Artificial intelligence based automatic classification, annotation, and measurement of the fetal heart using HeartAssist

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Supplementary Table S1. Hyper-parameters of the classification and segmentation models

	Classification model (ViT)	Segmentation model (CNN)
Input Size	224 x 224	1,024 x 512
Epoch	100	1,000
Batch Size	256	16
Base learning rate	0.001	0.0001
Momentum	0.9	0.9
Optimizer	SGD	ADAM
Weight decay	0	1e-06
Loss function	CrossEntropy	Softmax-with-Loss

ADAM, adaptive moment estimation; CNN, convolutional neural network; SGD, stochastic gradient descent; ViT, vision transformer

Supplementary Table S2. Computational complexity of the classification and segmentation models

	Classification model	Segmentation model
FLOPs	4.5 GFLOPS	10.7 GFLOPS
Parameters	22.5 M	13.3 M

FLOPs, floating point operations; GFLOPS, giga floating-point operations per second; M, million

Supplementary Table S3. Confusion matrix for evaluating the classification performance of HeartAssist

Results / GT values	TAV	4CV	LVOTV	RVOTV	3VV	3VTV	3VV PA	AAV	DAV	Bicaval view
TAV	657									
4CV		1,026	2							
LVOTV		4	658							
RVOTV				151	1	7	1	1	2	
3VV				14	314	20	3			
3VTV				2	19	185	1			
3VV PA			1	7	23	6	98	1		
AAV								516	3	
DAV								3	270	
Bicaval view			3					1	1	46

3VV, three-vessel view; 3VV PA, three-vessel view with pulmonary artery branches; 3VTV, three-vessel trachea view; 4CV, four-chamber view; AAV, aortic arch view; DAV, ductal arch view; GT, ground-truth; LVOTV, left ventricular outflow tract view; RVOTV, right ventricular outflow tract view; TAV, transverse abdominal view

Supplementary Table S4. Summary of previous studies on fetal cardiac image analysis and comparison with our study

Research	Year	Function	Technology	GA (weeks)	Dataset	Plane	Annotator	Expert validation	Performance
Xu *et al.* [1]	2020	Segmentation	DW-Net	N/A	895	4CV	Clinicians*	N/A	DSC: 0.827
Xu *et al.* [2]	2020	Segmentation	Cascaded U-Net	N/A	1,712	4CV	Doctors*	N/A	DSC: 0.856
Rachmatullah *et al.* [3]	2021	Segmentation	U-Net Otsu thresholding	18–23	519	4CV	N/A	N/A	Accuracy: 96.7%
Nurmaini *et al.* [4]	2021	Segmentation Detection	ResNet50 Mask R-CNN	18–24	1,149	4CV, 3VTV, LVOT, RVOT	2 MFM clinicians	N/A	mAP: 0.966 IoU: 0.800 DSC: 0.897
Zhang *et al.* [5]	2021	Classification Segmentation	FEN RPN CPN	20–34	1,455	4CV	2 sonographers	Sonographers*	mAP: 0.951 IoU: 0.945
Qiao *et al.* [6]	2022	Classification Detection	FLDS	N/A	1,250	4CV	2 radiologists	N/A	Recall: 0.971 mAP: 0.953 F1-score: 0.944
Our study		Classification Segmentation Annotation	CNN ViT	20–40	65,334	TAV, 4CV, LVOT, RVOT, 3VV, 3VTV, 3VV PA, AAV, DAV, Bicaval	1 expert in fetal echocardiography	1 expert in fetal echocardiography	Classification - Accuracy: 99.4% - Recall: 0.931 - Precision: 0.950 - F1-Score: 0.939; Annotation - Accuracy: 98.4%; Segmentation: - DSC: 0.974

3VV, three-vessel view; 3VV PA, three-vessel view with pulmonary artery branches; 3VTV, three-vessel trachea view; 4CV, four-chamber view; AAV, aortic arch view; CNN, convolutional neural network; CPN, Class prediction network; DAV, ductal arch view; DSC, Dice similarity coefficient; FEN, Feature extraction network; FLDS, feature learning detection system; GA, gestational age; IoU, Intersection over Union; LVOTV, left ventricular outflow tract view; mAP, mean average precision; RPN, Region proposal network; RVOTV, right ventricular outflow tract view; TAV, transverse abdominal view; ViT, Vision transformer; N/A, not available; MFM, maternal-fetal-medicine.

*Not mentioned how many experts were involved.

References

1. Xu, L. et al. DW-Net: A cascaded convolutional neural network for apical four-chamber view segmentation in fetal echocardiography. Computerized Medical Imaging and Graphics, 80, 101690 (2020).

2. Xu, L. et al. Convolutional-neural-network-based approach for segmentation of apical four-chamber view from fetal echocardiography. IEEE Access, 8, 80437–80449 (2020).

3. Rachmatullah, M. N. et al. Convolutional neural network for semantic segmentation of fetal echocardiography based on four-chamber view. Bulletin of Electrical Engineering and Informatics, 10, 1987–1996 (2021). DOI:10.11591/eei.v10i4.3060

4. Nurmaini, S. et al. Deep Learning-Based Computer-Aided Fetal Echocardiography: Application to Heart Standard View Segmentation for Congenital Heart Defects Detection. Sensors, 21, 8007 (2021). DOI:10.3390/s21238007

5. Zhang, B. et al. Automatic quality assessment for 2D fetal sonographic standard plane based on multitask learning. Medicine, 100, e24427 (2021). DOI:10.1097/MD.0000000000024427

6. Qiao, S. et al. FLDS: An intelligent feature learning detection system for visualizing medical images supporting fetal four-chamber views. IEEE Journal of Biomedical and Health Informatics, 26, 4814–4827 (2022).