Fetal Pose Estimation in Volumetric MRI using a 3D Convolution Neural Network

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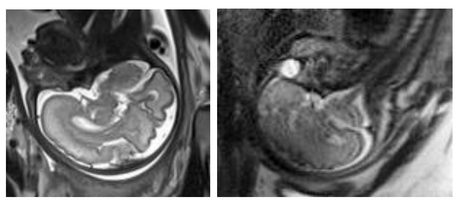
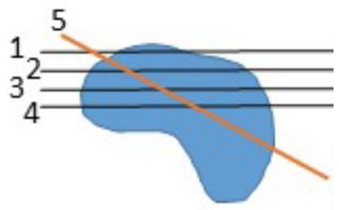
Motivation

- Fetal MRI
- Fetal motion is unpredictable and rapid
- Motion artifacts

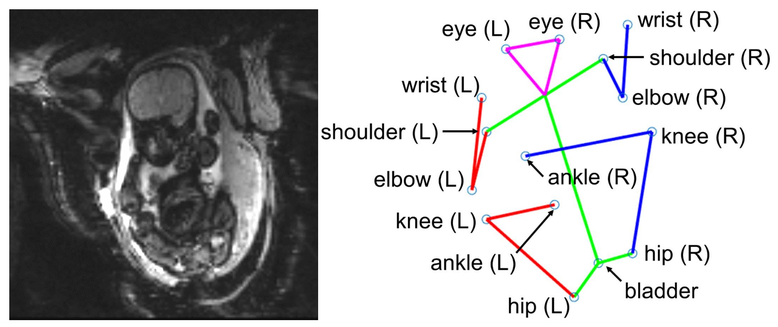




Final goal:
Building a fetal motion model for prospective motion correction in fetal MRI

This work:
Fetal pose estimation from EPI volume

Keypoint representation



Methods

Algorithm:

1.Generate keypoint heatmap from MRI

$$\hat{H} = [\hat{H}_1, \dots, \hat{H}_J] = G(I)$$

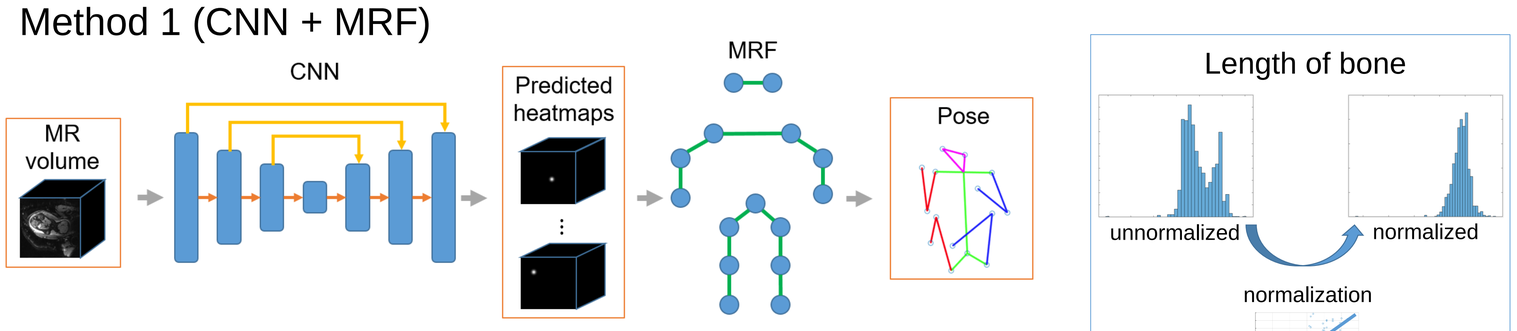
2.Infer keypoint location from heatmap

$$\hat{H} \to \hat{x} = [\hat{x}_1, \dots, \hat{x}_J]$$

Notations

I	image
H_i	Heatmap of keypoint i
x_i	Location of keypoint i
J	Number of keypoints
B	The set of keypoint connections
$\mu_{i,j}, \sigma_{i,j}^2$	Mean and variance of normalized distance between keypoint i and j
r_{GA}	Normalization factor
G, D	Generator and Discriminator

