A HYBRID QUANTUM-TRANSFORMER FRAMEWORK FOR SEVERITY GRADING AND ANALYSIS OF FETAL HEART ABNORMALITIES IN ULTRASOUND IMAGES

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Keywords:

Quantum Vision Transformer, ConvNeXt-Tiny, Explainable AI, Medical image analysis, Fetal cardiac ultrasound Image.

Introduction:

CHDs are among the most common fetal anomalies and a major cause of neonatal morbidity. Fetal cardiac ultrasound is the primary screening tool, but diagnosis remains challenging due to speckle noise, acoustic shadowing, fetal motion, and operator variability, with similar limitations seen in fetal neuroimaging. CNNs are widely used in medical imaging but often struggle with small and imbalanced datasets. Image enhancement techniques such as CLAHE and histogram equalization improve contrast and help highlight diagnostically relevant structures. Transformer-based models address these limitations by capturing long-range dependencies, with ViTs showing strong performance in fetal ultrasound tasks, while ConvNeXt-Tiny combines convolutional inductive biases with modern architectures for improved results. However, classical models rely on linear feature projections, limiting their effectiveness in low-data scenarios. Quantum Machine Learning (QML) introduces nonlinear transformations that enable richer feature representations, and Quantum Vision Transformers (QViT) integrate quantum circuits within transformer frameworks to better capture subtle structural variations.

Objectives:

1. To integrate image quality enhancement capabilities to handle low quality scans.
2. To enhance the model’s robustness and generalization across different imaging conditions and anatomical variations.
3. To build a hybrid quantum-transformer and compare against state-of-the-art models, to evaluate improvements in feature extraction and classification performance and also use XAI for explainable results.
4. To implement multi-class severity grading.

Methodology:

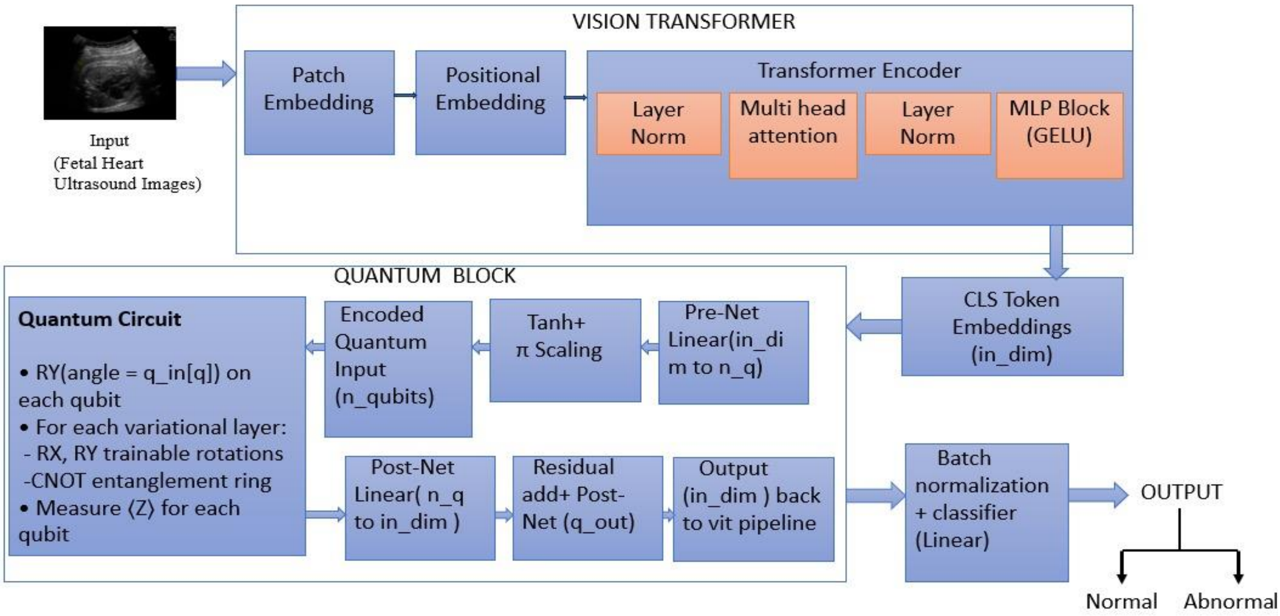

Fig. 1 Proposed QViT Architecture

1. Data Collection: Sample fetal heart ultrasound images were taken from public datasets and annotated by CDSIMER radiologists. Real-time data is being collected from CDSIMER to support the study.
2. Data Preprocessing: Images were resized, normalized, denoised, and augmented to improve model generalization.
3. Image Enhancement: CLAHE was the main enhancement technique due to better contrast and structural clarity.
4. Building and training model: A hybrid QViT model was developed and compared with ViT, Swin-T, and ConvNeXt-Tiny.
5. Testing and Evaluation: Performed 5-fold cross validation for generalizability of model and evaluated model performance using standard metrics and statistical measures.
6. Explainability: Generate heatmaps using Score-CAM to highlight cardiac regions influencing the model's decision.

