

A Deep CNN-Based Pipeline for Automated Classification of Anatomical Fetal Brain Views in Prenatal Ultrasound Imaging

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ABSTRACT

Fetal brain classification in prenatal ultrasound imaging is essential for detecting congenital anomalies and developmental disorders at an early stage. Accurate identification of anatomical planes supports clinicians in making timely diagnostic decisions. In this study, a labeled dataset of ultrasound images was used, covering four standard categories: Trans-cerebellum, Trans-thalamic, Trans-ventricular, and Other. A deep learning pipeline was developed using a pre-trained VGG19 CNN model with transfer learning for feature extraction. The architecture was fine-tuned by applying global average pooling and a softmax classifier. The system was trained with categorical cross-entropy loss and optimized using Adam. Results confirmed high classification accuracy, indicating the potential of automated tools to standardize imaging and reduce diagnostic variability in prenatal care.

Keywords: Fetal brain classification, prenatal ultrasound, deep learning, VGG19, transfer learning, medical image analysis.

1. INTRODUCTION

Human development begins long before birth, with the fetal brain representing one of the most delicate and vital aspects of this process. Brain formation starts in the earliest weeks of pregnancy and continues to mature throughout gestation, serving as the central organ responsible for growth, cognition, and behavior in later life. Any disruption during this period can lead to lifelong consequences, making early assessment of fetal brain health a critical priority in both research and clinical practice. Fetal brain development involves the creation of billions of neurons, their organization into specialized structures, and the establishment of neural pathways enabling sensory, motor, and cognitive functions. While genetics strongly influence this process, maternal health, nutrition, intrauterine conditions, and exposure to toxins or infections also play decisive roles. Even subtle disturbances during sensitive phases may result in disorders such as hydrocephalus, microcephaly, or developmental delays, which may otherwise remain unnoticed until after birth. Early recognition allows healthcare providers to monitor, diagnose, and intervene before complications escalate. Advances in imaging, including high-resolution ultrasound, fetal MRI, genetic testing, and artificial intelligence-driven analysis, now provide unprecedented insight into fetal brain structure and activity. These technologies facilitate timely interventions, parental counseling, and tailored clinical planning, improving neonatal outcomes and family preparedness. On a broader scale, public health initiatives supporting maternal care, nutrition, and prenatal screening enhance prevention and early detection efforts. Importantly, research continues to reveal connections between fetal brain health and long-term outcomes such as learning capacity, mental health, and personality. Thus, early detection is both a medical necessity and a moral responsibility, ensuring every child has the best foundation for future growth.

2. PROBLEM STATEMENT

Although fetal brain ultrasound imaging plays a critical role in prenatal diagnostics, accurate classification of standard anatomical views remains a considerable challenge. Manual interpretation of planes such as trans-thalamic, trans-ventricular, and trans-cerebellar depends heavily on radiologist expertise and is prone to variability or error, particularly in time-sensitive or resource-limited environments. Factors like inconsistent image quality, fetal movement, and operator skill further hinder reliable analysis. These challenges may result in delayed or missed identification of congenital and neurological disorders, posing serious risks to fetal health. Hence, there is

an urgent need for an automated and robust system to ensure accurate classification of fetal brain views.

3. OBJECTIVES

This study aims to address the limitations of manual and error-prone classification of fetal brain ultrasound images, which often lead to delayed or missed detection of congenital and neurological abnormalities. The primary goal is to develop an automated classification system using deep learning techniques to accurately identify four key anatomical views: Trans-cerebellum, Trans-thalamic, Trans-ventricular, and Other. The VGG19 CNN model, enhanced with transfer learning, is employed for feature extraction and classification, with training conducted on a labeled Kaggle dataset. Data preprocessing and augmentation are applied to improve generalization, while optimization is achieved using categorical cross-entropy loss and the Adam optimizer. Additionally, a user-friendly Flask-based web interface is implemented to provide real-time classification results, supporting clinical decision-making.

4. METHODOLOGY USED

1_Data Collection: The dataset used in this project was sourced from Kaggle, which provides a publicly available collection of fetal brain ultrasound images. These images were carefully labeled into four distinct anatomical categories: Trans-cerebellum, Trans-thalamic, Trans-ventricular, and Other. Such classification ensured a structured dataset suitable for supervised learning tasks. This dataset served as the foundation for training and validating the proposed classification model.

