Towards Realistic Ultrasound Fetal Brain Imaging Synthesis

Medical Imaging with Deep Learning 2023 (MIDL2023)

2nd of May 2023

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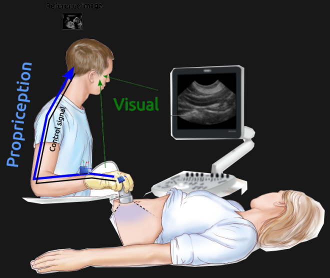
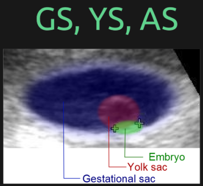
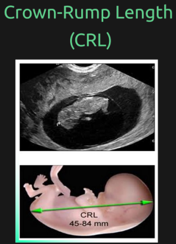
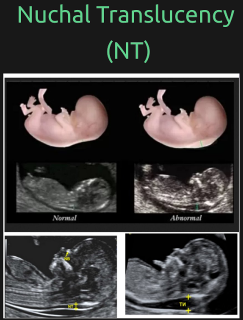
Dating US scan (12-week scan)

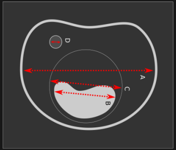
Clinical background











A: Gestational sac (GS),
B: Crown-rump length (CRL),
C: Amniotic sac (AS),
D: Yolk sac (YS)

[Wright-Gilbertson M. 2014 in PhD thesis; https://en.wikipedia.org/wiki/Gestational_age; National-Health-Service 2021. Screening for down's syndrome, edwards' syndrome and patau's syndrome. https://www.nhs.uk/pregnancy/your-pregnancy-care]

Challenges in Ultrasound biometric measurements

Clinical background

- intra-view variability of imaging equipment and inter-observer variability of sonographer skills,
- availability of expert clinicians or trained technicians to collect, to select, to classify and to validate regions of interest,
- the cost of acquisition of clinical data as it requires expensive imaging equipment and experts for data collection and validation
- the insufficient and limited amount of clinical data,
- data accessibility due to patient privacy or protection of personal health information,

[Sciortino et al. in Computers in Biology and Medicine 2017 https://doi.org/10.1016/j.compbiomed.2017.01.008; He et al. in Front. Med. 2021 https://doi.org/10.3389/fmed.2021.729978 Thomas L. A. van den Heuvel et al. https://hc18.grand-challenge.org/ Burgos-Artizzu, X et al. (2020). FETAL PLANES DB: Common maternal-fetal ultrasound images [Data set]. In Nature Scientific Reports (1.0, Vol. 10, p. 10200). Zenodo. https://doi.org/10.5281/zenodo.3904280]

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Research aims

- Investigate and implement GAN-based and Diffusion-based models to synthetise realistic high-quality fetal ultrasound images

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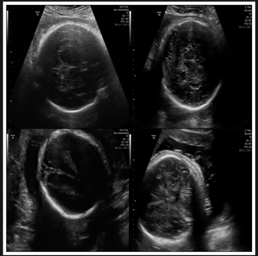
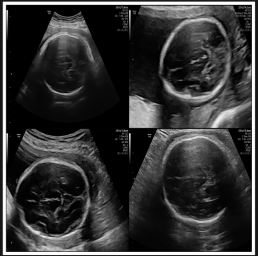
TransThalamic

Datasets of Fetal Brain Ultrasound Images



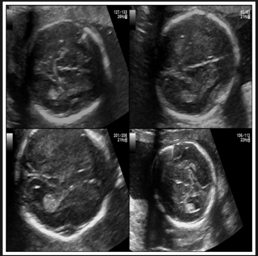
shape [1072,1,512,512]

Voluson E6



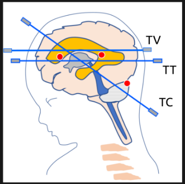
shape [123,1,512,512]

Voluson S10



shape [360,1,512,512]