Result and Conclusion:

The proposed QViT was evaluated against 3 state-of-art models. Among all models, QViT achieved the highest performance as summarized in the table below.

Model	Accuracy	Precision	Recall	AUC-ROC
ViT	0.7237	0.73	0.72	0.7424
ConvNext-Tiny	0.9342	0.9070	0.9750	0.9197
Swin-T	0.9474	0.9412	0.9412	0.9790
QViT (Proposed)	**0.9605**	**0.9632**	**0.9605**	**0.9944**

Table. 1 Performance comparison of ViT, ConvNeXt-Tiny, Swin-T and QViT.

- To ensure robustness, a 5-fold cross-validation strategy was employed. QViT demonstrated consistent performance with an average accuracy of 85.3%, a standard deviation of 3.5%, and an average AUC of 0.95, indicating strong generalizability on limited medical datasets.
- An ablation study was conducted to evaluate the contribution of the quantum feature mixing module. The baseline ViT achieved an accuracy of 72.37% and an AUC of 0.7424, whereas QViT achieved a 96.05% accuracy and 0.9944 AUC. This improvement highlights the effectiveness of the quantum block.
- Explainability analysis using Score-CAM revealed that the model focuses on clinically relevant cardiac regions rather than background noise.

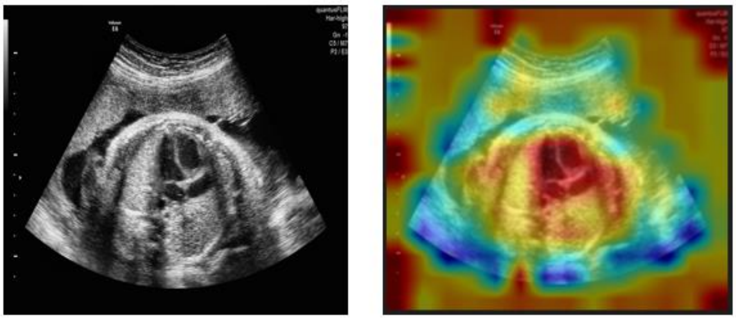

Fig. 2 score-CAM heatmap for an abnormal sample.

Project Outcome & Industry Relevance:

- This project presents a working hybrid Quantum Vision Transformer (QViT) model for fetal cardiac anomaly detection using ultrasound images which combines ViT features + stimulated quantum processing for richer feature representation. The system also integrates image enhancement techniques and explainable AI methods.
- The proposed approach is highly relevant to the healthcare and medical imaging industry, where early and accurate detection of congenital heart defects is critical. The integration of quantum-inspired learning improves performance in data-scarce scenarios, which is common in medical datasets.

Project Outcomes Learnings:

Key learnings include understanding the limitations of classical models, the benefits of nonlinear feature representations introduced by quantum components, and the importance of model interpretability in healthcare applications. Overall, the study establishes the potential of QViT as a reliable and scalable approach for real-world clinical decision support systems.

References:

1. [1] F. Li, P. Li, Z. Liu, *et al.*, “Application of artificial intelligence in VSD prenatal diagnosis from fetal heart ultrasound images,” *BMC Pregnancy and Childbirth*, vol. 24, no. 758, 2024.
2. [2] N. Htun and D. Tun, “Contrast enhancement methods for diagnostic imaging: A CLAHE-based evaluation,” *Biomedical Signal Processing and Control*, 2021.

3. [3] E. Jain, P. Kaushik, V. Kukreja, Sakshi, A. Dogra, and B. Goyal, “Fetal diagnostics using Vision Transformer for enhanced health and severity prediction in ultrasound imaging,” *Current Medical Imaging*, vol. 21, 2025.
4. [4] A. S. Moerdijk, N. H. Claessens, I. M. van Ooijen, P. van Ooij, *et al.*, “Fetal MRI of the heart and brain in congenital heart disease,” *The Lancet Child & Adolescent Health*, vol. 7, no. 1, pp. 59–68, 2023.
5. [5] A. G. Tan, N. Sethi, and S. Sulaiman, “Evaluation of prenatal CNS anomalies: Management and outcomes,” *BMC Pregnancy and Childbirth*, vol. 22, p. 210, 2022.

Future Scope:

Despite the advantages, there are limitations that need to overcome before the practical application of the system, such as the experiments were performed on small scale data sets using simulated quantum. In the future, we hope to collect more diverse data from different hospitals and carry out an overall classification by including more types of cardiac anomalies and assess the severity so as to add robustness of the model in different clinical settings.