Improving Prenatal Detection of Congenital Heart Defects Using Transfer Learning

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Summary

This study presents a methodology for detecting congenital heart defects (CHD) using transfer learning with the Mask R-CNN model on fetal echocardiographic images. It focuses on four key cardiac views: four-chamber (4C), three-vessel (3V), left ventricular outflow tract (LVOT), and right ventricular outflow tract (RVOT). Frames were extracted, labeled as normal or abnormal, and enhanced using median filtering and CLAHE. A sequential classification approach was used to distinguish views and detect abnormalities, covering major congenital heart defects such as ventricular septal defect, atrioventricular septal defect, tetralogy of Fallot, total anomalous pulmonary venous connection, Ebstein's anomaly, hypoplastic left heart syndrome, and complex transposition of the great arteries. The model achieved high diagnostic accuracy, with over 98% accuracy in classifying cardiac views and detecting abnormalities. These findings highlight the effectiveness of deep learning and image processing techniques in prenatal cardiac analysis, supporting early detection of congenital heart disease and advancing fetal cardiac healthcare.

Introduction

CHD is a major congenital disorder, affecting 8-9 per 1000 live births and accounting for 28-40% of all congenital anomalies [1]. Early detection through prenatal screening is crucial, yet challenges such as limited awareness, imaging variability, and diagnostic delays persist. CHD diagnosis is done from Ultrasound and fetal echocardiography, but their effectiveness depends on factors like operator expertise and equipment quality [2]. Deep learning models, particularly in medical imaging, offer promising solutions for automated CHD detection [3]. However, challenges such as limited labeled data and image quality variations hinder their clinical applicability, necessitating further advancements in AI-driven diagnostics [4].

Methods

Fetal echocardiogram videos were collected, containing both normal and CHD cases. Preprocessing (shown in Fig-1a) involved frame extraction, image greying, median filtering for noise reduction, and contrast enhancement using CLAHE. Manual classification of cardiac views (4C, LVOT, RVOT, 3V) was performed by fetal echo experts. Annotations were created using MAKE SENSE (https://www.makesense.ai/) for supervised deep learning. A Mask R-CNN [5] model with ResNet101 as the backbone was trained using transfer learning. The model classified cardiac views, detected abnormalities, and localized key structures. Stratified 5-fold cross-validation ensured robustness across seven binary classification tasks, resulting in 35 models. Training employed the Adam optimizer with a decreasing learning rate and early stopping to prevent overfitting. Testing followed a hierarchical pipeline (shown in Fig-1b), sequentially classifying frames into cardiac views and assessing abnormalities at each stage.

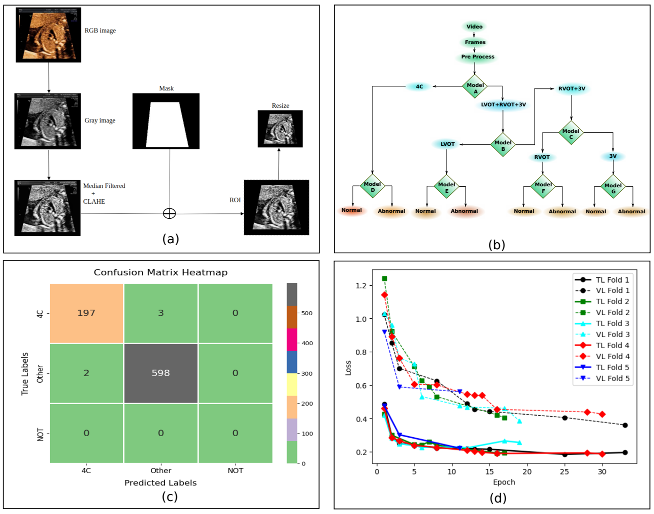

Figure 1: Shows (a) Pre-processing flowchart (b) Testing flow chart (c) Confusion Matrix (4C vs Other) (d) Loss graph (4C vs Other).

Results and Discussion

The study used transfer learning with Mask R-CNN for cardiac view classification and abnormality detection, achieving over 98% accuracy as revealed in confusion matrix (Fig-1c). Classification showed strong performance, with IoU scores between 0.78 and 0.85 (Table 1). LVOT was the most challenging due to anatomical complexity, while RVOT and 3V had near-perfect results. The loss graph (Fig-1d) decreased steadily across all folds as epochs progressed, indicating successful learning and optimization. The findings highlight the need for high-quality datasets and advanced preprocessing to enhance prenatal cardiac diagnostics, with further optimization required for complex views like LVOT.

Table 1: Classification Report (4C vs Other)

Class	**Precision**	**Recall**	**F1-Score**	**Support**
4C	0.99	0.98	0.99	200
Other	1.00	1.00	1.00	600
Accuracy			0.99	800
mean IoU			0.81	800

Conclusions

The study achieved over 98% accuracy in fetal cardiac view classification using Mask R-CNN. LVOT challenges underscore the need for optimization, highlighting the importance of quality datasets and advanced preprocessing in prenatal diagnostics.

References

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