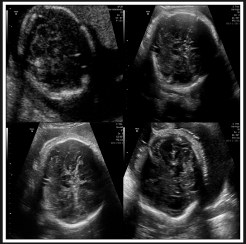
Aloka



[Burgos-Artizzu, X et al. (2020). FETAL PLANES DB: Common maternal-fetal ultrasound images [Data set]. In Nature Scientific Reports (1.0, Vol. 10, p. 10200). Zenodo. https://doi.org/10.5281/zenodo.3904280]

TransCerebellum Plain

Datasets of Fetal Brain Ultrasound Images

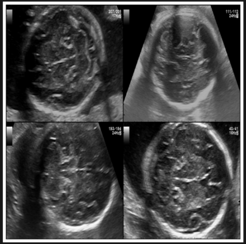


shape [492,1,512,512]

Voluson E6

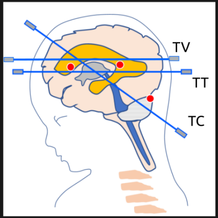
shape [68,1,512,512]

Voluson S10



shape [134,1,512,512]

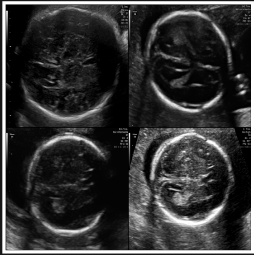
Aloka



[Burgos-Artizzu, X et al. (2020). FETAL PLANES DB: Common maternal-fetal ultrasound images [Data set]. In Nature Scientific Reports (1.0, Vol. 10, p. 10200). Zenodo. https://doi.org/10.5281/zenodo.3904280]

TransVentricular Plane

Datasets of Fetal Brain Ultrasound Images

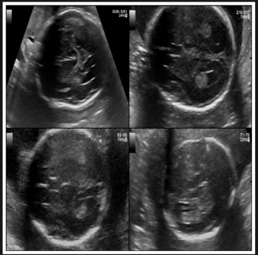


shape [408,1,512,512]

Voluson E6

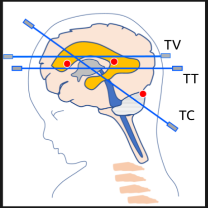
shape [59,1,512,512]

Voluson S10



shape [112,1,512,512]

Aloka



[Burgos-Artizzu, X et al. (2020). FETAL PLANES DB: Common maternal-fetal ultrasound images [Data set]. In Nature Scientific Reports (1.0, Vol. 10, p. 10200). Zenodo. https://doi.org/10.5281/zenodo.3904280]

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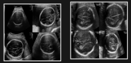
Machine Learning Pipeline

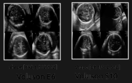
Fetal US imaging synthesis with GANs

1. Small datasets
(1K to 10K)

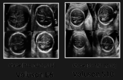
Trans-Thalamic

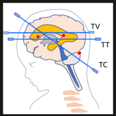


Trans-Cerebellum

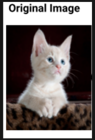


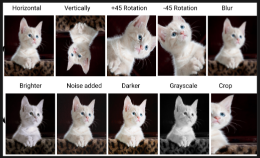
Trans-Ventricular



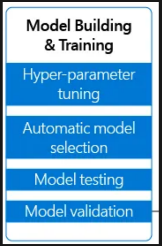


2. Image processing
(anonymisation,
and augmentations.)





3. ML pipeline
(Generative models,
tunning, training,
testing/validation,
deployment, etc.)



4. Quality assessment of US image Synthesis
(Visual Turing Test,
FID scores, etc.)

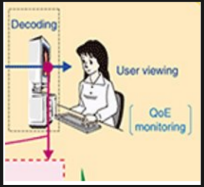


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Image Quality Assessment

Methods

Quality of synthesised images are evaluated with Fréchet inception distance (FID), measuring the distance between distributions of synthesised and original images (Heusel et al., 2017). The lower the FID number is, the more similar the synthesised images are to the original ones. FID metric showed to work well for fetal head ultrasound images compared to other metrics (Bautista et al., 2022).

