Deep Learning Based Spine Centerline Extraction in Fetal Ultrasound

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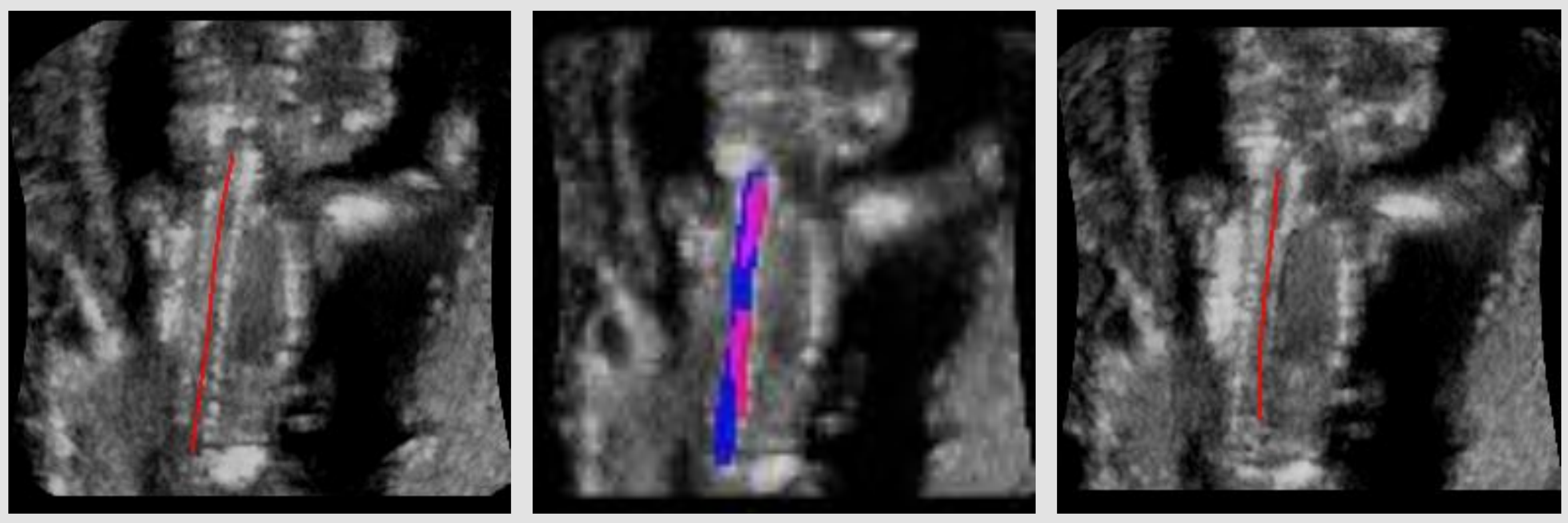
Abstract

Ultrasound is widely used for fetal screening. It allows for detecting abnormalities at an early gestational age, while being time and cost effective with no known adverse effects. Searching for optimal ultrasound planes for these investigations is a demanding and time-consuming task. Here we describe a method for automatically detecting the spine centerline in 3D fetal ultrasound images. We propose a two-stage approach combining deep learning and classic image processing techniques. First, we segment the spine using a deep learning approach. The resulting probability map is used as input for a tracing algorithm. The result is a sequence of points describing the spine centerline. This line can be used for measuring the spinal length and for generating view planes for the investigation of anomalies.



(a) (b) (c)

Example of a test case: (a) ground truth annotation of the spine centerline, (b) thickened ground truth centerline (blue) and FNET segmentation result (red), (c) traced centerline resulting from the FNET probability map. The images (a) and (c) are a flattened view following the annotated line and are therefore not a slice of the original dataset, whereas (b) is an image slice containing most of the thickened ground truth centerline.

Introduction

Fetal screening with ultrasound allows for detecting abnormalities at an early gestational age, such that therapeutically suitable interventions can be planned and performed as required. Currently, there is a trend towards using 3D ultrasound, since a 3D image contains much more spatial information about the location of several organs with respect to each other and it allows for a variety of workflow optimizations. One of the main fetal scans takes place in the second trimester with recommended standard measurements [1]. The localization of the abdominal cross-sectional plane with the corresponding measurement of the abdominal circumference is described in [2]. Another structure that is investigated is the fetal spine. First, the length of the spine provides an insight into the fetal growth. Second, a variety of spinal anomalies can be detected in 3D fetal ultrasound scans [3]. State-of-the-art fetal ultrasound examination is based on a manual search for optimal view planes, which is a demanding and time-consuming task. Hence an automatic detection of the spine centerline would be of huge benefit, since it allows for an automatic generation of view planes which are well-suited for the investigation of spinal anomalies.

Materials and Methods

Data: 400 3D fetal ultrasound scans, gestational age 15 - 41 weeks (mean 26 weeks), in-plane voxel size 0.12 - 0.51 mm (mean 0.25 mm), slice thickness 0.3 – 0.93 mm (mean 0.51 mm). Spinal canal is manually annotated by 5 – 10 landmarks, connected by straight lines. Label masks are created by dilating with different radii (Fig. (b) blue).

Preprocessing: Isotropic resampling, voxel size depending on gestational age [6]: 0.4 mm (14 weeks) – 1.6 mm (42 weeks).

Spine probability map generation: F-NET [4]: fully convolutional network architecture that processes images at multiple scales and different fields of view. Standard parameter settings, except reduction of resolution levels from 4 to 3. An example result can be seen in Fig. (b) red.

