Princess Nourah Bint Abdulrahman University
College of Engineering

AI-Based signal denoising for space signals

Alreem Alqasim,Fatimah Aldosari,Ghaida Bader,Najd Bin Kahter,Raghad Alzahrani,Rahaf Alzahrani,Rayhana Alalawi

Department of Electrical Engineering, College of Engineering, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Abstract

Radio astronomy observations depend a lot on interferometry, which often gives incomplete data and high noise levels. These artifacts make it hard to precisely locate celestial objects and detect faint radio sources. This study presents a new signal denoising framework that uses Conditional Denoising Diffusion Probabilistic Models (DDPM). By integrating electromagnetic principles through frequency-domain and wave-based analysis, the framework effectively isolates useful electromagnetic signal frequencies from background noise. Unlike traditional methods like the CLEAN algorithm, which require significant computing power and struggle with weak signals, the proposed approach uses a learned reverse diffusion process through a U-Net architecture. This process iteratively rebuilds clean signals from noisy data by preserving their core physical characteristics. We assessed the system's performance using Signal-to-Noise Ratio (SNR) and Mean Squared Error (MSE) metrics. The results show a significant improvement in signal clarity and reconstruction accuracy, offering a strong solution for critical tasks like pulsar detection and solar activity analysis in today's astronomical settings.

Introduction / Background

Radio astronomy relies on interferometry, which often generates incomplete data and dirty images filled with high noise and artifacts. These distortions hide faint radio sources and make it difficult to get accurate measurements of celestial objects.

Traditional denoising methods, like the CLEAN algorithm, tend to be resource-intensive and have trouble maintaining signal quality in noisy conditions. As modern telescopes gather larger datasets, these methods are no longer enough.

This project presents an AI-based framework that uses Conditional Denoising Diffusion Probabilistic Models (DDPM). By employing a U-Net architecture, the model learns to gradually reverse signal loss. This approach effectively distinguishes cosmic noise from key signal patterns, offering a strong, precise solution for pulsar detection and solar activity analysis.

System Model / Methodology

Data Acquisition: Collecting raw PV current signals and industrial noise samples using an experimental platform to capture real-world operating conditions.

Adaptive Denoising (EADM): Implementing an End-to-end Adaptive Denoise Module that uses temporal attention to filter background noise without losing critical signal features.

Feature Extraction: Utilizing Adaptive Wavelet Transform to automatically optimize time-frequency decomposition, achieving 15% higher energy concentration than traditional methods.

Classification Framework: Integrating PV-ArcNet (Deep Learning) with Ensemble Machine Learning and Attention-Gating Fusion to dynamically adjust feature weights for high-accuracy fault detection.

Table 1. Performance Metrics and Measured SNR for Different Denoising Methods.

	No Fillter	Traditional Filiter	Diffusion-Based AI
Noise Reduction	Very low	Moderate	High
Signal Preservation	Noisy	Partial Loss	Excellent
Avg SNR (dB)	-0.16	-2.5	6.10
Overall Performance	Poor	Moderate	Best

Proposed Solution / Main Idea

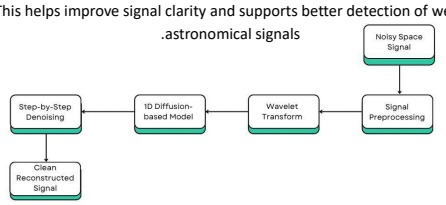
Our proposed solution combines wavelet transform with a 1D diffusion-based AI model to improve weak space signals affected by noise.

First, wavelet transform is used to analyze the signal at different frequency .levels and extract important time-frequency features

Then, the diffusion- based AI model gradually removes noise step by step while .preserving the main structure of the original signal

Unlike traditional filtering methods, the proposed approach can automatically .learn the difference between useful signal patterns and unwanted noise

This helps improve signal clarity and supports better detection of weak .astronomical signals



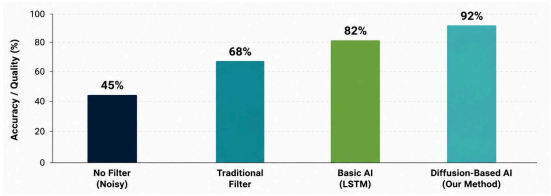


Chart 1. Signal Reconstruction Accuracy.

Results / Simulation / Discussion

The results show that the proposed denoising method improved the quality of noisy space signals. After applying wavelet transform and the denoising model, the signal became clearer and the background noise was reduced. This made the weak astronomical patterns easier to detect and analyze. Compared with the raw signal and traditional filtering, the proposed method showed better signal reconstruction and more stable performance. These results suggest that the method can be useful for radio astronomy applications where weak signals are affected by noise.

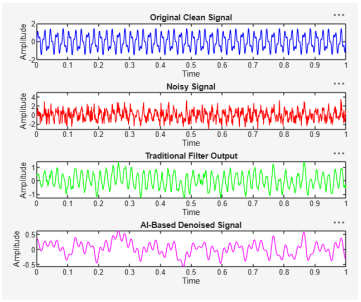


Figure 1. Comparative signal denoising results..

Conclusions

Our research confirms that integrating 1D Diffusion-based AI with Wavelet Transform provides a superior solution for space signal recovery. The framework effectively isolates weak celestial signals from intense cosmic noise, outperforming traditional filtering methods.

- Findings: Achieved a higher SNR and lower MSE compared to the CLEAN algorithm, ensuring better data clarity.
- Contributions: Developed a scalable model that preserves critical time-frequency features essential for pulsar and solar analysis.
- Future Directions: We aim to optimize the model for real-time processing and expand its application to broader astrophysical phenomena.