Diffusion-Super-Resolution-GAN (DSR-GAN)

Methods

We use a Denoising Diffusion Probabilistic Model (DDPM) (Ho et al., 2020) followed by a Super-Resolution-GAN (Ledig et al., 2017). To reduce computation time, we finetune a pretrained DDPM to produce 128x128 pixel images and then scale them up to 256x256 using SRGAN. After the DDPM and before SRGAN, histogram matching (Castleman, 1996) is applied to ensure that the colour distribution of the synthetic images matches the colour distribution of the real images.

Transformer-based-GAN

Methods

We use StyleSwin model, which features Swin Transformer layers designed to capture high quality details of the original images while simultaneously reducing memory usage, enabling synthesized images of higher resolutions (Zhang et al., 2022). Differentiable data augmentation (DiffAug) and adaptive pseudo augmentation (APA) are implemented to combat discriminator over-fitting due to limited data and ensure stability in training process (Zhao et al., 2020; Jiang et al., 2021).

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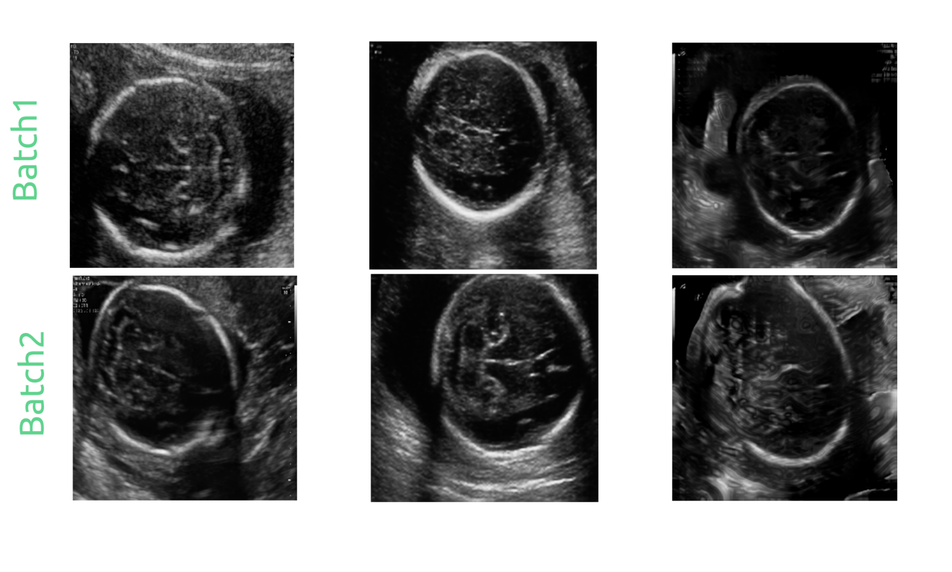
Experiments: Design and results



Experiments: Design and results

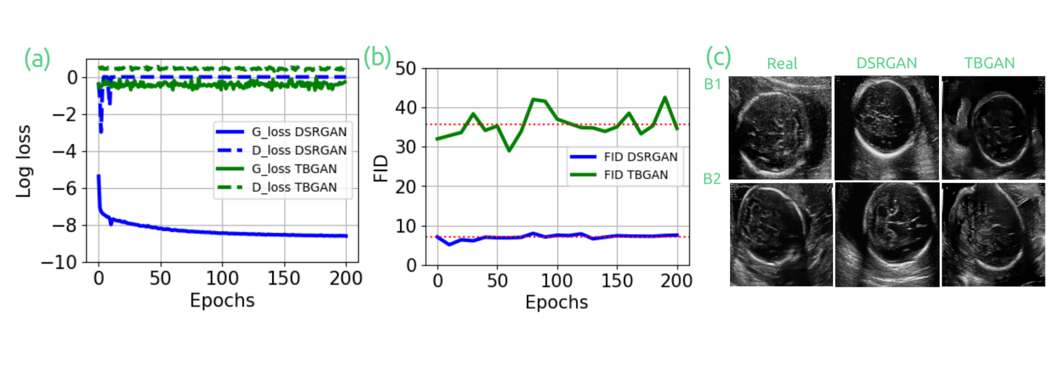


Figure: Results from Diffusion-Super-resolution-GAN (DSR-GAN) and transformerbased-GAN (TB-GAN): (a) Training losses for Generator and Discriminator networks, (b) FID scores, and (c) 256x256 pixel size trans-cerebellum images of two randomised batches (B1, B2) of real and synthesised (DSR-GAN and TB-GAN)

