Realizing City-scale Infrastructure Intelligence via Extensive Dynamic Analysis

-- WE RE-INVENTING VIBRATION MONITORING

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NEEDS/GAPS

Aging Infrastructure

Gov . earmarks $300 mill. to help 4500 buildings for maintenance works.

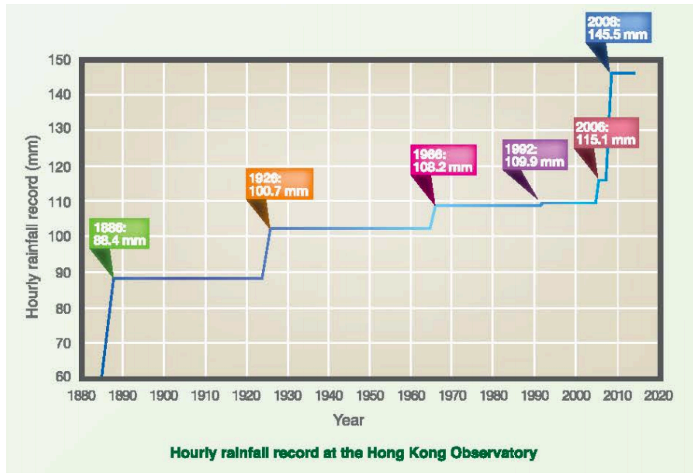
Predictive maintenance

The ultimate solution to targeted resource allocation and timely repair.
A powerful method is available to trace the fatigue behavior of materials is to monitor and perform frequency analysis on the large-scale vibrational movement.

BACKGROUND

Climate Change

Adverse impacts of climate change and uncertainty extreme weather (e.g. rainfall) causing non-uniform loadings challenge the stability of structures [1].



Available Sensor Nodes

Development of Analysis Methods Based on 50 low-cost yet accurate sensor nodes installed in Hong Kong, Taiwan and China[2].

4th generation OpenSSP		Trimble REFTEK 130S-01
3 x 3-CH Accelerometers 1 x 1-CH Gyroscope 1 x 3-CH Magnetometer	vs.	3 or 6-CH
24-bit ADC (add-on)		24-bit ADC
500-1000 Hz Sampling Rate		1000 Hz Sampling Rate
10 μsec Accurate GPS Clock		10 μsec Accurate GPS Clock (External)

