Standard Plane Localisation in 3D Fetal Ultrasound Using Network with Geometric and Image Loss

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Introduction

Motivation:

- 3D ultrasound (US) of fetal brain enables assessment of fetal development and detection of growth abnormalities.
- This requires the identification of 2D standard scan planes in the 3D volumes.
- Manual plane detection is operator-dependent and time-consuming.

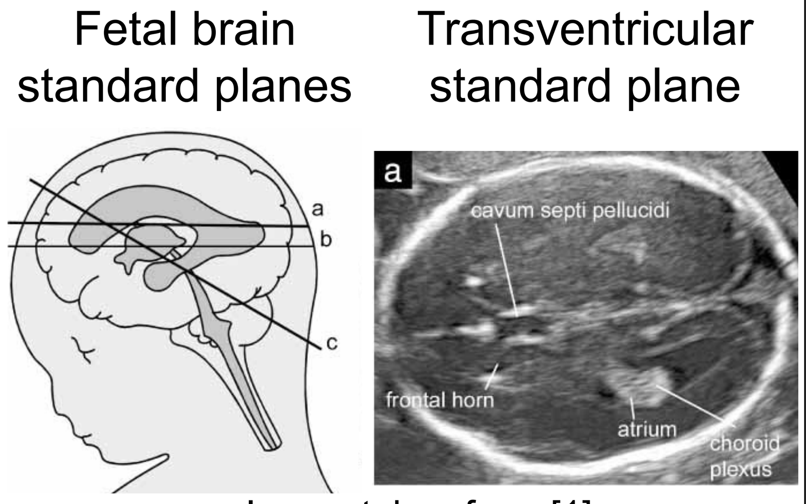


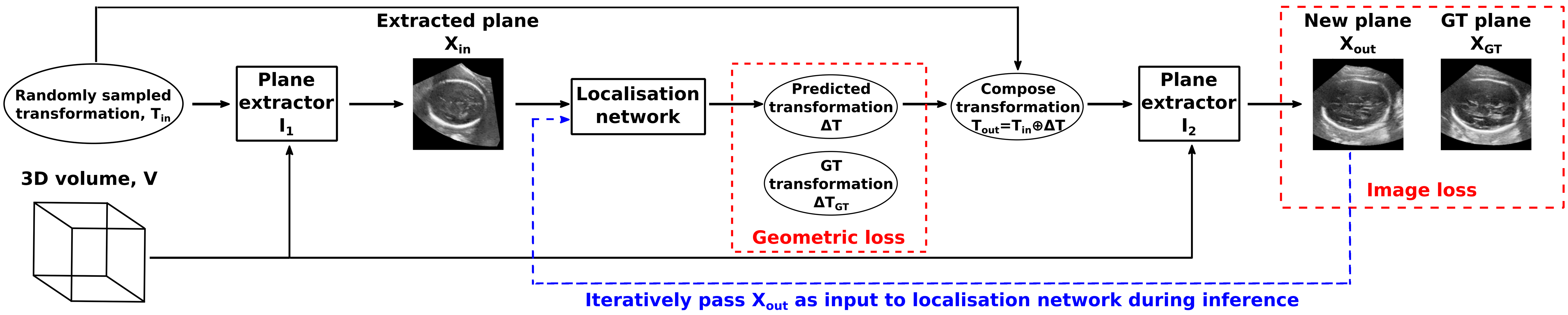
Image taken from [1]

Contributions:

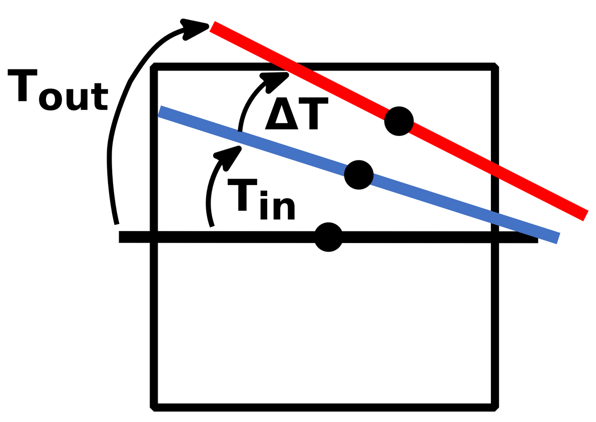
- Develop an automatic method for standard plane detection in 3D volumes by using a CNN to learn the relationship between a 2D plane image and the transformation parameters required to move that plane towards the corresponding standard plane.
- Explore two different training loss functions which exploit the geometric information and the image data of the extracted plane respectively

Method

Overall plane detection framework



Planes and Transformations



- Any plane is defined by a rigid transformation, w.r.t another plane.
- Black: Identity plane; Blue: Arbitrary plane; Red: GT plane
- Compose transformations: $T_{out} = T_{in} \oplus \Delta T$

