Software Injection Tests on DeepClean

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Overview

• Introduction

• Injection Dataset
  ◦ White Gaussian noise backgrounds
  ◦ Sine wave injections

• Dataset Properties on DeepClean

• Results: Software Injections and DeepClean

• Summary
Introduction

- Generate the white Gaussian noise background.
- Apply the band pass filter on background channels.
- Inject the sine wave with various frequencies.
- We will test the performance of:
  - Noise subtraction via DeepClean
  - Cross Spectrum Density of Strain-PEM and PEM-PEM
  - Transfer function around injected frequency.
Generate the white Gaussian noise background channels.

Apply Butterworth band pass filter: 100 - 150 Hz

White Gaussian Strain amplitude: $2e^{-20}$

White Gaussian PEM amplitude: $8e^{-3}$
Injection Dataset - Sine Wave Injection

- Inject sine wave with frequency: 125, 130, 135, 140, 145 Hz.
- Injection lasts for 300 seconds.
- Strain amplitude: 2e-21
- PEM amplitude: 8e-3 Pa
- No phase shift between Strain and PEM injection.
Dataset Properties

- GPS time to train: 1275891680 (duration: 320 seconds)
- GPS time to clean: 1275891680 (duration: 320 seconds)
- Strain channel: K1:CAL-CS_PROC_CO00_STRAIN_GAUSSIAN
- PEM channel: K1:PEM_Gaussian
- Sampling rate: 4096 Hz
- Bandpass filter: 10 Hz wide, centered at the injected frequency
- Epochs: 20

Loss function:

- $J = 1 \times J_{asd} + 0 \times J_{mse}$ : 125, 130, 135, 140, 145 Hz
- $J = 0 \times J_{asd} + 1 \times J_{mse}$ : 125, 130, 135, 140, 145 Hz
- $J = 0.5 \times J_{asd} + 0.5 \times J_{mse}$ : 125, 130, 135, 140, 145 Hz
Loss Function

- Loss function can be written as $J = \omega J_{asd} + (1 - \omega) J_{mse}$

- $\omega$ is a weighting factor that goes from 0 to 1.

- Amplitude spectrum density (ASD) loss function: $J_{asd} = \frac{1}{M} \sum_{i=0}^{M-1} \sqrt{\frac{S[r, r][i]}{S[h, h][i]}}$

  - $M$ is the number of frequency bins.

- Residual $r(t) = h(t) - p(t)$

- Raw strain data $h(t)$

- Predicted noise in strain $p(t)$

- Mean Squared Error (MSE) loss function: $J_{mse} = \frac{1}{N} \sum_{i=0}^{N-1} r[i]^2$

  - $N$ is the number of time-series samples.
\[ J = 1 \times J_{asd} + 0 \times J_{mse} \]
125 Hz
Predicted Strain (125 Hz)
ASD: Predicted Strain (125 Hz)
Raw and Cleaned Strain (125 Hz)
CSD: Strain-PEM (125 Hz)
CSD: PEM-PEM (125 Hz)
Transfer Function (125 Hz)
130 Hz
Predicted Strain (130 Hz)
ASD: Predicted Strain (130 Hz)
Raw and Cleaned Strain (130 Hz)
CSD: Strain-PEM (130 Hz)
CSD: PEM-PEM (130 Hz)
Transfer Function (130 Hz)
135 Hz
Predicted Strain (135 Hz)
ASD: Predicted Strain (135 Hz)
Raw and Cleaned Strain (135 Hz)
CSD: Strain-PEM (135 Hz)
CSD: PEM-PEM (135 Hz)
Transfer Function (135 Hz)
Predicted Strain (140 Hz)
ASD: Predicted Strain (140 Hz)
Raw and Cleaned Strain (140 Hz)
CSD: Strain-PEM (140 Hz)
CSD: PEM-PEM (140 Hz)
Transfer Function (140 Hz)
145 Hz
Predicted Strain (145 Hz)
ASD: Predicted Strain (145 Hz)
Raw and Cleaned Strain (145 Hz)
CSD: Strain-PEM (145 Hz)
CSD: PEM-PEM (145 Hz)
Transfer Function (145 Hz)
\[ J = 0 \times J_{asd} + 1 \times J_{mse} \]
125 Hz
Predicted Strain (125 Hz)
ASD: Predicted Strain (125 Hz)
Train Data ASD: Raw Strain and Cleaned Strain (125 Hz)
CSD: Strain-PEM (125 Hz)
CSD: PEM-PEM (125 Hz)
Transfer Function (125 Hz)
130 Hz
Predicted Strain (130 Hz)
ASD: Predicted Strain (130 Hz)
Train Data ASD: Raw Strain and Cleaned Strain (130 Hz)
CSD: Strain-PEM (130 Hz)
CSD: PEM-PEM (130 Hz)
Transfer Function (130 Hz)
135 Hz
Predicted Strain (135 Hz)
ASD: Predicted Strain (135 Hz)
Raw and Cleaned Strain (135 Hz)
CSD: Strain-PEM (135 Hz)
CSD: PEM-PEM (135 Hz)
Transfer Function (135 Hz)
Predicted Strain (140 Hz)
ASD: Predicted Strain (140 Hz)
Results of Epoch = 30 (see P156)
CSD: Strain-PEM (140 Hz)
CSD: PEM-PEM (140 Hz)
Transfer Function (140 Hz)
ASD: Predicted Strain (145 Hz)
Raw and Cleaned Strain (145 Hz)
CSD: Strain-PEM (145 Hz)
CSD: PEM-PEM (145 Hz)
Transfer Function (145 Hz)
\[ J = 0.5 \times J_{asd} + 0.5 \times J_{mse} \]
125 Hz
Predicted Strain (125 Hz)
ASD: Predicted Strain (125 Hz)
Raw and Cleaned Strain (125 Hz)

