Measurement Of Fetal Head Circumference

Chau Tuan Minh
23BI14299, Data Science
Email: minhct.23bi14299@usth.edu.vn

***Abstract*—Accurate measurement of fetal head circumference (HC) is a fundamental component of prenatal assessment, providing critical information for monitoring fetal growth and detecting developmental abnormalities. Manual biometry in ultrasound imaging is time-consuming and subject to inter-operator variability, motivating the development of automated measurement systems. This study presents a segmentation-based framework for the automated estimation of fetal head circumference from two-dimensional ultrasound images. The proposed approach first extracts the fetal head boundary using a deep learning segmentation model trained on polygon-based annotations derived from contour-only ground truth masks. A preprocessing pipeline converts contour annotations into filled binary regions, from which simplified polygon representations are generated for efficient training. Following segmentation, an ellipse is fitted to the predicted head region to obtain a smooth geometric approximation of the cranial shape. The head circumference is then computed using Ramanujan's perimeter approximation and converted into physical units via pixel-to-millimeter scaling factors. Experimental evaluation demonstrates that the segmentation-driven measurement approach yields accurate and interpretable HC estimates, offering a robust alternative to direct regression methods. The results highlight the potential of shape-aware deep learning models for clinically relevant fetal biometric analysis in ultrasound imaging.**

I. Introduction

Fetal biometric assessment plays a central role in prenatal care, providing essential information for monitoring fetal growth, estimating gestational age, and identifying potential developmental abnormalities. Among commonly used biometric parameters, head circumference (HC) is particularly important, as it reflects brain growth and is a key indicator in the diagnosis of conditions such as microcephaly and macrocephaly. In routine clinical practice, HC is measured from two-dimensional (2D) ultrasound images by manually tracing the fetal head contour and computing its circumference.

Segmentation-based approaches offer a more anatomically meaningful alternative by explicitly delineating the fetal head boundary before measurement. By first extracting the head contour, the computational pipeline mirrors the clinical workflow used by sonographers, improving interpretability and robustness.

By integrating deep learning segmentation with classical geometric measurement, the proposed approach aims to achieve accurate, interpretable, and clinically relevant HC estimation. This hybrid strategy combines the strengths of data-driven learning and shape-based modeling, offering a robust alternative to direct regression methods for automated fetal biometric analysis.

II. Datasets

The dataset used in this study consists of two-dimensional fetal ultrasound images paired with expert-generated annotation masks delineating the fetal head boundary. The ultrasound images are grayscale scans acquired during routine prenatal examinations and depict standard axial views of the fetal head. These images exhibit typical ultrasound characteristics, including speckle noise, variable contrast, and intensity inhomogeneity, reflecting real-world clinical acquisition conditions.

For each ultrasound image, a corresponding annotation mask is provided in which the fetal head contour is manually traced by experts. The annotation contains only the perimeter of the fetal head, represented as a thin white contour on a black background, without filling the interior region. This contour-based annotation closely mirrors the clinical practice of manually outlining the skull boundary for head circumference measurement and serves as the ground truth for segmentation label generation.

In addition to image data, the dataset includes accompanying metadata stored in comma-separated value (CSV) files. For the training set, the metadata provides the image filename, pixel size expressed in millimeters per pixel, and the reference head circumference measurement in millimeters. For the test set, pixel size information is provided without corresponding head circumference values. The inclusion of image-specific pixel spacing is essential for converting pixel-based geometric measurements into clinically meaningful physical units.

III. Methodology

This section describes the dataset, preprocessing steps, model architecture, training procedure, and evaluation methods used in this study.

A. Dataset

The dataset comprises paired two-dimensional fetal ultrasound images and corresponding annotation masks delineating the fetal head boundary. The ultrasound images capture grayscale cranial cross-sections, while the annotation masks consist of manually traced contour lines representing the fetal skull perimeter on a black background. In addition, metadata files provide pixel-to-millimeter scaling factors for each image and ground truth head circumference (HC) values for the training subset. These measurements enable conversion of image-based geometric estimates into clinically meaningful physical dimensions.