Centerline tracing: Probability map is used as input for a tracing algorithm [5] yielding a sequence of spine centerline points, connected by line segments (Fig. (c)).

Evaluation metrics:
Dice coefficient: for evaluating the F-NET segmentation result.
False negative rate (FNR): fraction of the ground truth line which is not contained in the detected spine centerline.
Mean distance: distance of the detected spine centerline to the ground truth line.

Experiment set-up: five-fold cross validation.

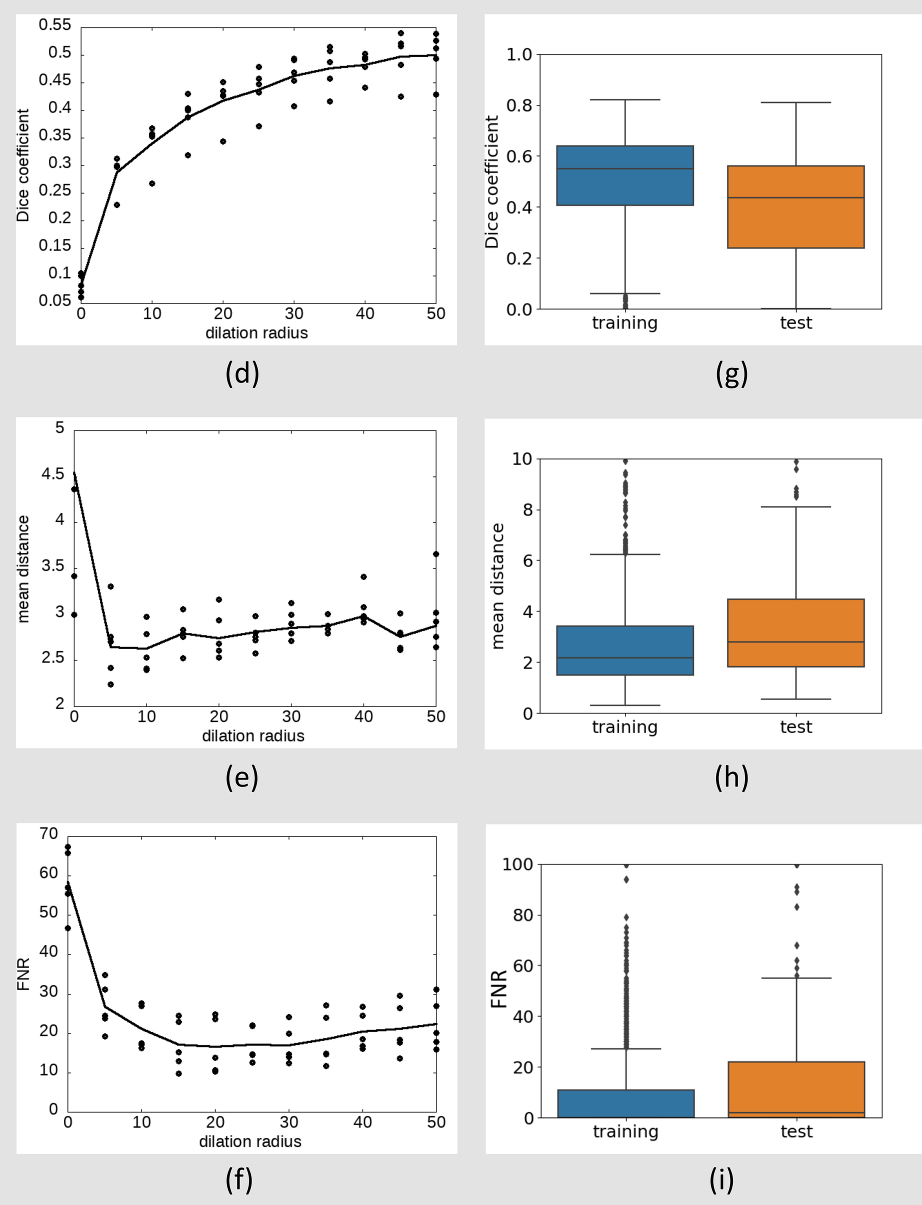
Discussion

- Dice coefficient is increasing with growing dilation radius (Fig. (d)), but Dice is not well-suited for elongated structures.
- FNR and mean distance show a drastic decrease when the dilation radius goes from 0 to 5, and then stay nearly constant, where the FNR shows a minimum at 15 (Figs. (e),(f)) → dilation radius 15 selected for further investigations.
- All three measures are better for training than test (Figs. (g),(h),(i)), however, these effects are not very pronounced, indicating only a slight over-fitting.
- In half of the test cases the FNR is below 3 (Fig. (i)), meaning that at least 97% of the annotated ground truth spine line is found.

Conclusion

Our presented fully automatic two-stage approach for detecting the spine centerline in 3D fetal ultrasound yields promising results. The resulting spine centerline can be used for selecting dedicated view planes. They can be presented to the physician for investigating the spine, for instance for measuring the length or detecting anomalies. An estimation of the spinal length can even automatically be proposed by calculating the length of the detected centerline. Furthermore, a flex view could be generated showing the spine and the outgoing ribs in a straightened view for further investigation.

Results



Dice coefficient (d), mean distance (e) and FNR (f) as a function of the dilation radius. The points indicate the values for the five folds, the line is the mean over all folds.
Box-whisker-plots for the Dice coefficient (g), mean distance (h) and FNR (i) for a dilation radius of 15.

References

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