Anomalous Quench in Superconducting Coils

A Machine Learning Perspective

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The Physics

Fermilab uses high-energy superconductors for particle physics experiments.

These are built using coils of magnetic material that are about 1/2" in diameter. The coils carry current that becomes supercharged at levels up to 14.5 TeV

As the current is varied from i=0, physical imperfections arise in the coil

These imperfections lead to an energetic saturation called a ***quench***. This is the same phenomenon as in seismic activity, where a rift, break, or imperfection occurs in a material.

The quench is audible, and can be detected using acoustic sensors placed at the beam site

As such, superconducting magnets must be trained by gradually raising the current to approach full capacity

The Problem

Quench is not a well understood problem

- nonlinear system
- industrial environmental noise

Anomalies in machine operating sounds occur before the magnet saturates and are audible. The goal is to predict the quench before it happens to avoid a total shutdown of the experiment. This can be costly at best, and dangerous at worst due to the sudden buildup of energy in the beam.

The goal of my project is to determine when the magnet is going to quench by comparing anomalous and normal audio data from the magnet under normal operating conditions.

Methods

The DCASE Challenge is a tutorial for anomaly detection in industrial applications

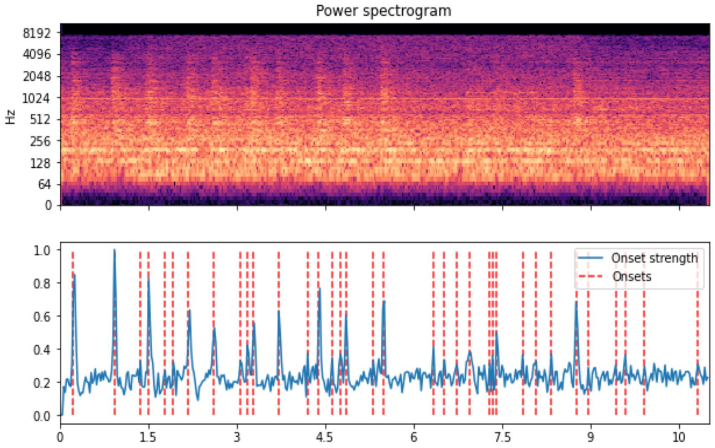
We explore a variety of methods used to determine anomaly scores for the data

Keras model is run to train and test anomaly score for the data

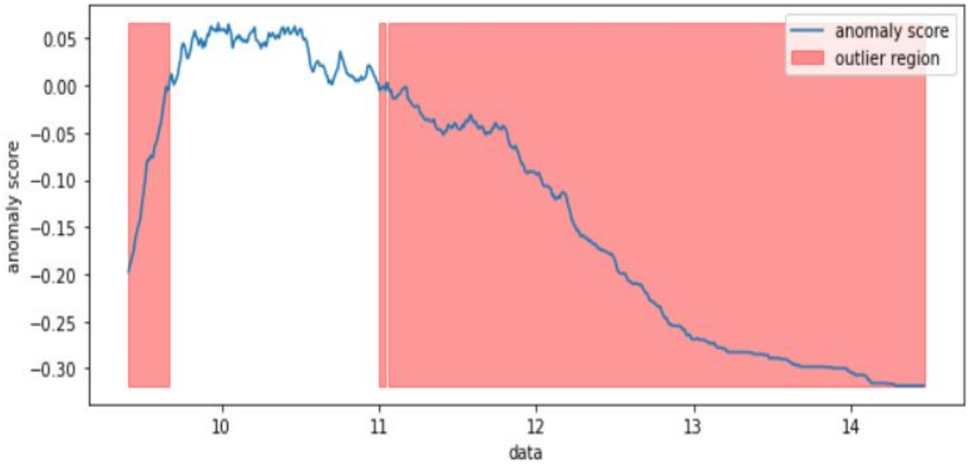
Execute various low-level MIR tasks to the audio data for analysis

