Segmentation-Based Fetal Cranium Biometry - Project Report

1. Problem Understanding & Overall Approach

The objective of this work is to automatically identify the fetal cranium in ultrasound images and compute two biometry measurements - **Biparietal Diameter (BPD)** and **Occipitofrontal Diameter (OFD)** - using a **segmentation-based approach**.

The solution is designed as a two-stage pipeline:

1. **Segmentation Stage**
   A U-Net model is trained to generate a binary mask of the fetal cranium.

2. **Measurement Stage**
   Classical computer-vision techniques are applied to the predicted mask to:

   ○ extract the largest cranium contour

   ○ fit an ellipse to the contour

   ○ derive **BPD (minor axis) and OFD (major axis)**

   ○ compute corresponding landmark points.

This approach intentionally separates perception (deep learning) and geometry (ellipse fitting), making the method **interpretable, modular, and anatomically consistent** rather than purely end-to-end.

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2. Data Pre-Processing & Augmentation

Dataset

- 622 ultrasound images
- Corresponding filled-ellipse cranium masks (`*_Annotation.png`)

  Train/validation split applied

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Pre-Processing Pipeline

- Convert to grayscale
- Resize to **512×512**
- Normalize input intensity
- Convert masks to binary (0/1)
- Fill fragmented edges via contour filling

Rationale:
Ultrasound scans contain noise and variable contrast. Normalization and binary mask cleaning improve learning stability and edge continuity.

Post-Processing

- Morphological opening → remove small blobs
- Morphological closing → smooth head boundary
- Keep largest connected component
- Fit ellipse & compute biometry axes

Rationale:
CNN predictions may be fuzzy near borders - morphology enforces **geometric smoothness** before measurement.

Only light augmentations were used, since heavy rotation or deformation risks altering anatomical shape.

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3. Model Development & Experiments

✔ Final Model - U-Net with Dice + BCE Loss

Encoder–decoder architecture with skip connections

- Output channel = 1 (sigmoid activation)

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- Loss = **Dice Loss + Binary Cross-Entropy**
- Optimizer = Adam (lr = 1e-4)
- Input resolution = 512×512

Reasoning
U-Net preserves spatial resolution through skip-connections, making it highly suitable for medical image segmentation tasks.

Experiment-1 - Dice-Only Loss (Initial Attempt)

- Model converged but predictions remained mid-range (≈0.48–0.57)
- Masks were weak and non-binary
- Ellipse incorrectly spanned full image

Insight:
Dice-only loss lacked pixel-wise penalty → BCE component was necessary for confident foreground/background separation.

Experiment-2 - Lower-Resolution Training (256px)

- Faster training but produced coarse boundaries
- Ellipse stability degraded for small or tilted heads

Conclusion:
Higher-resolution input preserves cranium curvature and improves measurement reliability.

Experiment-3 - Strong Augmentation Trials

Large rotations / intensity jitter introduced artifacts

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● Model performance degraded on anatomical edges

Learning:
Ultrasound anatomy is sensitive - augmentations must remain realistic.

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4. Evaluation Metrics

Since the dataset does not include ground-truth BPD/OFD values, evaluation focuses on **segmentation quality and visual consistency of measurements**, which aligns with the task objective.

◇ Quantitative Segmentation Metrics

Metric	Result
Train Dice Score (final)	~0.92–0.93
Validation Dice Score (final)	**~0.91–0.92**
Tester Dice Score(final)	~0.92

The high Dice score indicates strong overlap between predicted masks and annotated cranium regions.

◇ Qualitative Measurement Evaluation

The following observations were consistent across validation samples:

- Ellipse tightly follows cranium boundary
- BPD and OFD axes align anatomically
- Mask geometry remains stable across:
    - head tilt
    - contrast variation

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    - moderate noise

Failure cases were rare and usually corresponded to very weak ultrasound edges or incomplete annotation regions.

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5. Future Improvements (If More Time Was Available)

Potential enhancements include:

- **Attention-U-Net / U-Net++** for sharper boundary focus
- **Boundary-aware or contour loss** to reinforce edge accuracy
- **Test-time augmentation averaging** for smoother predictions
- **Mixed-precision inference** for faster deployment
- **Pixel-to-millimetre calibration** to convert measurements to clinical scale

These extensions would primarily improve **contour precision and robustness**.

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6. Key Takeaways

- A segmentation-first approach produces **transparent and controllable** head biometry measurements.
- The hybrid **Dice + BCE loss** plays a crucial role in generating confident binary masks.
- Post-processing with morphology and ellipse fitting significantly improves **measurement stability**.
- Combining deep learning with geometric reasoning leads to a more **interpretable biomedical pipeline**.
- Iterative experimentation and failure analysis were essential to refining the solution.

Conclusion

The developed pipeline successfully segments the fetal cranium and derives BPD/OFD measurements through an interpretable, geometry-driven approach. Even without explicit numeric ground-truth labels, the high Dice score and strong visual alignment of the ellipse indicate that the proposed method is reliable and practically applicable for segmentation-based fetal head biometry.