ML systems for detection of Intrusions / Leaks in gas pipelines using Distributed Acoustic Sensing data

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Overview

Introduction

- Can we monitor pipelines using fiber optic cables ?

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- Yes! But How?

Introduction

- Can we monitor pipelines using fiber optic cables ?
- A fiber optic cable can be re-purposed as a distributed sensor
- With the profile of light sent into the fiber and its back-scattering profile, the fiber can sense acoustic and temperature changes in its vicinity.

In a nutshell

- When there is a perturbation (acoustics / vibration), the frequency of the perturbation causes strain in the optical fiber.
- The strain induced in the optical fiber due to perturbation results in phase changes in the back scattering profile.

Motivation

- When used as a distributed sensor, the optical fiber is a very sensitive data acquisition medium, which records very minute details

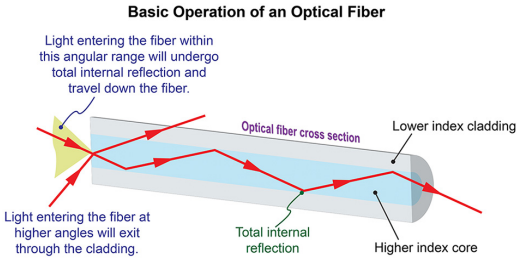

Figure: Working Principle of an optical fiber

Motivation

- Optical fibers can detect / record the events in their vicinity by looking at the changes in their system due to vibrations, acoustics and temperature.

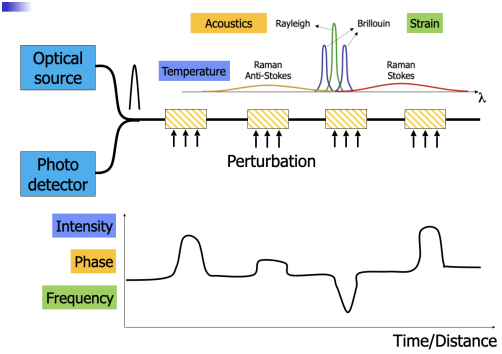

Figure: Working Principle of DAS

Motivation

If someone walks over a fiber optic cable which is buried, it can be detected!

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Why ML for DAS?

- DAS is used to monitor infrastructure. Events near infrastructure can be detected using anomalous values.
- But, it is essential to classify events to prevent damage.

Why ML for DAS?

- We have data and labels!

Problem Statement

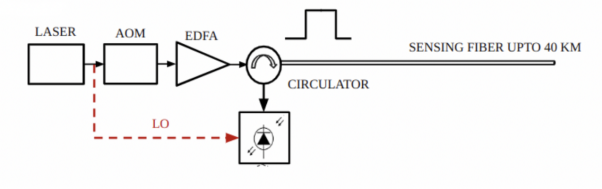
With a given optical fiber network, using data from DAS setup, detect and classify intrusions and leak for gas pipelines.

Existing Literature

- [Shiloh et al., 2019] proposed a CNN based model to classify events using data from both PSD & Phase plots - this uses VGG16 based networks - where the DAS data is generated using GAN networks
- Support Vector Machines and Neural Network based methods were proposed by [Tejedor et al., 2017] - The review paper also lists other methods to do event classification based of Gaussian Mixture Models and Hidden Markov Models - they have used real time data from a testbed with only 3 type of events
- [Sun et al., 2020] have proposed a model based on CNN layers - using Phase plots - the model uses real time data from fibers of length less than 5 km

Data Acquisition

- The setup contains a fiber amplifier and a reviver connected to the same end of the fiber.



Data - Waterfall Plots

- With the setup, we get the I & Q components of the signal. With this, the change of phase is calculated and plotted in time domain.
- This is a called as a **Waterfall plot**

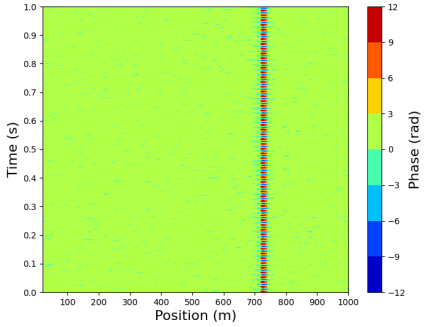


Figure: 1km Fiber, a repeating event at 720m

Data - Spectral Plots

- The periodogram (fast Fourier transform) of the phase plot gives the changes in power of the back scattered light plotted in frequency domain. This gives the power spectral density of the given data.
- This is a called as a **Spectral plot**

