Direct estimation of fetal head circumference from ultrasound images based on regression CNN

Jing Zhang[1] jing.zhang@insa-rouen.fr
Caroline Petitjean[1] caroline.petitjean@univ-rouen.fr
Pierre Lopez[1] pierre.lopez@etu.univ-rouen.fr
Samia Ainouz[1] samia.ainouz@insa-rouen.fr

[1] Normandie Université, INSA Rouen, Université de Rouen, LITIS Lab

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Background

Head Circumference (HC)–One of fetal biometrics.
The HC can be used to estimate the gestational age and monitor growth of the fetus.

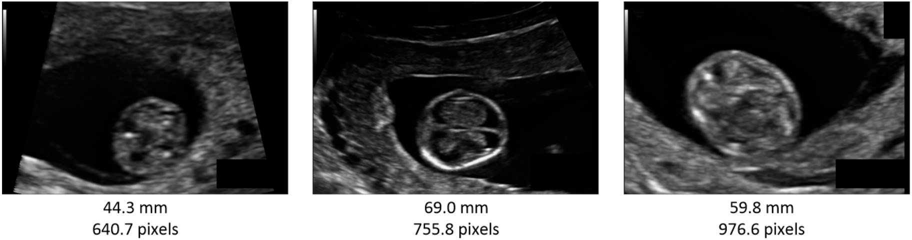
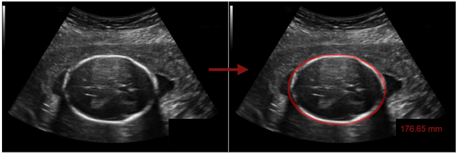


Figure: Ultrasound images of fetal head[1],corresponding head circumference (HC) is displayed in millimeters and pixels.

[1]Dataset is public in https://hc18.grand-challenge.org/

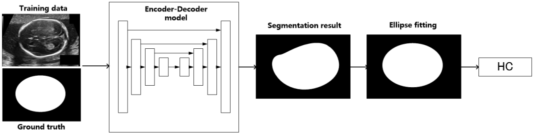
Related works



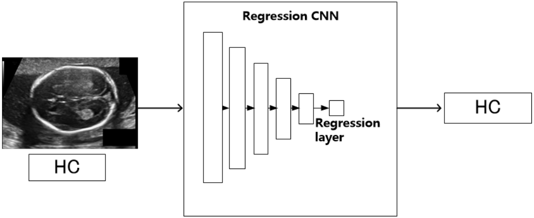
- Manually annotated by an experienced sonographer and a medical researcher(van den Heuvel et al., 2018).
- Automated measurements based on segmentation:
  - Image processing algorithm (Lu, Wei, Jinglu Tan, and Randall Floyd, 2005)
  - Machine learning technique (Feature extraction+ellipse fitting) (van den Heuvel et al.,2018).
  - Deep learning technique (CNN based model to segment and ellipse fitting(Kim et al., 2019)).

Our method

State of the art:



Our method:



Benefits of our method:

- Doesn't need Ground truth images, no segmentation errors.
- Can estimate the HC value directly by a regression CNN model.

Regression CNN architecture

2 changes from classic CNN to regression CNN model:

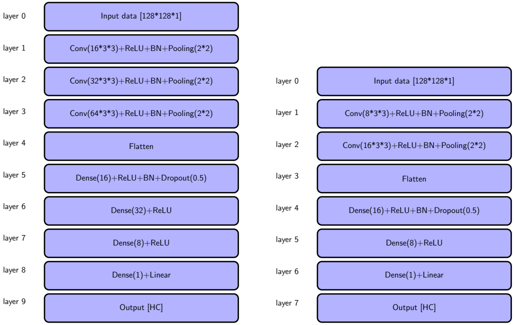
- Last layer: linear regression layer.
- Loss function: regression loss.
  - $MAE = \frac{1}{n}\sum_{i=1}^{n}|p_i - g_i|$
  - $MSE = \frac{1}{n}\sum_{i=1}^{n}(p_i - g_i)^2$
  - $HL = \begin{cases} \dfrac{1}{n}\displaystyle\sum_{i=1}^{n}\dfrac{1}{2}(p_i - g_i)^2, & \text{for} \quad |p_i - g_i| < \delta \\ \dfrac{1}{n}\displaystyle\sum_{i=1}^{n}\delta * (|p_i - g_i| - \dfrac{\delta}{2}), & \text{otherwise} \end{cases}$

Note: predicted (resp. ground truth) values are denoted p_i(resp. g_i).

