Detailed Methodology and Working of Fetal Heart Sound Extraction System Using SVM and Signal Processing Techniques

Introduction

Extracting fetal heart sounds (FHS) from noisy abdominal phonocardiograms (PCG) is a challenging but critical task in biomedical signal processing. FHS extraction aids in monitoring fetal health, diagnosing abnormalities, and ensuring proper fetal development. The proposed methodology combines advanced signal processing techniques with machine learning to achieve accurate extraction and classification of fetal heart sounds, even in the presence of noise and overlapping signals.

This document outlines the details of the methodology, from data preprocessing to model training and deployment, and explains how it ensures reliable and efficient signal enhancement and classification.

Components of the Methodology

1. Data Collection

The dataset comprises abdominal PCG recordings from pregnant women, collected during the 36th to 40th weeks of pregnancy. These recordings are mixed signals containing:

- **Fetal heart sounds**.
- **Maternal heart sounds**.
- **Environmental noise and interference**.

The recordings are often labeled to identify regions where fetal heart sounds are dominant, enabling supervised learning for classification.

2. Preprocessing

Preprocessing is essential for improving signal quality and preparing it for feature extraction and classification.

Savitzky-Golay Filtering:

- A smoothing filter applied to reduce high-frequency noise in the signal.
- **Key Advantages**:
  - Preserves the shape and features of the signal.
  - Avoids over-smoothing, which can distort the heart sounds.

Normalization:

- The amplitude of the signal is normalized to a specific range to ensure consistency across different recordings.

Segmentation:

- The signal is divided into smaller frames or windows to facilitate feature extraction and analysis.

3. Blind Source Separation (BSS)

Fast Independent Component Analysis (Fast ICA):

- Separates the mixed abdominal PCG into independent components.
- Works by maximizing the statistical independence of the components.
- Outputs multiple components, one of which is the fetal heart sound.

Advantages of Fast ICA:

- Effectively separates overlapping signals.
- Works well for single-channel recordings, making it ideal for abdominal PCG signals.

4. Feature Extraction

Features are extracted from both the time and frequency domains to represent the signal comprehensively.

Time-Domain Features:

- **Mean and variance**: To quantify the overall behavior of the signal.
- **Signal energy**: To distinguish between regions of high and low activity.
- **Zero-crossing rate**: Useful for detecting periodic signals like heart sounds.

Frequency-Domain Features:

- **Power spectral density (PSD)**: Represents the distribution of signal energy across frequencies.
- **Dominant frequency**: Indicates the primary frequency component of the fetal heart sound.

Wavelet-Based Features:

- Wavelet decomposition is applied to analyze the signal at multiple resolutions.
- Coefficients from specific frequency bands are used as features.

5. Classification Using Support Vector Machine (SVM)

Why SVM?

- SVM is a robust classifier that works well with small and imbalanced datasets.
- It maps input features to a higher-dimensional space using a kernel function, enabling better separability of classes (FHS vs. Noise).

Training Phase:

1. The preprocessed dataset is used to train the SVM model.

2. Features are labeled as either "Fetal Heart Sound" or "Noise."

3. The trained model is saved for future use.

Prediction Phase:

1. New signals are preprocessed, and features are extracted.

2. The saved SVM model is loaded.

3. Features are passed to the model to classify the signal as FHS or Noise.

6. Post-Processing and Output Generation

Once fetal heart sounds are identified and extracted:

- **Graphical Output**: The preprocessed signal, along with the extracted fetal heart sound, is plotted for visualization.

- **Audio Output**: The extracted fetal heart sound is saved as an audio file for playback and analysis.

Implementation Framework

Phase 1: Training

- Preprocess the dataset (filtering, segmentation).

- Extract features (time-domain, frequency-domain, wavelet-based).

- Train the SVM model using labeled features.

- Save the trained model.

Phase 2: Prediction and Deployment

- Preprocess the new signal.

- Extract features from the signal.

- Load the saved SVM model.

- Predict and classify segments of the signal.

- Output the extracted fetal heart sound as a graph and audio file.

Evaluation Metrics

To evaluate the effectiveness of the methodology, the following metrics are used:

- **Signal-to-Noise Ratio (SNR)**: Measures the enhancement of the fetal heart sound.

- **Accuracy**: Proportion of correctly classified signal segments.

- **Precision and Recall**: Evaluates the classifier's ability to identify fetal heart sounds without false positives or negatives.

- **F1-Score**: Balances precision and recall to provide a single performance metric.

Advantages of the Technique

1. **Robust Noise Handling**:

   o The combination of Savitzky-Golay Filtering and Fast ICA effectively removes noise and isolates fetal heart sounds.

2. **Accurate Classification**:

   o SVM ensures high accuracy, even with small datasets, due to its ability to handle non-linear separability.

3. **Portability**:

   o The method is designed for deployment on low-power devices like Raspberry Pi, making it suitable for real-world applications.

4. **Real-Time Capability**:

   o Efficient preprocessing and classification allow for real-time fetal heart sound extraction and monitoring.