Related Work Summary & Comparison Table

Related Work Summary

Fetal Phonocardiography (fPCG) has emerged as a promising, non-invasive, and low-cost alternative to traditional fetal monitoring methods like Cardiotocography (CTG) and fetal Electrocardiography (fECG). Recent research focuses on overcoming the primary challenge of fPCG: the low signal-to-noise ratio caused by maternal physiological sounds (heartbeat, respiration, digestion) and external environmental noise. The literature presented here covers signal extraction techniques, validation studies, dataset publication, and classification methodologies.

Signal Extraction and Validation

A significant portion of the work addresses the extraction of clean fetal heart signals from contaminated abdominal recordings. Khandoker et al. (2018) proposed a four-channel fPCG system utilizing a multi-lag covariance matrix-based eigenvalue decomposition technique to separate fetal heart sounds (fHS) from maternal sounds [1]. Their study validated the extracted beat-to-beat fetal heart rate (fHR) against fECG in 15 healthy pregnant women, achieving a high correlation ($r = 0.96$). Similarly, Ibrahim et al. (2017) applied a similar blind source separation (BSS) technique combined with wavelet denoising on data from 20 subjects [2]. Their comparative study validated the fPCG-derived heart rates against standard CTG, reporting a Spearman correlation of 0.95 and confirming the method's viability for detecting accelerations and decelerations in late pregnancy.

Methodological Reviews and Data Availability

The field is also supported by comprehensive reviews and the release of open datasets. Kahankova et al. (2023) provided an extensive review of state-of-the-art processing methods, including Wavelet Transform (WT), Empirical Mode Decomposition (EMD), and Adaptive Filters [3]. The review highlighted that while WT-based methods are dominant, performance varies significantly based on the mother wavelet and thresholding rules used. Addressing the scarcity of public data, Faiza et al. (2025) published a dataset of raw fPCG signals contaminated with maternal heart sounds, collected from 8 participants [4]. This dataset includes simultaneous ground-truth recordings from Doppler ultrasound and pulse oximeters, facilitating rigorous testing of separation algorithms.

Classification Approaches

Beyond extraction, automated classification of heart sounds is critical for diagnosis. Khan et al. (2019) explored machine learning approaches for classifying normal versus abnormal heart sounds using the Kaggle dataset [5]. By extracting time, frequency, and statistical features, they compared multiple classifiers, determining that a Bagged Tree model achieved the highest accuracy of 80.5%. While this study focused on general heart sounds, the authors noted the methodology's potential application to fetal abnormality detection.

Comparison of Studies

Table 1: Comparison of fPCG Studies and Methods

Title	Dataset Name & URL	Dataset Description	Methods Name	Accuracy	Pros	Cons	Citation
Validation of beat by beat fetal heart signals...	Proprietary (Tohoku Univ. Hospital)	**Samples:** 15 pregnant women (33-40 weeks). **Data:** 10-min simultaneous fPCG/fECG.	Multi-lag covariance matrix based eigenvalue decomposition; Wavelet Transform (WTST-NST)	**Correlation:** $r = 0.96$ (fHR vs fECG). **Mean diff:** -1.3 bpm.	Non-invasive; High correlation with fECG; Simple sensor harness.	Small sample size (15); Tested only on healthy late-term pregnancies; No public data.	[1]
A Comparative Study on Fetal Heart Rates...	Proprietary (Al Ain Hospital)	**Samples:** 20 pregnant women (>34 weeks). **Data:** Simultaneous fPCG and CTG.	Multi-lag covariance matrix decomposition; Multi-resolution wavelet denoising.	**Correlation:** Spearman $\rho =$ 0.95. **Mean diff:** -0.21 bpm.	Low-cost sensors; Validated against clinical CTG; Effective source separation.	Sensitive to sensor placement/noise; Limited to >34 weeks gestation.	[2]
A Review of Recent Advances...	Reviews multiple: SUFHSDB, SFPDB, FPCGDB	**Samples:** Varies (e.g., 109 subjects in SUFHSDB). **Classes:** Normal vs Pathological.	Review of: Wavelet Transform (WT), EMD, Blind Source Separation (BSS), Adaptive Filters.	Varies by study reviewed (e.g., 99.9% acc in some works).	Comprehensive overview of noise/methods; Lists open databases.	Review paper (no novel model); Notes lack of standardized large-scale databases.	[3]
Raw fetal PCG dataset contaminated with Mother's PCG	Mendeley Data (Open Access)	**Samples:** 8 pregnant participants (32-36+ weeks). **Data:** 21 recordings (1 min each).	Dataset Descriptor (Collection via stethoscope/mic; Validation via Doppler).	N/A (Data Article).	Open access; High sampling rate; Includes maternal/fetal references.	Small dataset (8 subjects); Raw data requires significant preprocessing.	[4]
Computer Aided Detection of Normal and Abnormal Heart Sound	Kaggle Heart Sounds `www.kaggle.com`	**Samples:** 118 recordings. **Classes:** Normal, Abnormal.	Bagged Tree, Subspace KNN, LDA, Quadratic SVM.	**Bagged Tree:** 80.5% **Quadratic SVM:** 70.3%	High specificity (96% TPR) for Bagged Tree; Compares multiple ML classifiers.	General PCG (not explicitly fetal); Limited feature set; Low accuracy for SVM.	[5]

References

[1] A. H. Khandoker, E. Ibrahim, S. Oshio, and Y. Kimura, "Validation of beat by beat fetal heart signals acquired from four-channel fetal phonocardiogram with fetal electrocardiogram in healthy late pregnancy," *Sci. Rep.*, vol. 8, no. 1, Art. no. 13635, Sep. 2018.

[2] E. A. Ibrahim, S. Al Awar, Z. H. Balayah, L. J. Hadjileontiadis, and A. H. Khandoker, "A comparative study on fetal heart rates estimated from fetal phonography and cardiotocography," *Front. Physiol.*, vol. 8, Art. no. 764, Oct. 2017.

[3] R. Kahankova, M. Mikolasova, R. Jaros, K. Barnova, M. Ladrova, and R. Martinek, "A review of recent advances and future developments in fetal phonocardiography," *IEEE Rev. Biomed. Eng.*, vol. 16, pp. 562–576, 2023.

[4] T. H. Faiza, M. S. Hossain, S. Islam, N. Sakib, T. Faruk, and M. K. Islam, "Raw fetal PCG dataset contaminated with mother's PCG," *Data Brief*, vol. 63, Art. no. 112107, Dec. 2025.

[5] M. F. Khan, M. Atteeq, and A. N. Qureshi, "Computer aided detection of normal and abnormal heart sound using PCG," in *Proc. 11th Int. Conf. Bioinf. Biomed. Technol. (ICBBT)*, Stockholm, Sweden, May 2019, pp. 62–66.