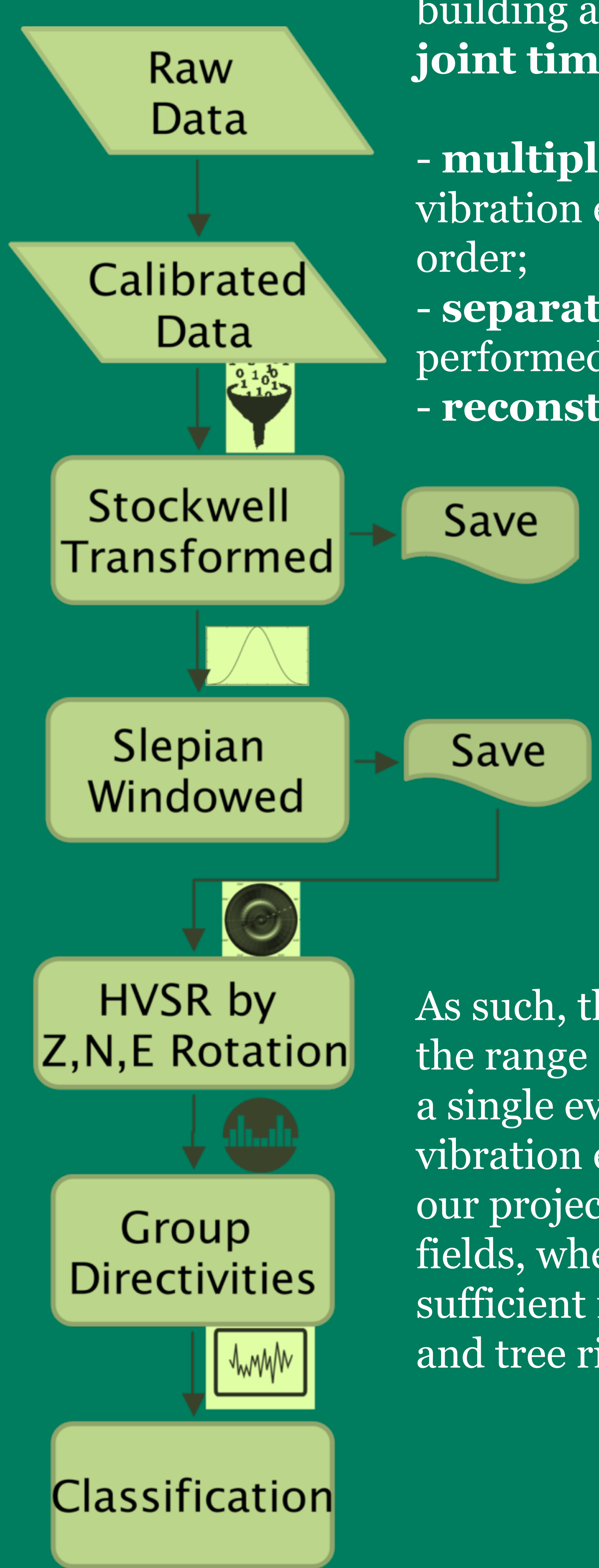
PAIN POINTS OF TECHNOLOGIES

In the times of aging infrastructures and the uncertainty of extreme weather [3], maintenance in civil engineering has been harder than ever before.

- Rare Earthquake Event for Monitoring
- Mixed Modes of vibration within Each Event
- High Cost to Satisfy Monitoring Set Up Requirements

To create the **paradigm** of predictive maintenance by enabling wide-scale terrestrial deployment of accelerometers **without** compensating the data accuracies; **augment** the range of features that can be generated from a single event, giving solution to the deficiency of vibration event and data records.

Procedures & Innovative Methodology



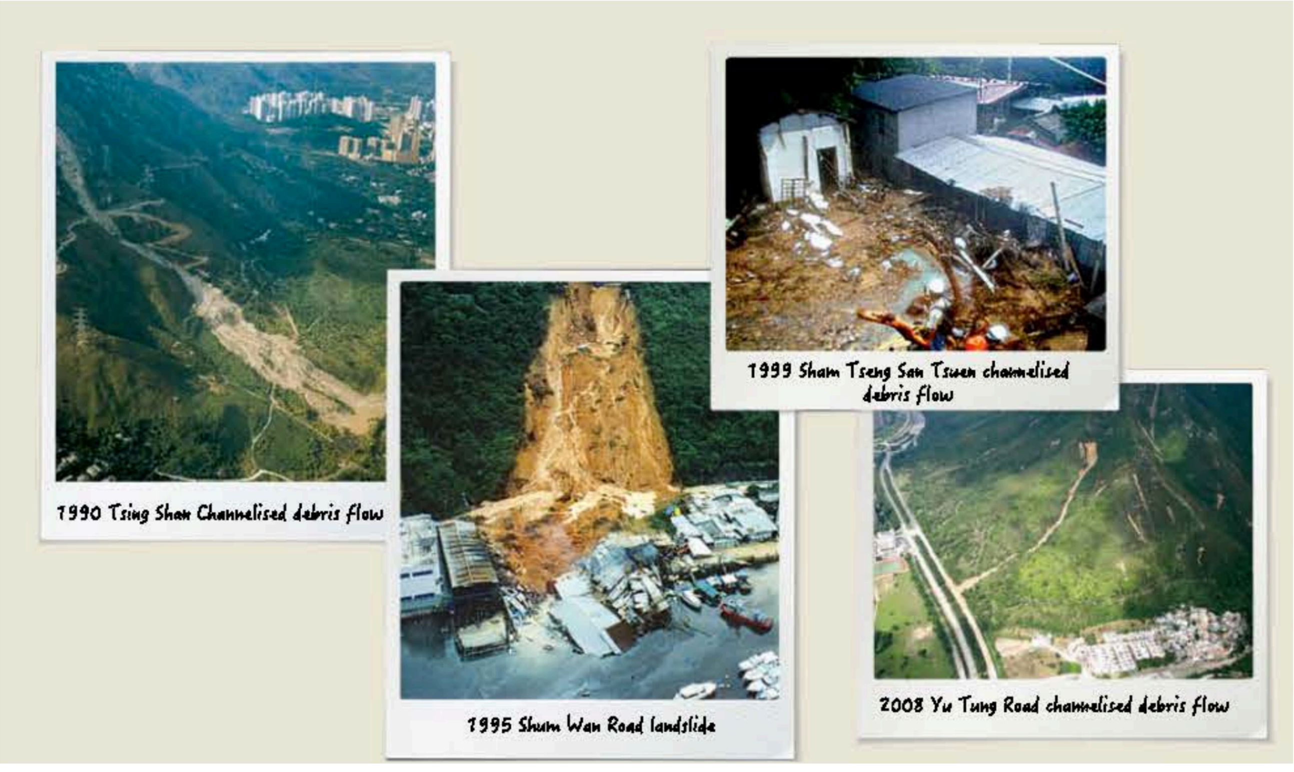
Our goal is to solve the above pain points by building a set of dynamic analytical tools on top of **joint time-frequency representation** so that:

- **multiple features** can be extracted from a single vibration event for data-driven analysis to be in order;
- **separation of vibration modes** can be performed and finally,
- **reconstruction** of the slope response.

As such, these techniques successfully augment the range of features that can be generated from a single event, giving solution to the deficiency of vibration event and data records. The concept of our project is suitable to be applied to other fields, where vibration is catchable with sufficient intensity (e.g., Machinery diagnostics and tree risk monitoring).

Urgency of Slope Failures in Hong Kong :

- Climate Change
- Large Terrain Area
- Dense Urban Development
- High Population



Slope as An Example:

The slope is a typical and common component of infrastructures study failures of slopes considering its frequent occurrence in Hong Kong with disastrous consequences.

References

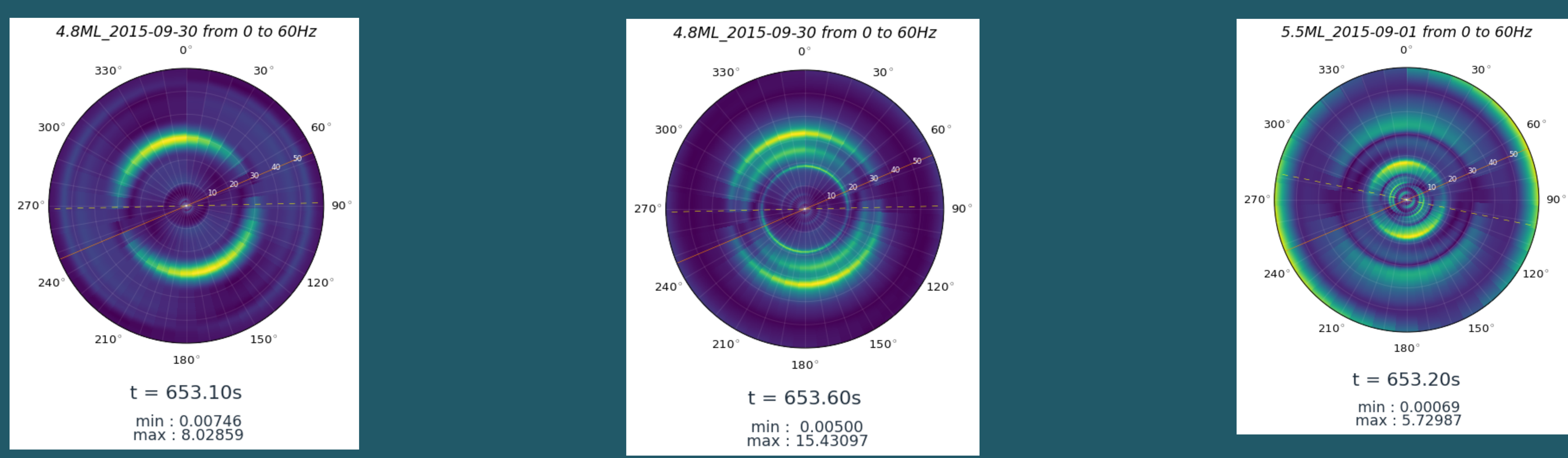
[1] Improved seismic monitoring: improved decision-making: assessing the value of reduced uncertainty. Washington, D.C.: National Academies Press, 2006.
[2] TAN Pin Siang (2015). A Scalable Architecture for Continuous, In-time Landslide Early Warning and Monitoring. Hong Kong University of Science and Technology, 2015, p. 120-134.
[3] Ellingwood, B. (2000) Performance-Based Design: Structural Reliability Considerations. Advanced Technology in Structural Engineering: pp. 1-8.