Plane Extractor

- $X = I(V, T)$
- Extract 2D plane image X from 3D volume V given transformation T w.r.t. identity plane
- Implementation similar to spatial transformer network [2]

Localisation Network

- $\Delta T = \text{CNN}(X_{in})$
- A CNN regresses 3D transformation ΔT given 2D plane image X_{in}
- ΔT represented by translation $\boldsymbol{t}$ and quaternion $\boldsymbol{q}$
- Similar to pose estimation [3]

Network Training

Geometric loss: $L_{geom} = \|\Delta T_{GT} - \Delta T\|_2^2 = \|\boldsymbol{t}_{GT} - \boldsymbol{t}\|_2^2 + \left\|\boldsymbol{q}_{GT} - \frac{\boldsymbol{q}}{\|\boldsymbol{q}\|}\right\|_2^2$

Image loss: $L_{img} = \|X_{GT} - X_{out}\|_2^2$

Iterative Network Inference

$$\begin{aligned} &\text{for } i = 1{:}N \\ &\quad \Delta T_i = \text{CNN}(X_i) \\ &\quad T_{i+1} = T_i \oplus \Delta T_i \\ &\quad X_{i+1} = I(V, \Delta T_{i+1}) \end{aligned}$$

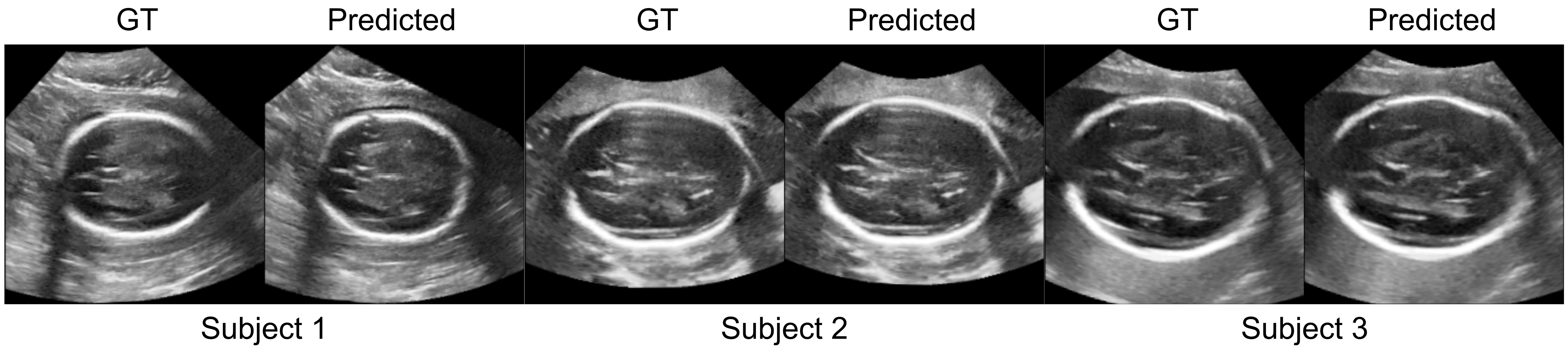
Results

- 72 3D ultrasound volumes of fetal brain with manual transventricular planes.
- 51 training, 21 testing
- Evaluation metrics:
  δx: Distance between plane centres
  $\delta\theta$: Angle between plane normals
  PSNR: Peak signal-to-noise ratio
  SSIM: Structural similarity

Evaluation of plane detection method using different training losses

Method	δx (mm)	$\delta\theta$ (°)	PSNR	SSIM
L_{geom}	6.51 ± 4.86	14.1 ± 8.2	15.6 ± 2.0	0.393 ± 0.082
L_{img}	10.23 ± 16.08	16.6 ± 8.2	15.1 ± 2.3	0.372 ± 0.090
$L_{geom} + L_{img}$	5.85 ± 3.95	12.9 ± 7.0	15.7 ± 2.1	0.400 ± 0.101
$L_{geom} + L_{img} +$ Orthogonal input planes	$\mathbf{3.45 \pm 1.73}$	$\mathbf{12.4 \pm 12.8}$	$\mathbf{16.5 \pm 1.9}$	$\mathbf{0.418 \pm 0.080}$

Visualisation of ground truth and detected transventricular standard planes



Conclusion

We presented a new method for standard plane detection in 3D fetal US by using a CNN to regress transformations iteratively. We use a combined training loss that accounts for both geometric and image information to improve detection accuracy. As future work, we are exploring other training loss functions and multiple planes detection.

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[1] Sonographic examination of the fetal central nervous system: guidelines for performing the 'basic examination' and the 'fetal neurosonogram', *Ultrasound Obstet Gynecol*, 29: 109-116

[2] Jaderberg *et al*. Spatial transformer networks. *NIPS*, 2015

[3] Kendall *et al*. PoseNet: A convolutional network for real-time 6-DOF camera relocalization. *ICCV*, 2015