Method 1 (CNN + MRF)



Minimize energy function of MRF

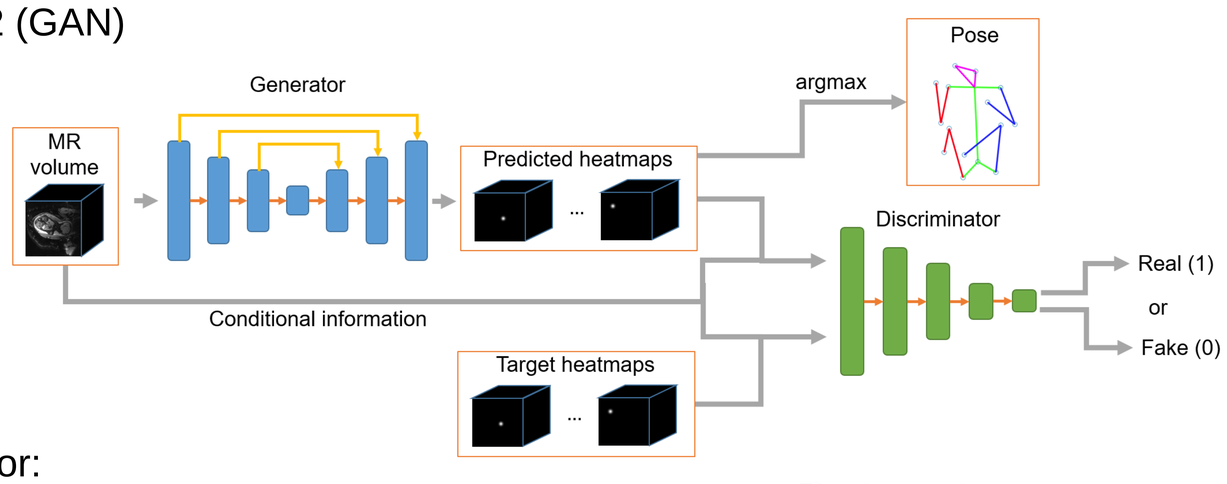
$$\hat{x} = \underset{x \in X_1 \times \cdots \times X_J}{\operatorname{argmin}} E(x) \qquad X_i = \{\text{top 3 peaks in } \hat{H}_i\}$$

$$E(x) = \sum_{i=1}^{J} f_i(x_i) + \alpha \sum_{(i,j) \in B} g_{i,j}(x_i, x_j)$$

$$f_i(x_i) = -\log \hat{H}_i(x_i)$$

$$g_{i,j}(x_i, x_j) = -\frac{(\|x_i - x_j\|_2 / r_{\mathrm{GA}} - \mu_{i,j})^2}{\sigma_{i,j}^2}$$

Method 2 (GAN)



Generator:
- Generate heatmaps that can fool the discriminator

Discriminator:
- Distinguish between generated and ground truth heatmaps
- Model possible fetal pose configuration implicitly

Adversarial training

$$G^* = \underset{G}{\operatorname{argmin}} L_G \,, D^* = \underset{D}{\operatorname{argmin}} L_D$$

$$L_G = \|G(I) - H\|_2^2 + \lambda \|D([G(I), I]) - 1\|_2^2$$

$$L_D = \|D([G(I), I])\|_2^2 + \|D([H, I]) - 1\|_2^2$$

Dataset

Multislice EPI time series

Size of dataset:
- ~20k frames
- 77 subjects
- train: 49, val: 14, test: 14

Resolution: 3mm x 3mm x 3mm
TR: ~3.5 s / TE: 32 ms

Data augmentation:
- Flipping
- Rotation
- Intensity scaling

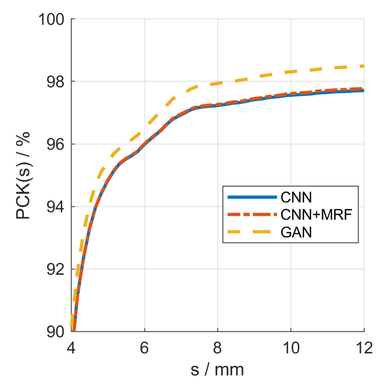
Results

Percentage of Correct Keypoints (PCK)