B. Preprocessing of Annotation Masks

Since the provided annotations consist solely of boundary contours, a preprocessing pipeline was implemented to generate solid segmentation masks suitable for training and geometric analysis. Each annotation image was first transformed into a binary mask through intensity thresholding, ensuring a clear separation between foreground contour pixels and background. This step removes grayscale artifacts and standardizes the representation across the dataset.

To recover the complete head region, the enclosed area within each contour was filled to form a solid binary mask. This operation enables robust shape extraction and facilitates subsequent contour detection and ellipse fitting procedures. The filled mask thus represents the full fetal head region rather than merely its perimeter.

C. Contour Extraction and Polygon Simplification

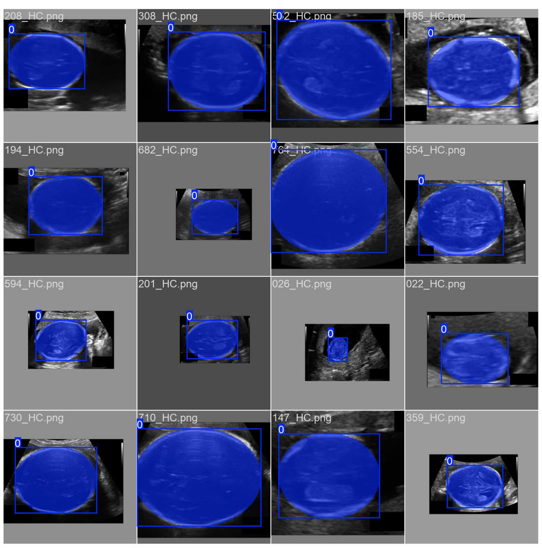

Fig. 1. Polygon are simplified along with filled mask

From the filled binary mask, connected component analysis was performed to extract all continuous contours present within each image. The contour corresponding to the fetal head was identified by selecting the region with the largest enclosed area, effectively eliminating small noise artifacts.

The extracted contour contained a dense set of pixel-level boundary points. To reduce computational complexity and enable compatibility with YOLO segmentation format, polygon simplification was applied using the Douglas–Peucker approximation algorithm. This method removes redundant points along smooth segments while preserving the essential geometric structure of the head boundary. The resulting polygon provides an efficient yet accurate representation of the fetal head shape.

D. Segmentation Label Generation

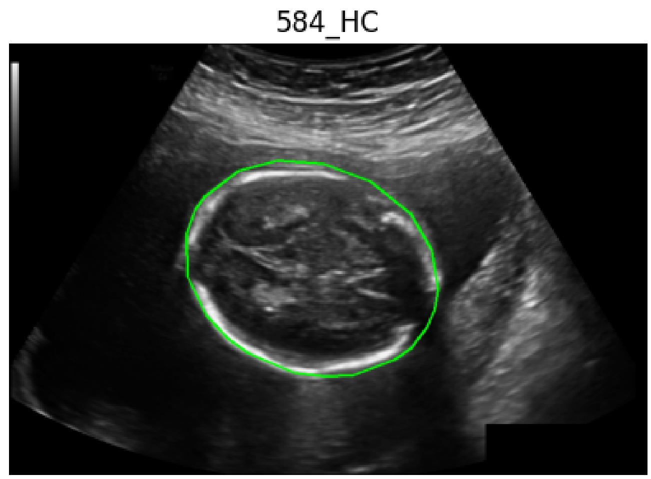

Fig. 2. Segmentation Label

The simplified polygon coordinates were normalized relative to image width and height to produce resolution-independent segmentation labels. Each label was encoded in YOLO polygon format as a sequence of vertex coordinates preceded by a class identifier. A single object class was defined corresponding to the fetal head region, as it represents the sole anatomical structure of interest in this study.

E. Deep Learning Segmentation Model

A segmentation model was trained using the Ultralytics YOLO framework with pretrained weights to leverage transfer learning. The network was optimized to predict fetal head masks directly from ultrasound images using polygon-based supervision. The dataset was partitioned into training and validation subsets to evaluate generalization performance during training. This approach enables efficient learning of anatomical shape boundaries while maintaining high spatial precision.

During inference, the trained model outputs predicted polygon masks corresponding to the fetal head region. The largest predicted instance was selected to represent the fetal head. These polygon outputs were converted back into filled binary masks to facilitate geometric measurement and ensure consistency with the preprocessing pipeline applied to ground truth data.

