

Technical Report: AI-Powered Digital Signal Analysis System

Prepared by: Romina Farhad

Date: February 2026

Project Repository: <https://github.com/rominafarhad/pulse-ai-analyzer>

1. Executive Summary

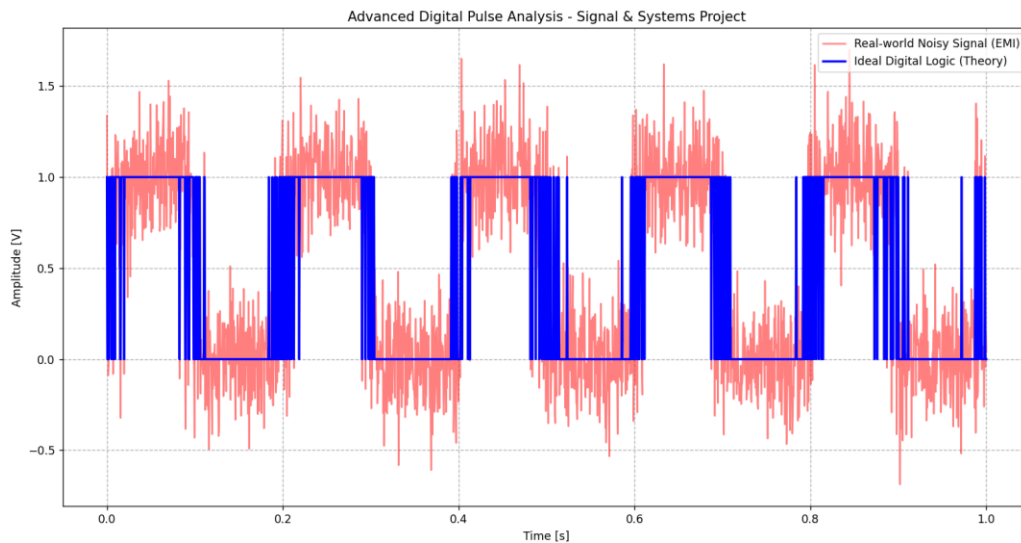
This project demonstrates a complete engineering pipeline for digital signal analysis. It involves simulating a digital pulse signal, applying Digital Signal Processing (DSP) filters to mitigate noise, and utilizing Unsupervised Machine Learning for automated anomaly detection.

2. Phase 1: Signal Simulation & Noise Modeling

In this stage, a 5Hz square wave was generated to simulate a digital clock signal. To replicate real-world conditions, Gaussian White Noise and Timing Jitter were introduced, representing Electromagnetic Interference (EMI) often found in industrial environments.

Objective: To create a "noisy" baseline for testing recovery algorithms.

Parameters: Sampling Rate = 2000Hz, Duration = 1.0s.

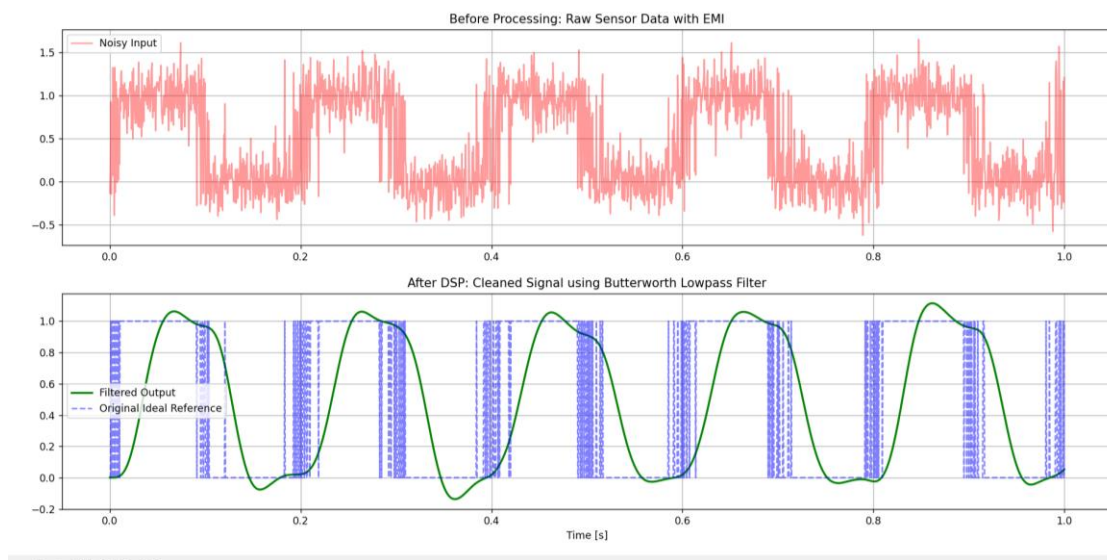


3. Phase 2: Digital Signal Processing (DSP)

To recover the original signal, a 4th-order Butterworth Low-pass Filter was implemented. This filter is designed to allow low-frequency logic transitions to pass while attenuating high-frequency noise.

Cutoff Frequency: 15Hz

Outcome: The filtered output (Green) shows a significant reduction in noise, restoring the pulse integrity required for digital logic interpretation.

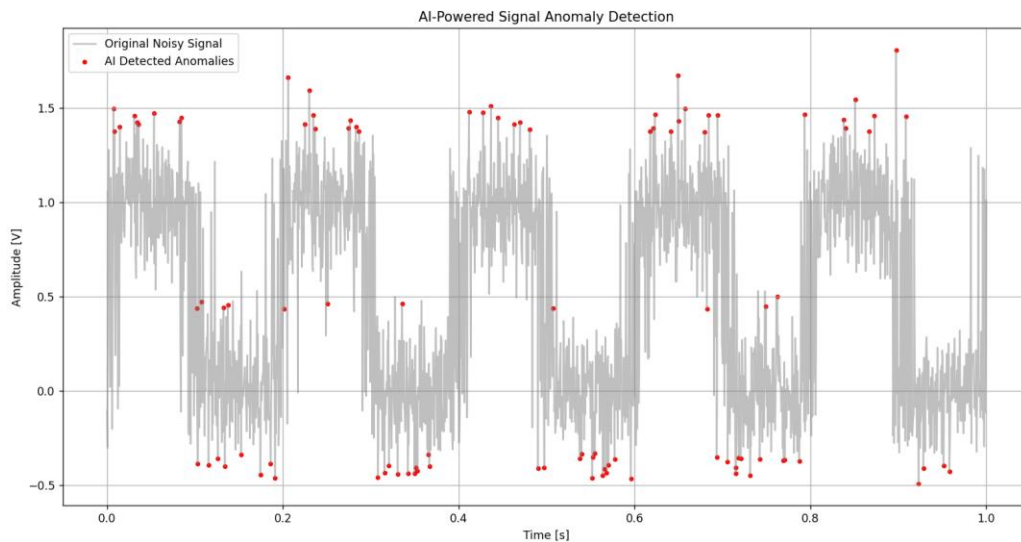


4. Phase 3: AI-Driven Anomaly Detection

Standard filtering might not identify specific transient errors. We integrated the Isolation Forest algorithm (Machine Learning) to detect outliers. This "Self-Diagnostic" feature automatically flags segments where the signal quality drops below acceptable thresholds.

Model: Scikit-Learn Isolation Forest

Detection Method: The AI labels points as anomalies based on their deviation from the learned signal pattern.



5. Conclusion

The integration of traditional DSP with AI provides a robust framework for Predictive Maintenance. By automatically identifying anomalies, the system can alert engineers to potential hardware failures before they occur, ensuring higher reliability in digital systems.