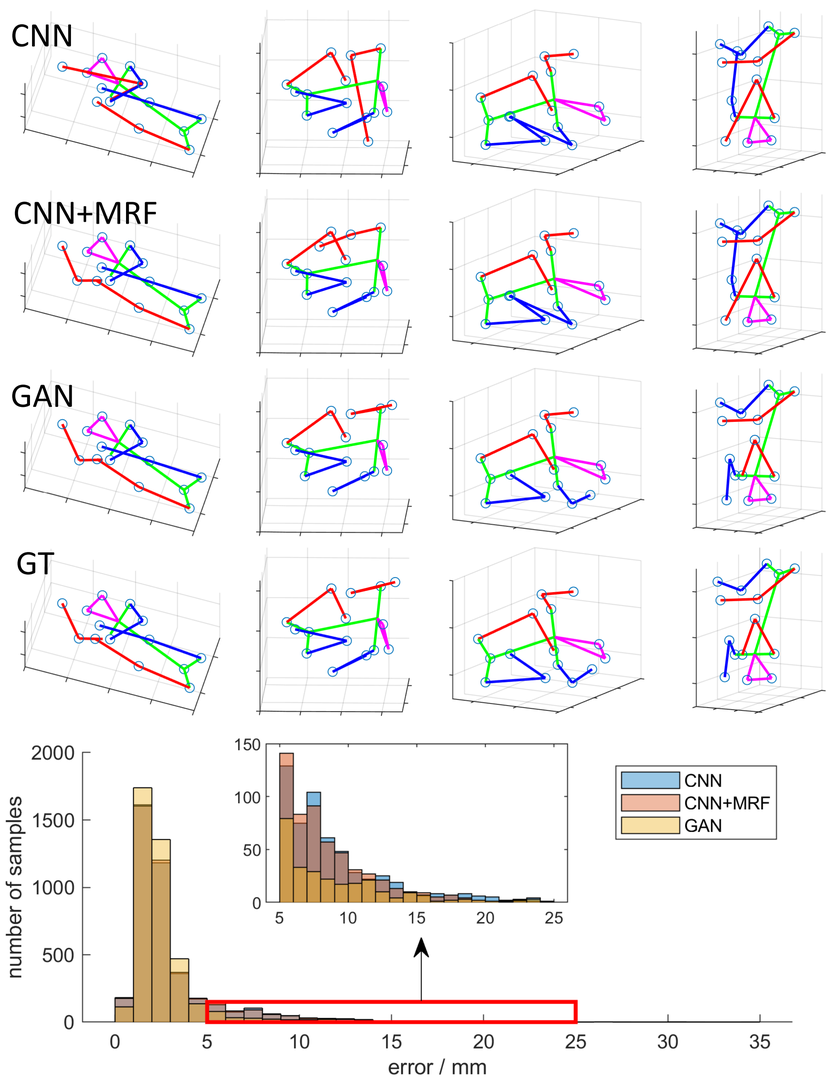
$$PCK(s) = \frac{\#\text{ sample with error} < s}{\#\text{ sample}} \times 100\%$$

	PCK@5mm
CNN	94.8%
CNN+MRF	95.0%
GAN	95.4%

	PCK@10mm
CNN	97.5%
CNN+MRF	97.7%
GAN	98.3%



	CNN	CNN+MRF	GAN
Mean error (mm)	3.12	3.02	2.64
std (mm)	3.09	2.69	2.33
Median error (mm)	2.27	2.27	2.26
Time (ms / volume)	297	648	297



Conclusion

We propose methods for fetal pose estimation in volumetric MRI, potentially enabling low latency tracking of fetal pose for prospective motion correction.

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