Results & Discussion

*Perform evolution and aggregation across Multiple Earthquake Events through **Time-Frequency Representation***

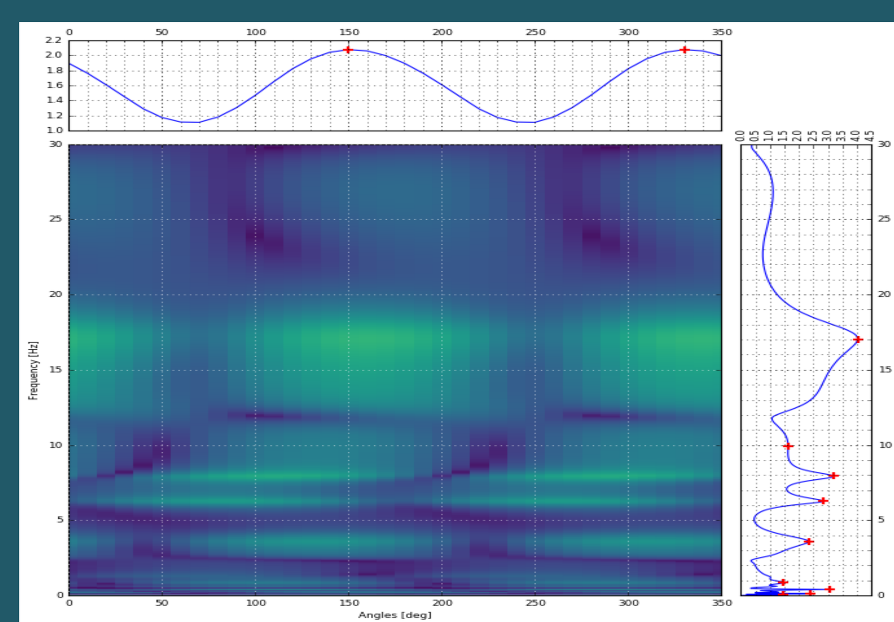
Horizontal-to-Vertical Spectral Ratio (HVSR) Graphs

There is a most preferential direction for spectral ratio lying with the local slope failure (cleavage dip). For the aggregated HVSP polar diagram, the two directivities show that different structures having variable features so that they respond to earthquake and release seismic energy in a unique direction.



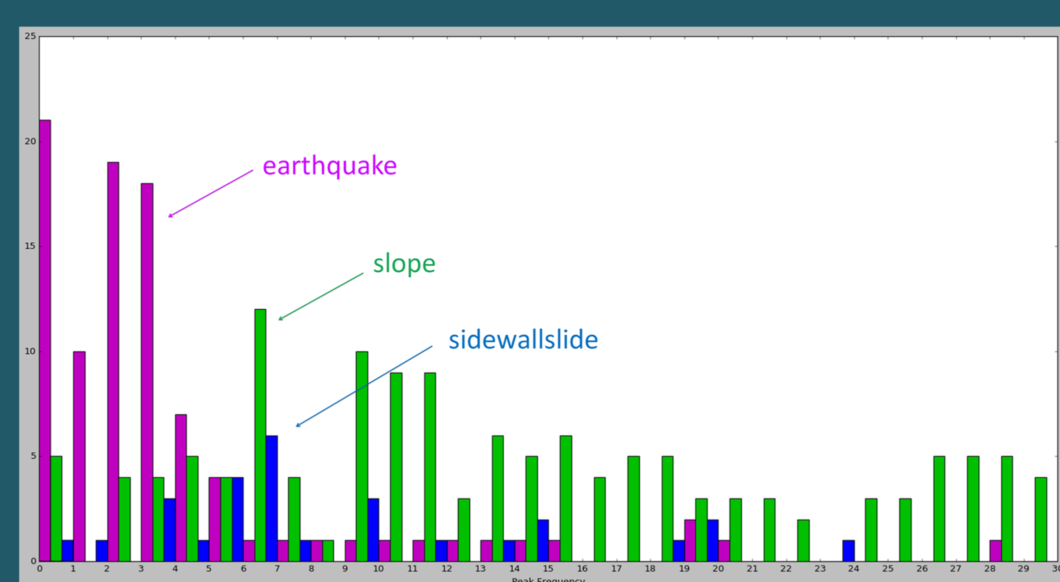
Joint Angle Frequency Plot

For every windowed S-transform, there is a frequency-domain angle-frequency spectral. From each frequency-domain angle-frequency spectral, we can identify several peak frequencies. From each of these peak frequency, there may be or maybe not a dominant direction.



