Numerical Analysis 1

Mini-project Proposal Form

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PROJECT DESCRIPTION:

This project aims to create an electrocardiogram (ECG) signal denoising technique combining Singular Value Decomposition (SVD) and Fast Fourier Transform (FFT). The ECG signal is a frequently utilized tool for identifying different cardiac diseases, however it is frequently tainted by noise that can impair the diagnostic process. The suggested approach intends to enhance the ECG signal's diagnostic usefulness by removing noise.

The ECG signal will be broken down into its component parts using SVD as the first step in the algorithm. Using a thresholding method, this technique will determine which signal components have the highest noise in them. A clean ECG signal will subsequently be created by reconstructing the remaining signal elements using FFT.

Several measures, including the signal-to-noise ratio (SNR), root mean squared error (RMSE), and correlation coefficient (CC) between the denoised and original ECG signals, can be used to assess the algorithm's performance.

The overall goal of this research is to provide a reliable denoising method for ECG signals that can increase the signal's diagnostic value. The suggested approach is adaptable to other ECG-based diagnostic instruments and has the potential to enhance patient outcomes.

INPUTS AND OUTPUTS:

The input for this project would be the ECG signal contaminated with noise. The ECG signal would be obtained from Physionet databases. The signal may be in the time-domain or frequency-domain representation.

Link to Dataset: https://physionet.org/content/apnea-ecg/1.0.0/

The output of this project would be a denoised ECG signal that has improved diagnostic value. The denoised ECG signal will be in the time-domain. Additionally, the output will include metrics such as signal-to-noise ratio (SNR), root mean squared error (RMSE), and correlation coefficient (CC) between the denoised and the original ECG signals, to evaluate the performance of the algorithm.

SOLUTION ALGORITHM:

1. **Preprocessing:**
   - Apply a bandpass filter to the ECG signal to remove unwanted frequency components.
   - Normalize the signal to have zero mean and unit variance.
2. **Construct the Hankel matrix:**
   - Set the Hankel matrix window size L.
   - Form the Hankel matrix by stacking the columns of the matrix created by sliding the window along the ECG signal.

3. **Perform SVD on the Hankel matrix:**
    - Compute the SVD of the Hankel matrix to obtain the singular values and singular vectors.
    - Identify the noise components in the Hankel matrix by analyzing the singular values.
    - Determine the threshold value for removing the noise components.
    - Truncate the Hankel matrix by removing the noise components.
4. **Reconstruct the ECG signal using the inverse SVD:**
    - Compute the inverse SVD of the truncated Hankel matrix to reconstruct the denoised ECG signal.
5. **Apply FFT to the denoised signal:**
    - Apply FFT to the denoised ECG signal to convert it to the frequency domain representation.
    - If necessary, apply additional filtering in the frequency domain to remove residual noise.
    - Apply Inverse FFT to obtain a time domain representation of denoised signal.
6. **Performance evaluation:**
    - Calculate metrics such as signal-to-noise ratio (SNR), root mean squared error (RMSE), and correlation coefficient (CC) between the denoised and original ECG signals to evaluate the performance of the algorithm.

The above algorithm will be implemented on MATLAB. The details of the implementation may vary depending on the specific requirements of the project and the tools used. In addition, the selection of the Hankel matrix window size and the threshold for noise component removal may require some experimentation to obtain the best denoising performance.

CORNER CASES:

In the proposed project of denoising ECG signals using SVD on Hankel's matrix and FFT, there are several corner cases that should be considered to ensure the robustness and reliability of the algorithm. Some of these corner cases are:

1. **ECG signals with very low signal-to-noise ratio (SNR):** If the ECG signal has a very low SNR, the noise components can be close to or even exceed the amplitude of the ECG signal. In such cases, it can be challenging to separate the signal from the noise and the denoising algorithm may not work well.
2. **ECG signals with non-stationary noise:** If the noise in the ECG signal is non-stationary, such as sudden spikes or sudden changes in the frequency characteristics, the algorithm may not be able to effectively remove the noise.
3. **ECG signals with artifacts:** If the ECG signal contains artifacts such as muscle noise or electrode drift, the algorithm may not be able to distinguish the artifacts from the ECG signal and may inadvertently remove some of the ECG signal components.
4. **ECG signals with sharp waveform features:** If the ECG signal contains sharp waveform features such as QRS complexes, the FFT may not be able to accurately represent these features in the frequency domain due to the leakage effect, which can result in loss of information and reduced denoising performance.
5. **ECG signals with incomplete or missing data:** If the ECG signal contains incomplete or missing data, such as due to electrode detachment or lead failure, the algorithm may not be able to accurately reconstruct the missing data, which can affect the denoising performance.

To address these corner cases, it may be necessary to use additional preprocessing techniques, such as adaptive filtering or wavelet analysis, or to modify the denoising algorithm to better handle specific types of noise or signal characteristics. Additionally, thorough testing and validation using diverse datasets and types of noise can help to identify and address these corner cases.

TESTING:

I'll utilize a dataset of ECG signals with various kinds and amounts of noise to evaluate the technique. The Apnea - ECG Database is one such dataset that is often utilized in ECG signal processing studies.

The testing process can be broken down into the following steps:

1. Load the ECG signals from the dataset and add different types of noise such as baseline wander, powerline interference, and muscle artifact to simulate real-world scenarios.
2. Apply the denoising algorithm to the noisy ECG signals using both SVD on Hankel's matrix and FFT.
3. Calculate the performance metrics such as SNR, RMSE, and CC between the denoised and original ECG signals for both denoising methods.
4. Compare the denoised signals and performance metrics obtained using SVD on Hankel's matrix and FFT.
5. Analyze the results and draw conclusions about the effectiveness of each denoising method for the given types and levels of noise.

In addition to the Apnea – ECG Database, there are many other publicly available datasets that can be used for testing and validation of ECG signal denoising algorithms. The testing process can be repeated using different datasets and types of noise to obtain a more robust evaluation of the algorithm's performance.