Acoustic Noise in Gravitational-wave Detectors

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Introduction

• The sensitivity of gravitational-wave detectors can be affected by sporadic short-duration noises (so-called glitches) from distinct non-astrophysical sources.

• It is essential to find the glitches' origin to mitigate them.

• We employ machine learning techniques to identify acoustic noise that produces glitches in gravitational-wave detectors.

• We summarize the feature extraction procedures, unsupervised and supervised learning combined with parallel computing techniques to achieve this goal.

This work is possible thanks to the efforts of the LIGO, Virgo, KAGRA scientific collaboration members.
Background

- **Gravitational waves** are ripples in the space time.
- Gravitational-wave detectors are extremely sensitive instruments, capable of measuring changes in distance thousand of times smaller than the diameter of a proton.
Background

• Gravitational-wave detectors such as LIGO, consist of an L-shape laser interferometer and several auxiliary systems that make its control possible.

• LIGO uses thousands of sensors monitoring its status and local environment to characterize its behavior and noise.
Motivation

In summary:
• We have a lot of noise and a lot of data to analyze.
• We need an automated tool to find the noise’s origin.

This work can help to:
• Improve the detector’s sensitivity.
• Validate candidate events.
Acoustic Noise

• We call acoustic noise the one recorded by microphones.
• We choose it because we consider it easier to recognize by humans.
• We use Omicron triggers to collect the data.
• Omicron is a computational tool that finds segments (so-called triggers) of data distinct from the rest.
For example:

- **Thunderstorms** are frequent in the south of Louisiana, USA.
- Rumbling thunder strikes **elevate ground motion**.
- **Light-scattering** noise is generated when light is reflected from moving surfaces and resonates in optical cavities.
- Scattering **reduces** the gravitational-wave detector’s **sensitivity**.
Acoustic noise in LIGO Livingston during O3

• We use Omicron triggers of the LIGO Livingston X-end microphone.

• The high count of triggers on Sundays between 14:00 h and 22:00 h contrasts with the low trigger count on Tuesdays because we studied observing times.

• The detector is more likely to be locked on the quiet Sunday afternoons than on Tuesdays, dedicated for maintenance.
Acoustic Noise Identification

This work has been developed with the help of graduate students at the Texas A&M University - Laboratory of Space Systems and Optomechanics.

- Feature extraction
- Dimensionality reduction
- Clustering
- Classification
Feature Extraction

• The **mel-frequency cepstral coefficients (MFCC)** are features that encode the sound to mimics the function and capabilities of the human ear.

• They were introduced in the 1980s and used in speech recognition and environmental sound classification.

• In MATLAB – Audio Toolbox and in Python – Librosa package.

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**Figure 1:** The mel-filterbank is designed as half-overlapped triangular filters equally spaced on the mel-scale.
High-throughput computing

• High-throughput computing (HTC) is the use of distributed computing facilities for applications requiring large computing power over a long period of time [1].

1. Rajkumar Buyya, ... S. Thamarai Selvi, in Mastering Cloud Computing, 2013

• HTC is a resource to complete your analyses in a shorter time.

• HTCondor is an open-source HTC software framework.

• The Open Science Grid (OSG) is a nationally-funded consortium of computing resources available for most researchers.
High-throughput computing

- We need 3 files to complete the feature extraction of several samples.
Dimensionality reduction and clustering

- For dimensionality reduction, we employ t-distributed stochastic neighbor embedding (t-SNE).
- We use spectral clustering, a graph-based algorithm for clustering data points.
- We use triggers with SNR > 100 (665 observations) since we expect these loud triggers to affect the detector’s sensitivity if any.
What is the effect on the detector?

Thunderstorm

Vehicle

Closing door
Classification

• MATLAB offers a convenient tool to compare the performance of the classifiers.

• We use the same data set to train the classifiers.

• Once we choose a classifier, we can use it for other microphones.
Summary

• Gravitational-wave detectors are extremely sensitive and are affected by local environmental noise.

• We employ microphones, machine learning techniques, and high-throughput computing to find the origin of the noise.

• We use mel-frequency cepstral coefficients to obtain features from the microphones’ recordings.

• Noise produced by events such as thunderstorms and passing-by-vehicles couple into the detector output.

• Our tool can be used to complement the Data Quality Reports for gravitational-wave event candidates.
Resources

• MFCC introduction
  • https://medium.com/prathena/the-dummys-guide-to-mfcc-aceab2450fd

• Computational options
  • https://librosa.org/doc/latest/index.html
  • https://www.mathworks.com/help/audio/ref/mfcc.html

• High-throughput computing
  • https://support.opensciencegrid.org/support/home