CNN regressors

We tested 4 architectures:

– Custom Regression CNN_1M
– Custom Regression CNN_263K
– Regression VGG16
– Regression ResNet50



(a) Regression CNN_1M (b) Regression CNN_263K

Experiment

- The HC18 dataset
  - HC18 training dataset: 999 US images, ground truth HC values range from 439.1 pixels (44.3 mm) to 1786.5 pixels (346.4 mm).
  - Data augmentation: horizontal flipping, translation (5 pixels offset), rotation (10 degrees)
  - Image preprocessing: Resizing(800*540 to 224*224). Normalization: images: $\frac{x-\mu}{\sigma}$. The HC values: $\frac{HC}{\max(HC)}$.
- Experimental setup
  - Hyper parameter: 5-fold cross validation, $\delta = 0.5$ in Huber loss, learning rate $1e^{-3}$, Adam optimizer, batch size is 8.
  - Metrics: Mean Absolute Error (mae), percentage of mae (pmae).
  - Implementation: Keras and Tensorflow.

Performance of 4 CNN regresssor models

Table: Performance of regression models in terms of mean absolute error (mae) in pixels and %mae (± standard deviation) for three different loss functions: MSE, MAE, HL

	CNN_263K		CNN_1M		Reg-VGG16		Reg-ResNet50	
loss	mae(pix)	pmae(%)	mae(pix)	pmae(%)	mae(pix)	pmae(%)	mae (pix)	pmae(%)
MSE	90.18±86.42	8.74±12.51	50.96±58.61	4.96±7.85	**38.85**±40.31	5.31±5.63	**36.21**±35.82	4.62±4.27
MAE	101.85±108.51	10.99±18.48	51.61±59.96	5.15±8.66	40.17±40.99	5.26±5.79	37.34±37.46	4.85±4.93
HL	98.18±89.77	9.69±13.9	53.87±66.46	5.45±9.08	40.7±40.07	5.67±5.19	38.18±37.32	5.16±4.84

– The loss MSE performs best among three loss functions.
– The Regression VGG16 and Regression ResNet50 are better than the customized model.

Performance of CNN regresssor based on VGG16 and ResNet50

Table: Performance of Reg-Resnet50 vs Reg-VGG16 in terms of mae (pixels and mm). †: significantly different ($p < 0.05$) from all other methods.

	Reg Resnet50		Reg VGG16	
loss	mae (pixels)	mae (mm)	mae (pixels)	mae (mm)
MSE	36.21±35.82†	**4.52**±4.27†	38.85±40.31	**4.87**±5.81
MAE	37.34±37.46	4.78±4.41	40.17±40.99	5.46±5.99
HL	38.18±37.32	4.68±4.37	40.7±40.07	5.19±5.42

- The loss MSE with ResNet performs best.
- Room for improve in prediction error (segmentation error is around 2 mm ((Sobhaninia et al., 2019))).

Qualitative results

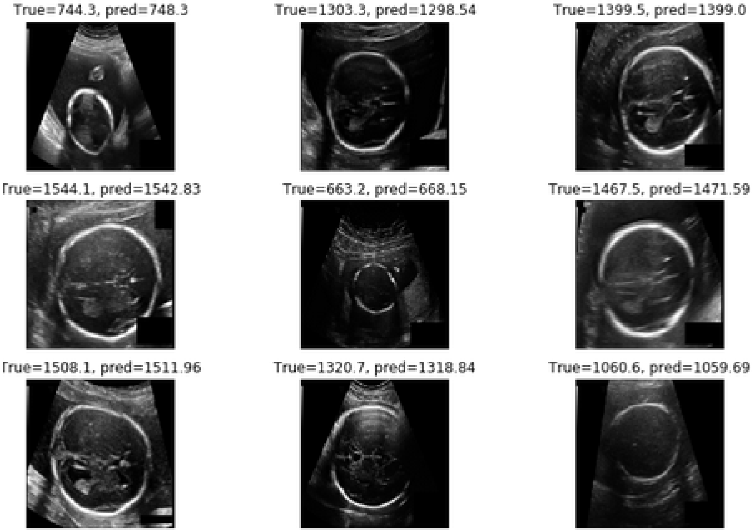


Figure: Good prediction with Reg-Resnet50-MSE

Conclusion

- We proposed a regression CNN model that can directly estimate the HC value.
- Encouraging results are obtained according to the experiment results, while room for improvement is left.
- Future work will focus on improving the performance like attention mechanism and multi-task learning.

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Thank you for your attention!