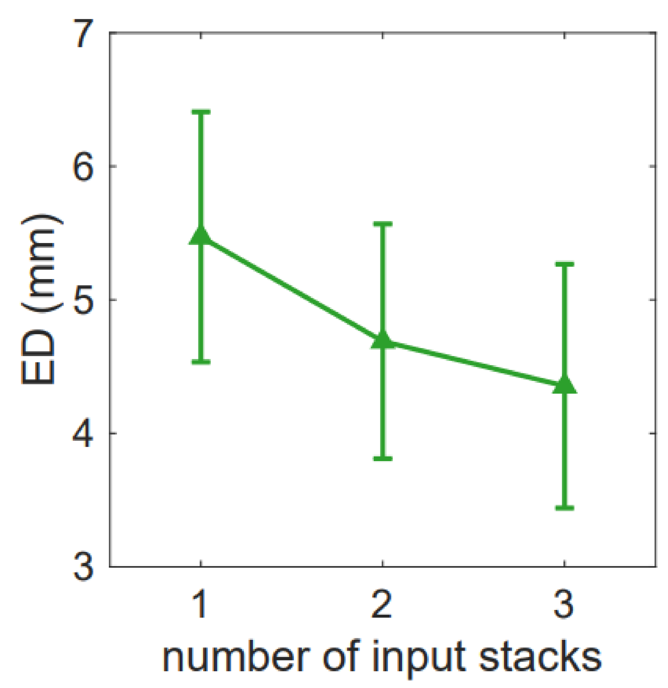
- Labeling the 3D position of a slice is impossible
- Simulate motion trajectories and sample 2D slices from high-quality MR volumes
- Data augmentation: MR artifacts, image noise, bias field, contrast jitter, etc.