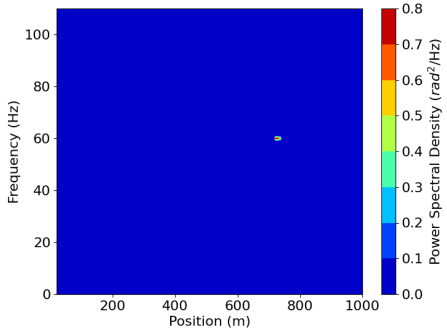
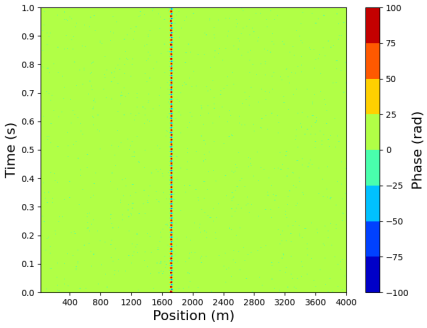
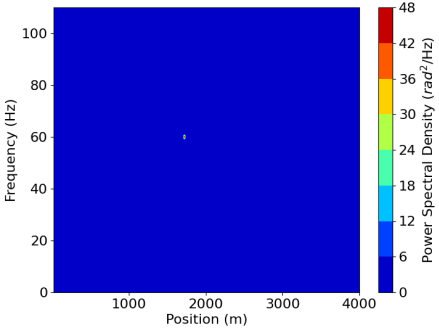


Figure: 1km Fiber, with a repeating event with 70Hz perturbation at 720m

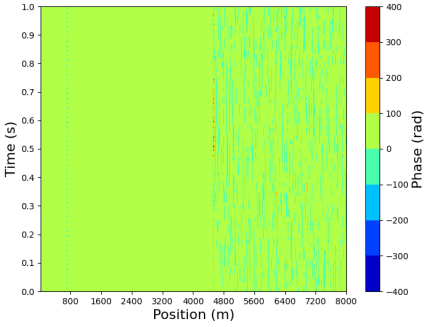
Data - More examples

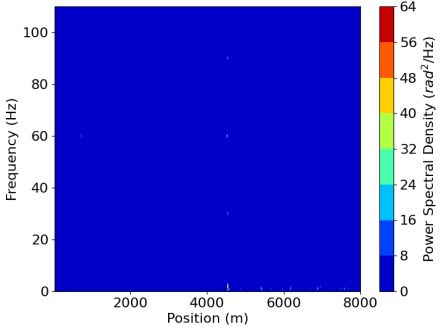




4km Fiber, with a repeating event with 60Hz perturbation at 1700m

Data - More examples





8km Fiber, with two repeating events with 60Hz and 90Hz perturbation at 4500m and 700m respectively