Statistical analysis and an isolation forest let us compare anomaly regions

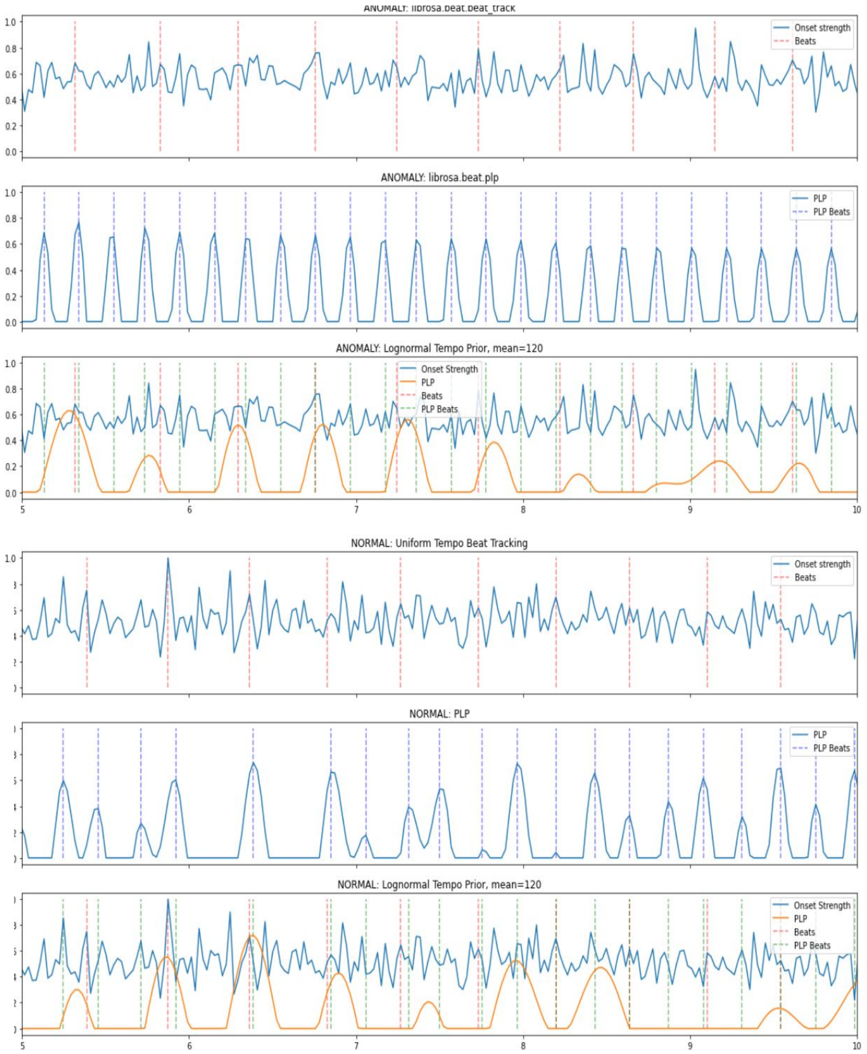
Results



Power spectrogram
Hz
8192
4096
2048
1024
512
256
128
64
0
Onset strength
Onsets
1.0
0.8
0.6
0.4
0.2
0.0
0
1.5
3
4.5
6
7.5
9
10



anomaly score
outlier region
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
10
11
12
13
14
data



ANOMALY: librosa.beat.beat_track
Onset strength
Beats
ANOMALY: librosa.beat.plp
PLP
PLP Beats
ANOMALY: Lognormal Tempo Prior, mean=120
Onset Strength
PLP
Beats
PLP Beats
NORMAL: Uniform Tempo Beat Tracking
Onset strength
Beats
NORMAL: PLP
PLP
PLP Beats
NORMAL: Lognormal Tempo Prior, mean=120
Onset Strength
PLP
Beats
PLP Beats

The Future

The eventual goal is to use the info from anomaly detection to set an audio pattern at the beam site that will give ample notice of the anomalous sounds in the machine.

This will be deployed using low power applications of machine learning: tinyML