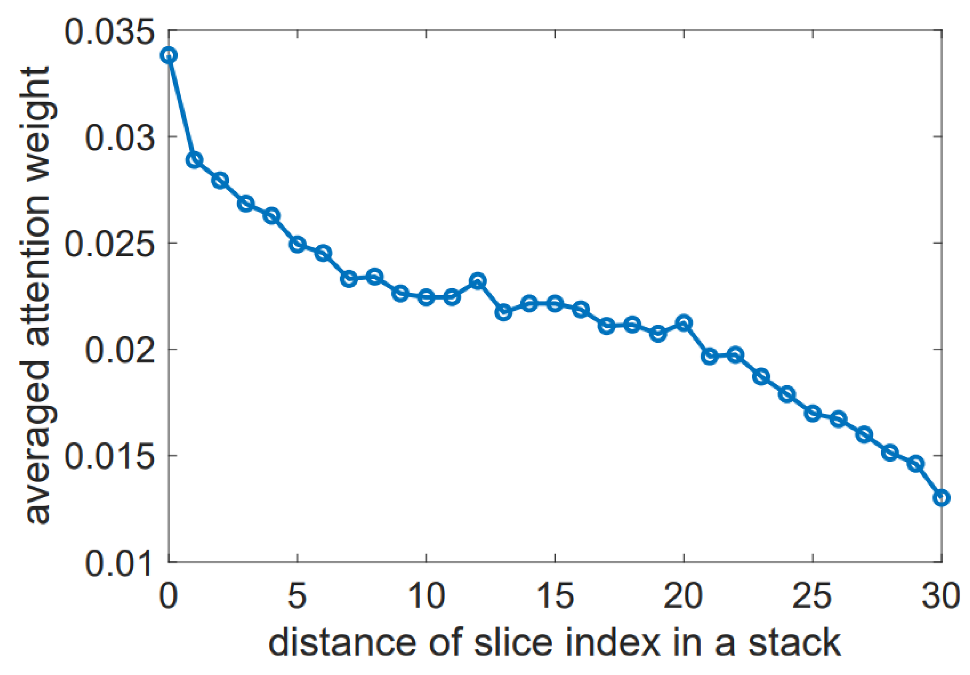
Results

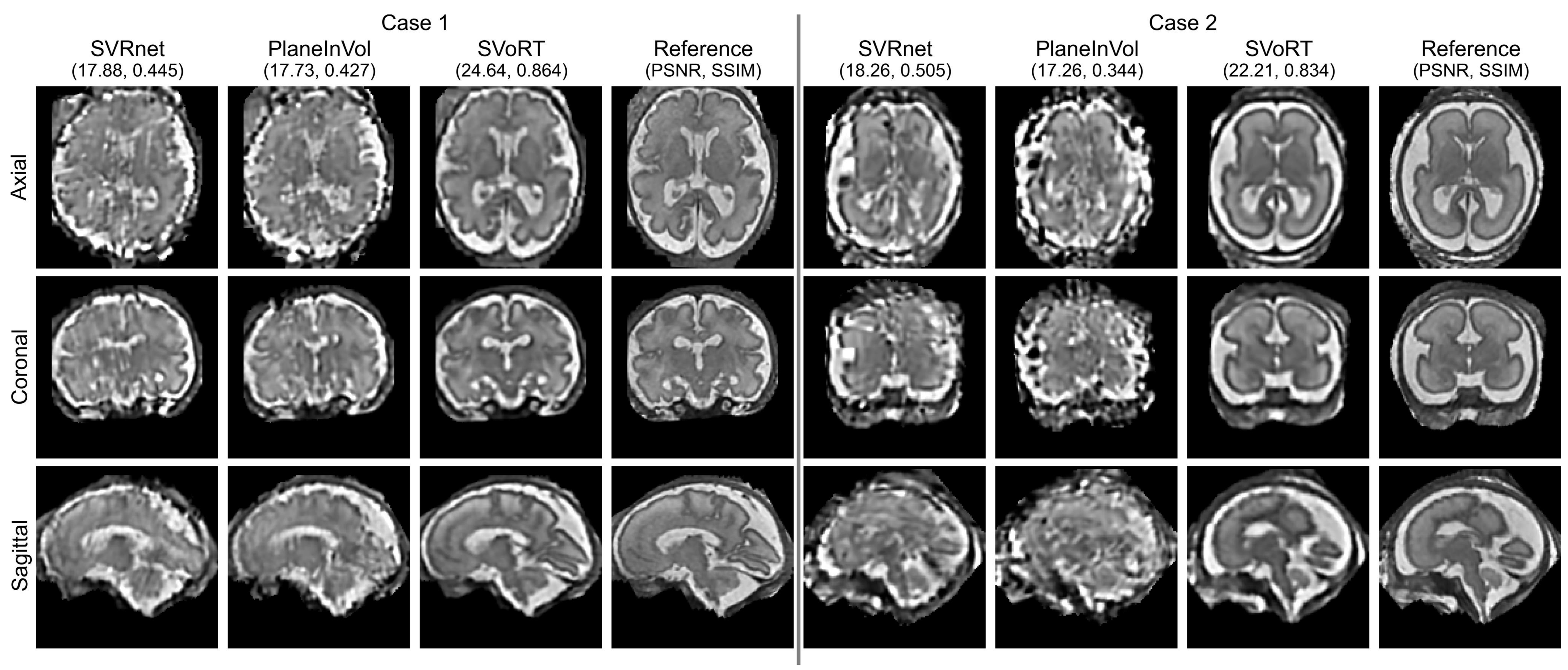
ED: Euclidean Distance, GD: Geodesic Distance

Method	transformation		slice		volume	
	ED (mm)	GD (rad)	PSNR	SSIM	PSNR	SSIM
SVRnet	12.82	0.256	20.53	0.823	19.54	0.669
PlaneInVol	12.49	0.244	19.96	0.808	18.98	0.615
SVoRT	**4.35**	**0.074**	**25.26**	**0.916**	**23.32**	**0.858**
w/o PE	9.97	0.194	21.44	0.841	20.74	0.742
w/o Vol	5.08	0.088	23.97	0.894	22.89	0.844
K=1	5.99	0.103	23.02	0.876	22.57	0.836
K=2	5.65	0.097	23.25	0.878	22.64	0.837









- Slices near the boundary of fetal brain are ambiguous.
  - SVoRT exploits the positional information of
  - It is able to register such cases better and lead to lower errors.
- The positional embedding serves as a prior for the relative locations of slices in a stack, which facilitates the registration
- The auxiliary volume estimation improves the accuracy of transformation prediction by providing 3D context.
- The iterative update enable the model to progressively refine the predictions.
- The attention weights verify that adjacent slices are highly correlated and the correlations are important for registration.

Conclusion

- By jointly processing the stacks of slices as a sequence, SVoRT registers each slice by utilizing context from other slices, resulting in lower registration error and better reconstruction quality.
- Evaluations show that SVoRT learns more robust features and provides a robust and accurate solution to the initialization of 3D fetal brain reconstruction.

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