2) Data Preprocessing: To maintain consistency, all ultrasound images were resized to a uniform resolution of 224×224 pixels, which aligns with the input requirement of the VGG19 model. Pixel values were normalized to improve computational efficiency and stabilize training. Categorical labels were encoded to make them compatible with the model. Furthermore, data augmentation techniques such as flipping, rotation, zooming, and brightness adjustments were applied to increase dataset diversity and prevent overfitting.

3) Feature Extraction: Feature extraction was carried out using a pre-trained VGG19 Convolutional Neural Network (CNN). This model is known for its ability to capture spatial and structural features in medical imaging tasks. The pre-trained layers were retained to leverage previously learned features from large-scale datasets. By doing so, the need for manual and time-consuming feature engineering was minimized while ensuring robust feature abstraction from ultrasound images.

4) Model Selection: VGG19 was selected due to its reliability and effectiveness in handling image classification challenges. The original classification layers of the network were removed, and new layers customized for fetal brain view classification were appended. Transfer learning was employed to adapt the network for this specific medical task, thereby improving accuracy while reducing computational overhead.

5) Model Training: The training process utilized categorical cross-entropy as the loss function, suitable for multi-class classification tasks. The Adam optimizer was adopted for its efficiency in handling complex datasets. The dataset was divided into training and validation sets, ensuring fair performance evaluation. Early stopping was incorporated to avoid overfitting, preserving the best-performing model configuration.

6) Model Evaluation: The model's performance was evaluated using standard metrics such as accuracy and validation loss. A confusion matrix was also generated to examine class-wise performance and identify areas where the model may misclassify. This step ensured reliability and robustness when dealing with unseen ultrasound data.

7) Integration with Flask: Once trained, the final model was integrated into a Flask-based web application. This interface allows users to upload fetal brain ultrasound images and obtain classification results in real-time. The application enhances clinical utility by making the system accessible, interactive, and supportive of decision-making in prenatal diagnostics.

5. LITERATURE SURVEY

Article [1] 'Fetal Brain Planes Classification Using Deep Ensemble Transfer Learning from U-Net Segmented Fetal Neurosonography Images' by Md. Nazmul Hasan and A. B. M. Aowlad Hossain in 2024: This study proposes

a deep learning-based method for automatically categorizing fetal brain planes from ultrasound images using trans-thalamic, trans-cerebellum, and trans-ventricular planes. The research employs U-Net for brain region segmentation and an ensemble CNN model including Inception V3, ResNet50-V2, and DenseNet-201 with max voting for classification. The framework achieved 97.68% testing accuracy using 2019 fetal brain ultrasound images, demonstrating superior performance compared to individual models and showing excellent localization capability through Grad-CAM visualization.

Article [2] 'Using deep-learning algorithms to classify fetal brain ultrasound images in standard axial planes as normal or abnormal' by H.N. Xie et al. in 2020: This pioneering study evaluated the feasibility of using deep-learning algorithms for binary classification of fetal brain sonographic images as normal or abnormal in standard axial planes. The research utilized 15,372 normal and 14,047 abnormal fetal brain images from 10,251 normal and 2,529 abnormal pregnancies, achieving 96.3% overall accuracy with 96.9% sensitivity and 95.9% specificity. The algorithms demonstrated excellent segmentation performance with 97.9% precision and successfully localized lesions precisely in 61.6% of abnormal images, establishing the foundation for automated fetal intracranial abnormality detection.

Article [3] 'Evaluation of deep convolutional neural networks for automatic classification of common maternal fetal ultrasound planes' by X.P. Burgos-Artizzu et al. in 2020: This comprehensive study evaluated state-of-the-art CNNs for automatically classifying 2D maternal-fetal ultrasound images using a large dataset of over 12,000 images from 1,792 patients in real clinical settings. The research focused on 5+1 widely used maternal-fetal anatomical planes and included fetal brain planes, representing the largest ultrasound dataset available at the time. The study demonstrated the maturity of deep learning techniques for clinical maternal-fetal ultrasound classification and provided a benchmark protocol mimicking real-world scenarios with unbalanced data distribution