Data Acquisition @ IIT-M

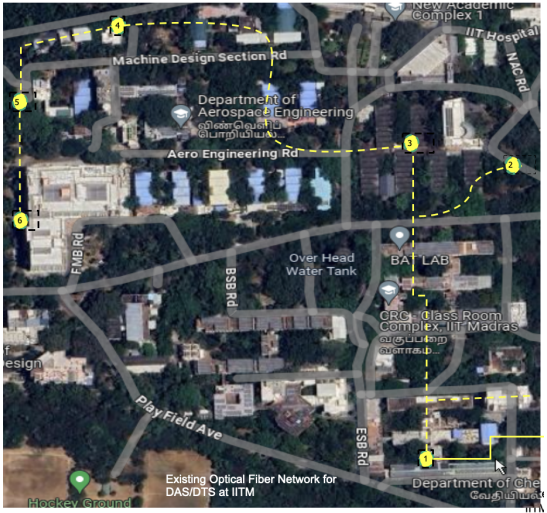


Figure: Optical fiber network inside IITM campus

Real Time Data

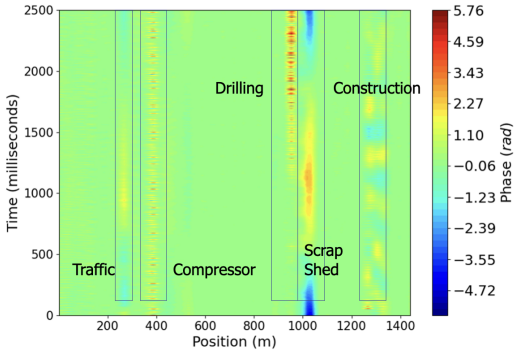


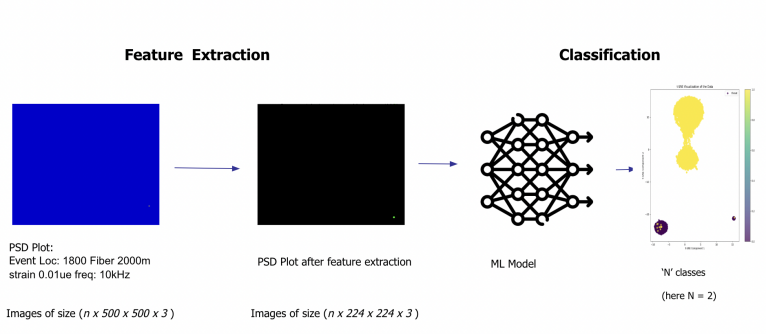
Figure: 1.5km Fiber, with multiple events recorded on campus

DAS Dataset

- Currently, the dataset is organized into classes - threat and no_threat, created using simulations
  - threat class contains 12800 PSD plots
  - no_threat class contains 3840 PSD plots
- More data is being collected to create a multi class dataset with specific events (e.g.) using an excavator, using a jack hammer, etc.

Model

- The benchmark model is based on FiberNet by Shiloh et el which uses learned representations from a VGG16 based network to do classification.
- Our initial model was based on SVMs with PCA used for feature extractions.



Model

- Our current model consists of [He et al., 2015]'s ResNet18 network as a feature extraction network and a SVM as a classifier.
- This is the robust model so far with a testing accuracy of 98%

Results

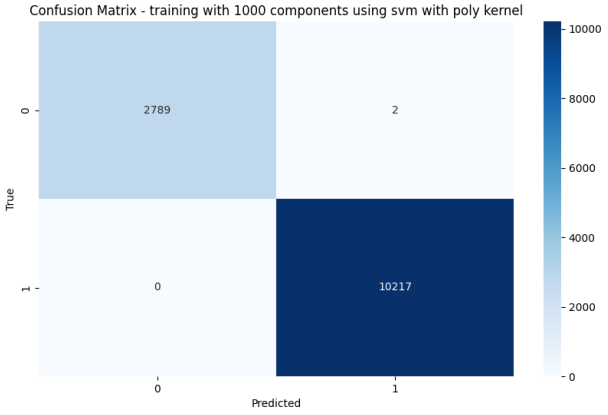


Figure: Confusion matrix for training

Results

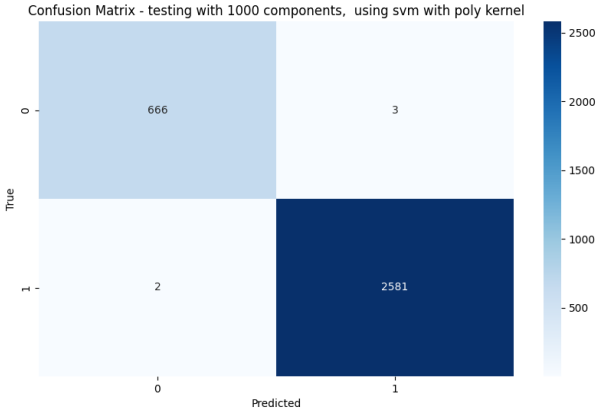


Figure: Confusion matrix for testing

Challenges

- When there are more than one event happening at the same location at same time, it is hard to classify the event - it has to be posed as a multi label classification problem.
- Simulation images have events which are happening due to specific frequencies. In reality, the perturbations happen due to a spectrum of frequencies.

Future Scope

- To build a model which can detect events due to a spectrum of frequencies
- Check if a multi label classification setup can be done for this problem.

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Acknowledgments

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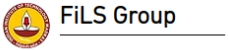

Russia's war on Ukraine latest: Pipelines likely sabotaged by pro-Ukraine group

Reuters

Thank you!