Fetal imaging synthesis with difussion models

Future work

a

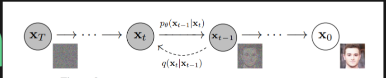


Figure 2: The directed graphical model considered in this work.

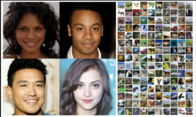


Figure 1: Generated samples on CelebA-HQ 256 × 256 (left) and unconditional CIFAR10 (right)

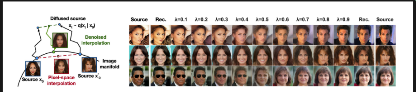


Figure 8: Interpolations of CelebA-HQ 256x256 images with 500 timesteps of diffusion.

b

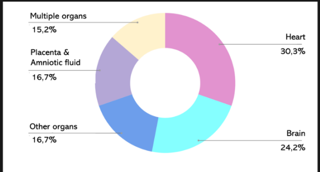
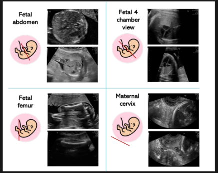
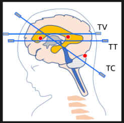
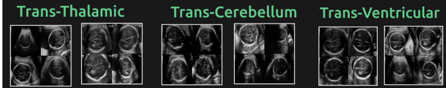


Fig. 7. Number of papers surveyed in Sec. IV according to the anatomical structure.



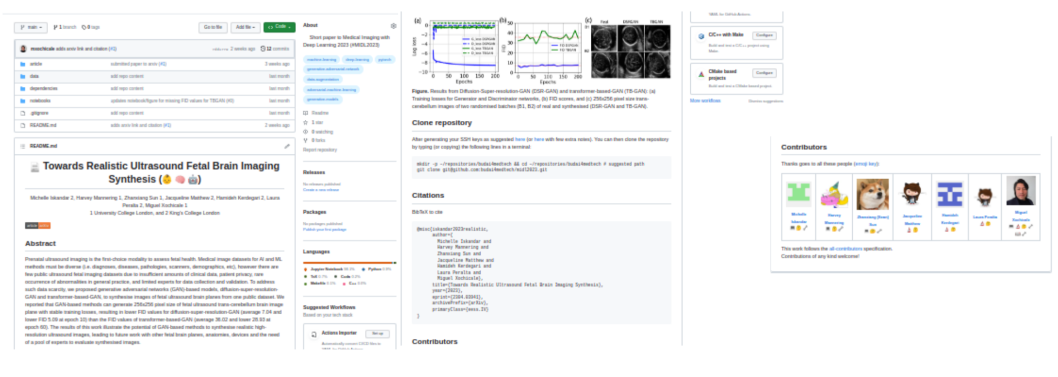
c





[(a) Ho et al. 2020 "Denoising Diffusion Probabilistic Models" https://arxiv.org/abs/2006.11239 (b) Fiorentino et al. 2022 "A Review on Deep-Learning Algorithms for Fetal Ultrasound-Image Analysis" https://arxiv.org/abs/2201.12260 (c) Burgos-Artizzu, X et al. (2020). FETAL PLANES DB: Common maternal-fetal ultrasound images [Data set]. In Nature Scientific Reports (1.0, Vol. 10, p. 10200). Zenodo. https://doi.org/10.5281/zenodo.3904280]

GitHub repository: github.com/budai4medtech/midl2023



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