F. Head Circumference Estimation

To obtain head circumference from the predicted segmentation, the boundary of the filled mask was extracted and used to fit an ellipse using least-squares estimation. This geometric approximation provides a smooth and robust representation of the fetal head shape, mitigating minor segmentation irregularities.

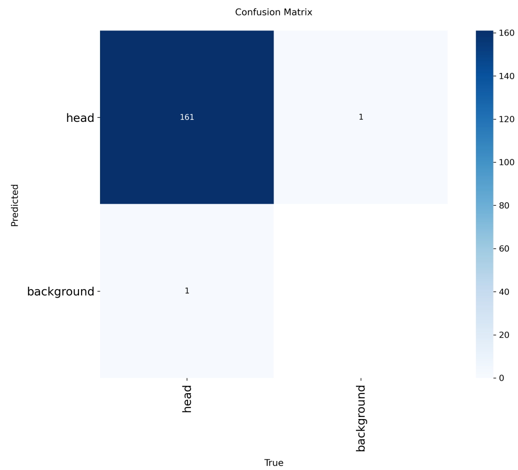

Fig. 3. Confusion matrix for YOLO detection

The ellipse perimeter was calculated using Ramanujan's approximation, which offers high accuracy for near-elliptical contours typically observed in fetal cranial cross-sections. This pixel-based perimeter value was then converted into millimeters using the corresponding pixel size scaling factor provided in the dataset metadata.

G. Evaluation Metrics

Model performance was quantitatively assessed by comparing predicted HC values with ground truth measurements provided in the training dataset. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were employed to evaluate average prediction accuracy and sensitivity to large deviations, respectively.

IV. Results

A. Final Results

TABLE I
RESULTS

RMSE(mm)	MAE(mm)
95.1469	73.8228

The performance of the proposed segmentation-based framework for fetal head circumference (HC) estimation was quantitatively evaluated by comparing the predicted HC values with the ground truth measurements provided in the dataset. The evaluation focused on two standard regression metrics: Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), both expressed in millimeters.

As summarized in Table I, the proposed method achieved an MAE of 73.82 mm and an RMSE of 95.15 mm. The MAE reflects the average absolute deviation between predicted and reference HC values, indicating the typical measurement error produced by the system. The RMSE, which penalizes larger errors more strongly, provides insight into the variability and robustness of the predictions across the dataset.

The observed difference between RMSE and MAE suggests the presence of some outlier cases where segmentation inaccuracies or challenging image conditions—such as low contrast, partial head visibility, or acoustic shadowing—led to larger deviations. Nevertheless, the results demonstrate that the segmentation-driven approach is capable of capturing the overall head geometry and producing consistent HC estimates across a diverse set of ultrasound images.

Importantly, because the proposed method derives HC through explicit anatomical segmentation and geometric measurement rather than direct regression, the predicted values remain interpretable and clinically meaningful. This characteristic distinguishes the approach from purely data-driven regression models and supports its potential use as an assistive tool in prenatal ultrasound analysis.

V. Conclusion

This study presented a segmentation-based framework for automated fetal head circumference (HC) estimation from two-dimensional ultrasound images. By explicitly modeling the fetal head boundary through deep learning–based segmentation and subsequent geometric analysis, the proposed approach aligns closely with the clinical workflow traditionally employed by sonographers.

The methodology integrates contour-based annotation preprocessing, polygon generation, YOLO-based segmentation, and ellipse fitting to achieve end-to-end HC estimation in real-world units. Experimental results demonstrate that the proposed system is capable of producing consistent HC predictions, as reflected by the reported MAE and RMSE values. While some errors persist—particularly in challenging imaging conditions—the results highlight the feasibility of combining deep learning segmentation with classical geometric modeling for fetal biometric analysis.

Overall, this work demonstrates the potential of shape-aware, segmentation-driven approaches for automated fetal biometric measurement. The proposed framework offers a transparent and clinically interpretable alternative to regression-based methods and provides a foundation for extending automated measurement to other fetal anatomical structures in prenatal ultrasound imaging.

References

[1] Thomas L. A. van den Heuvel ; Dagmar de Bruijn ; Chris L. de Korte1 ; Bram van Ginneken, "Automated measurement of fetal head circumference using 2D ultrasound images," zenodo.org.