Article [4] 'Automated classification of common maternal fetal ultrasound planes using multi-layer perceptron with deep feature integration' by Thunakala Bala Krishna and Priyanka Kokil in 2023: This research presents an automated classification technique for common maternal fetal ultrasound planes using deep learning models with integrated feature extraction from multiple CNNs. The study utilized AlexNet and VGG-19-GAP for deep feature extraction and employed a multi-layer perceptron for classification of maternal fetal ultrasound images. The methodology demonstrated significant improvements over state-of-the-art methods through extensive experiments on publicly available datasets, with particular focus on improving inter-class variance and reducing misclassification between anatomical planes like abdomen, femur, and thorax.

Article[5] 'Transfer learning for accurate fetal organ classification from ultrasound images' by H. Ghabri et al. in 2023: This paper proposes a deep-learning model for automating fetal organ classification from ultrasound images using transfer learning techniques. The research addresses the challenge of accurate fetal organ identification in prenatal diagnostics by leveraging pre-trained CNN architectures adapted for ultrasound image analysis. The study demonstrates the effectiveness of transfer learning in medical imaging applications, particularly for fetal ultrasound where labeled datasets are often limited. The proposed methodology shows promising results for clinical implementation in automated fetal organ detection and classification systems.

Article[6] 'Review on deep learning fetal brain segmentation from ultrasound images' by T. Ciceri et al. in 2023: This comprehensive review examines deep learning algorithms developed specifically for fetal brain segmentation from ultrasound images, categorizing them according to their target anatomical structures. The paper provides systematic analysis of various CNN architectures, segmentation techniques, and evaluation metrics used in fetal brain ultrasound analysis. The review covers recent advances in automated fetal brain structure identification, measurement extraction, and abnormality detection, serving as a valuable resource for researchers working on prenatal ultrasound image analysis and establishing current state-of-the-art benchmarks in the field.

Article [7] 'Automated deep bottleneck residual 82-layered architecture for fetal brain anomaly detection' by F. Rauf et al. in 2023: This study presents a deep bottleneck residual CNN architecture with 82 layers specifically designed for automated fetal brain anomaly detection from ultrasound images. The research focuses on developing a robust classification system capable of identifying various fetal brain abnormalities with high accuracy and reliability. The proposed architecture incorporates advanced residual learning techniques to address the vanishing gradient problem in very deep networks while maintaining computational efficiency. The study demonstrates superior performance in detecting fetal brain anomalies compared to existing methods, contributing to early prenatal diagnosis and intervention strategies.

6. SYSTEM DESIGN

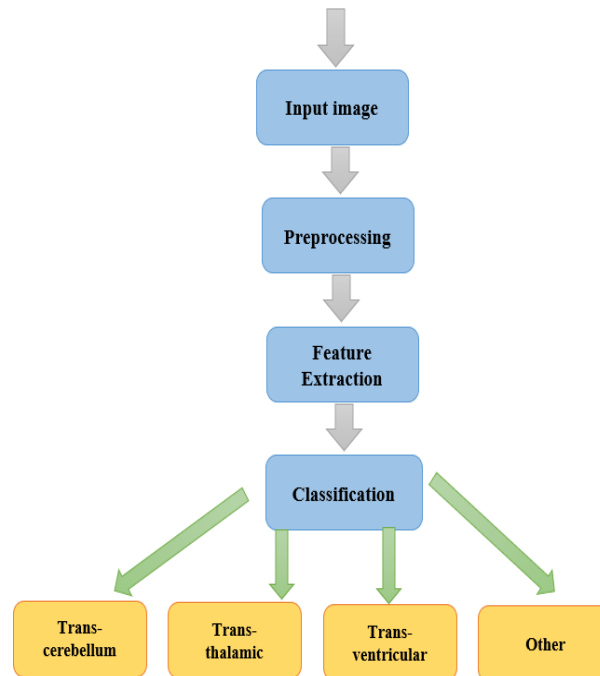


Figure 1: System Architecture of Baby fetal brain detection

The proposed system for fetal brain ultrasound classification is designed to effectively process medical images and identify anatomical views with high accuracy. The workflow begins at the input stage, where users or clinicians upload ultrasound images through a simple web-based interface. These images then undergo preprocessing steps such as resizing, normalization, and augmentation, which ensure uniformity, minimize noise, and enhance the model's adaptability to diverse image qualities. After preprocessing, the images are fed into a Convolutional Neural Network (CNN), with VGG19 serving as the backbone for feature extraction. This architecture is adept at capturing intricate spatial and structural details, allowing the model to learn hierarchical patterns of fetal brain anatomy. The extracted features are passed to a classification layer that assigns each image to one of four classes: Trans-cerebellar, Trans-thalamic, Trans-ventricular, or Other. This streamlined design provides a robust and automated solution for early fetal brain assessment.