Feature Classification Represented by Histograms

The slope, the 'sidewallslide' and the 'earthquake' are the main desired directions for engineering consideration in a seismic event. The x-axis is the peak frequency while the y-axis is the counts of the aggregate frequency of all windows. (Purple for earthquake; peak at 0-3 Hz, green for slope, peak at 6-7 Hz).

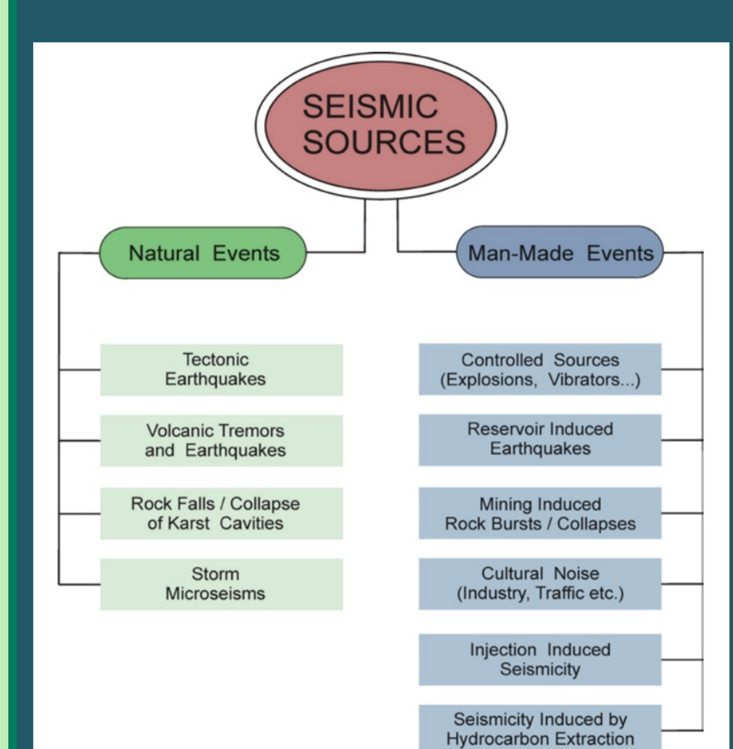


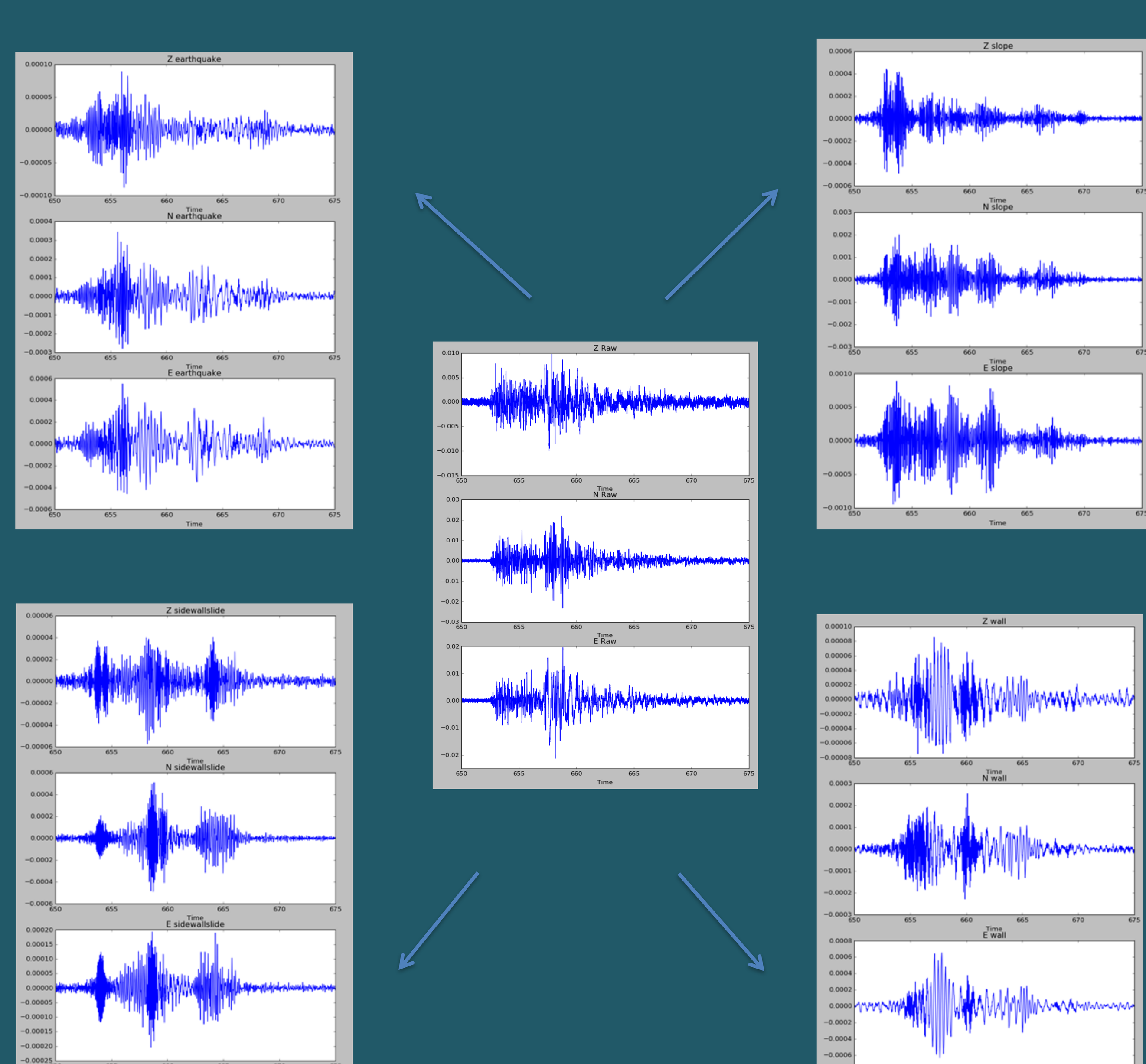
Binary Masks Filtering

The binary mask generated in frequency domain can allow us to filter the response and collect the wanted directivity. The vibration in ZNE directions exactly for Earthquake is extracted. By performing inverse S-transform on the filtered data, we can perfectly replicated the earthquake signals in time domain again and eliminate noise or influence of surrounding environment.

Time Domain Signal Reconstruction & Decomposition

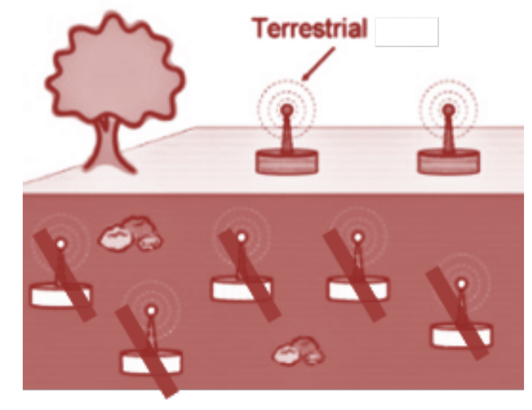
from Obtained Features (Inverse S-transform)





Market Value of This Project

(1) Economic Benefit



Cost Saving in Data Acquisition without Strict Requirements (e.g. Underground installation)

Reducing Waste of Resources by Elongating the Life Span

High Demand of Fatigue Detection as Aging infrastructures Require Targeted Repair of Critical Parts

(2) Large Development Potentials

Universality of Natural Oscillation

Multiple Features from Single Event

Data-driven Methods

(3) Widely Applications

Monitoring Not Only for Civil Engineering Infrastructures:

Power Supply | Power Transmit | Railway | Machine | Factories | Tree Risk

Summary

Traditional Method	Innovative Technique	Obtained Outcome/Improvement
Maintenance Based on Factors of Safety	Real-Time Monitoring and Extensive Dynamic Analysis	Locating Weak Slopes by Model and Prediction with Classified Features
Computation with Heavy Memory Load	Distributed Processing	High-Performance Computation
Bulk Storage of Data	Real-Time Analysis to Discover Essential Features	Cheap Storage of Key Features Real-Time Accessibility Worldwide
Redundant Cost of Data Acquisition	Lowered Requirement of Monitoring system	Data Acquisition with Reliable Classification

- In this project, our team applied the programming skills and data science into slope engineering.
- By real-time monitoring and analysis, the reinforcement and maintenance of landslide-prone slopes more convenient and low-cost, saving human power in checking and monitoring.
- There is no existing system in civil engineering fields, suggesting a large potential market.
- Moreover, vibration is a common feature in every structure and material, which means the procedure in this system is universal and is suitable to be applied to other infrastructures such as buildings, bridges, and tunnels.