Results of Epoch = 40 (see P149)
CSD: Strain-PEM (125 Hz)
CSD: PEM-PEM (125 Hz)
Transfer Function (125 Hz)
130 Hz
Predicted Strain (130 Hz)
ASD: Predicted Strain (130 Hz)
Raw and Cleaned Strain (130 Hz)
CSD: Strain-PEM (130 Hz)
CSD: PEM-PEM (130 Hz)
Transfer Function (130 Hz)
Predicted Strain (135 Hz)
ASD: Predicted Strain (135 Hz)
Raw and Cleaned Strain (135 Hz)
CSD: Strain-PEM (135 Hz)
CSD: PEM-PEM (135 Hz)
Transfer Function (135 Hz)
140 Hz
Predicted Strain (140 Hz)
ASD: Predicted Strain (140 Hz)
Raw and Cleaned Strain (140 Hz)
CSD: Strain-PEM (140 Hz)
145 Hz
Predicted Strain (145 Hz)
ASD: Predicted Strain (145 Hz)
Raw and Cleaned Strain (145 Hz)
CSD: Strain-PEM (145 Hz)
CSD: PEM-PEM (145 Hz)
Transfer Function (145 Hz)
Summary

- We prepare the white Gaussian noise background channels.

- We apply the Butterworth band pass filter (100–150 Hz) on background channels.

- We prepare the 300 seconds long single-frequency injection to the strain and PEM channels.

- In this test, we have shown
  - ASD+MSE and MSE loss functions show better performances on noise subtraction via DeepClean than ASD loss function only.
  - Cross Spectrum Density (CSD) of Strain-PEM and PEM-PEM around injected frequency.
  - Transfer function around injected frequency.
Background: Strain and PEM
125 Hz
Background: Strain and PEM
Sine Wave Injection: Strain and PEM
Injected Background: Strain and PEM

**Injected STRAIN**

- Dimensionless value ranges from $-7.5 \times 10^{-21}$ to $7.5 \times 10^{-21}$
- Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)

**Injected PEM**

- Dimensionless value ranges from $0.0000$ to $0.0100$
- Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)
Strain ASD: Background and Injection
PEM ASD: Background and Injection
130 Hz
Background: Strain and PEM
Sine Wave Injection: Strain and PEM
Injected Background: Strain and PEM
Strain ASD: Background and Injection
PEM ASD: Background and Injection
135 Hz
Background: Strain and PEM
Sine Wave Injection: Strain and PEM

**Strain**

- y-axis: Dimensionless
- x-axis: Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)

**PEM**

- y-axis: Dimensionless
- x-axis: Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)
Injected Background: Strain and PEM

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Injected STRAIN

Dimensionless [0; 10^{-21}]

Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)

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Injected PEM

Dimensionless [0; 0.010]

Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)
Strain ASD: Background and Injection

Strain ASD: Background and Injection (135 Hz)

- **Background**
- **Injection**

![Graph showing Strain ASD: Background and Injection](image)
PEM ASD: Background and Injection
140 Hz
Background: Strain and PEM
Sine Wave Injection: Strain and PEM

**STRAIN: Sine Waves Injection**

- Dimensionless $[\times 10^{-21}]$
- Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)

**PEM: Sine Waves Injection**

- Dimensionless $[\times 10^{-3}]$
- Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)
Injected Background: Strain and PEM

Injected STRAIN

Injected PEM
Strain ASD: Background and Injection

![Graph showing Strain ASD: Background and Injection (140 Hz)]
PEM ASD: Background and Injection

PEM ASD: Background and Injection (140 Hz)
145 Hz
Background: Strain and PEM

**STRAIN: Before Injection**

**PEM: Before Injection**
Sine Wave Injection: Strain and PEM
Injected Background: Strain and PEM
Strain ASD: Background and Injection
PEM ASD: Background and Injection
125 Hz with

\[ J = 0.5 \times J_{asd} + 0.5 \times J_{mse} \]

Epoch = 40
ASD: Predicted Strain (125 Hz)
Raw and Cleaned Strain (125 Hz)
CSD: Strain-PEM (140 Hz)
CSD: PEM-PEM (125 Hz)
Transfer Function (125 Hz)
140 Hz

\[ J = J_{mse} \]

Epoch = 30
Predicted Strain (140 Hz)
ASD: Predicted Strain (140 Hz)
Raw and Cleaned Strain (140 Hz)
CSD: Strain-PEM (140 Hz)
CSD: PEM-PEM (140 Hz)
Transfer Function (140 Hz)