7. SCREENSHOTS

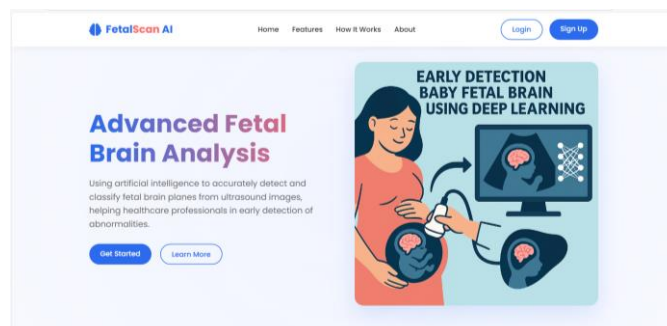


Figure 6: Home page

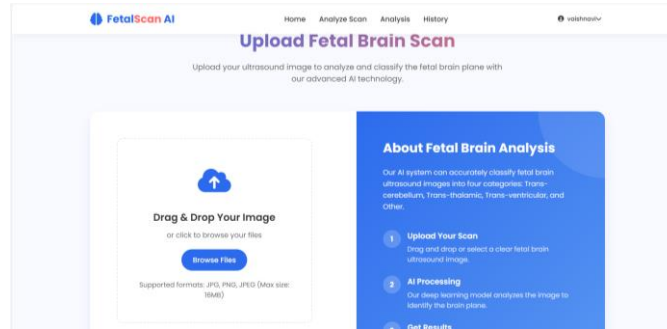


Figure 7: Selecting Image

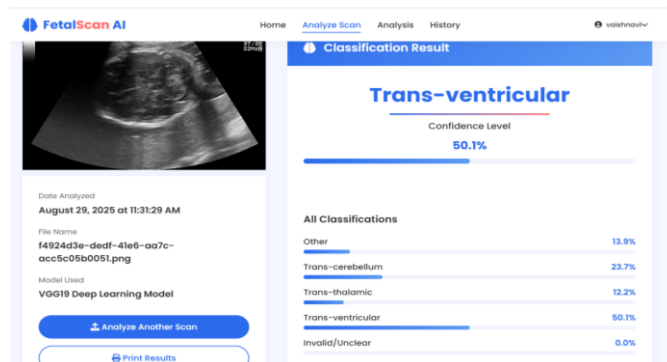


Figure 8: Predicated Result

8. CONCLUSION

In this research, a deep learning-based approach was developed for the automated classification of fetal brain ultrasound images, aiming to support early and accurate detection of anatomical views during prenatal screening. Using the VGG19 Convolutional Neural Network with transfer learning, the system successfully classified four standard planes—Trans-cerebellar, Trans-thalamic, Trans-ventricular, and Other. Preprocessing and augmentation enhanced dataset quality and diversity, while fine-tuned feature extraction layers enabled the model to capture critical spatial and structural details of the fetal brain. The trained system achieved high accuracy, confirming its robustness and reliability in clinical applications. An additional contribution of this project is the deployment of a Flask-based web application, which allows users to upload ultrasound images and receive instant classification results, thereby offering clinicians rapid, automated decision support. Looking ahead, future improvements could focus on expanding the dataset with high-resolution images from diverse clinical settings to strengthen model generalization. Incorporating advanced architectures such as EfficientNet or transformer-based networks may further boost predictive accuracy and efficiency. Enhancements to the web interface, including DICOM support, multilingual functionality, and integration with hospital systems, would increase clinical applicability. Furthermore, adopting explainable AI methods would provide interpretability, helping clinicians trust and understand model predictions, while extending usability to resource-constrained environments through mobile health platforms.

9. REFERENCES

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