MScR Project Description

Title: Applying deep-learning denoising to improve seismic event detectability in urban environments
Blacknest Supervisors: Stuart Nippress and David Green
Location: Bristol University / AWE Blacknest
Anticipated Start Date: October 2024

Project Summary:

The global deployment of low-cost, easy-to-deploy, seismometers (such as Raspberry Shakes) has led to a rapid increase in the availability of open-access seismic data in areas where traditional seismic observatories are not located. These instruments are recording previously unknown small magnitude earthquakes, a range of anthropogenic sources of noise (including trains, traffic, heavy rain, football matches) and also events of opportunity (e.g., Figure 1). Such recordings are of interest to AWE Blacknest because they can potentially provide additional recordings for analyzing events of interest. However, high levels of anthropogenic seismic noise, and non-ideal deployment locations, complicate the detection of signals with these sensors, especially when they are sited in urban environments. Simple spectral filtering often fails to isolate the signal from noise when their frequency content overlaps. Recently, deep-learning-based denoising algorithms have been developed to assist in filtering out strong persistent noise sources. The successful MScR candidate will work alongside colleagues at the University of Bristol and AWE Blacknest to understand how such denoising techniques can be optimised for use within urban environments, through applications to datasets from both the US and UK.

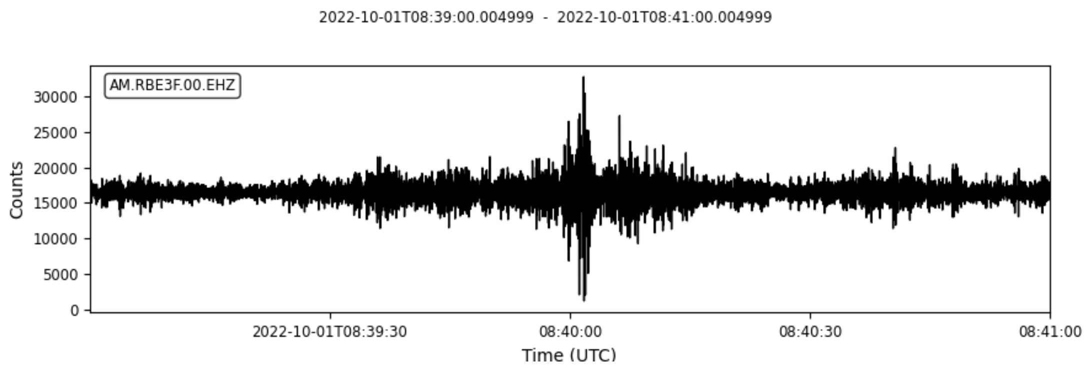

Figure 1. Raspberry Shake seismogram of the demolition of the former steelworks in Redcar, UK. The demolition required 1.6 tonnes of explosives. This was the only seismometer (both broadband and Raspberry Shake) to record the event. The instrument is located ~10 km from the site of the demolition.

Responsibilities:

Under direction from the project supervisors the successful applicant will be expected to:

- Undertake a literature review of previous seismogram denoising and urban seismology research.
- Learn to use pre-existing denoising software and use these codes to identify strategies for optimally processing recordings from Raspberry Shake sensors.
- Analyse signals from events for which both Raspberry Shake and broadband recordings are available.
- Write up results within a thesis (and hopefully a peer-reviewed journal paper), so that results can be disseminated to interested parties.

Skills required:

The successful applicant is expected to:

- Have taken introductory wave physics and time series data analysis module as part of their degree.
- Have a basic understanding of a computer programming language (e.g., python, matlab, shell scripting) and the willingness to learn more throughout the placement.
- Be willing to interact and communicate with the wider Blacknest and Bristol teams in order to identify solutions to issues/problems.
- Have some working experience with using a UNIX/linux type computer system, or have the confidence to quickly learn the basics.

About the Blacknest Team:

Staff at AWE Blacknest have, for 60 years, been researching techniques to distinguish seismic signals generated by underground nuclear explosions from those generated by earthquakes. Such techniques are part of the verification system for the Comprehensive Nuclear-Test-Ban Treaty which is currently being ratified by United Nations member states. In addition, Blacknest scientists develop techniques to analyze signals generated by explosions in the atmosphere, in the oceans, and at the interfaces between these media. Experts within the team provide advice to the UK Government upon request.

Project Background:

Traditional broadband seismometers are expensive and complicated to purchase, install and maintain, making them impractical for use by novices and people with limited budgets. The development of low-cost, easy to use seismometers, like Raspberry Shakes (https://raspberryshake.org), are helping remove these limitations allowing both the general public and private organizations install and run seismometers often in areas which previously had limited deployments (e.g., Calais *et al.*, 2019). Despite being a fraction of the cost, these instruments were demonstrated to perform suitably well for both teleseismic and local earthquakes (Anthony *et al.*, 2019).

In recent years, urban seismology has become an active research field (e.g. Green *et al.*, 2015). The global deployment of Raspberry Shakes, with open data, has led to a wealth of seismic data in urban environments (e.g., Díaz *et al.*, 2020). As well as large regional and teleseismic earthquakes, these instruments are recording previously unknown small magnitude earthquakes, a range of anthropogenic sources of noise (including trains, traffic, heavy rain, football matches (Díaz *et al.*, 2020)) and also events of opportunity (Figure 1).

However, high levels of anthropogenic seismic noise complicate detecting signals from seismic events in urban environments. This is further compounded for data recorded by Raspberry Shake instruments, which due to the ease of deployment can be found in a variety of locations (e.g., sheds, basements and window sills). Although traditional post-processing (e.g., filtering) of seismic waveforms can elucidate these signals, generally simple spectral filtering fail when seismic signals and noise overlap within the same frequency bands. Recently, deep-learning-based denoising algorithms have been developed (e.g., Tibi *et al.*, 20221; *Yang et al.*, 2022). These machine-learning-based denoising algorithms are trained by exploiting the rich noise resource, within the framework of DeepDenoiser, to filter out the strong noise levels present for seismic data recorded in urban settings. Yang *et al.* (2022) apply a UrbanDenoiser to an earthquake sequence in an urban area (Long Beach, U.S) and demonstrate an increase in signal quality and the ability to recover signals at an SNR level down to 0 dB.

Initially this project will concentrate on collecting open-source seismic waveforms recorded by both broadband seismometers and Raspberry Shakes. These instruments will be located in an urban environment in a region (e.g., Long Beach, U.S.) that has both local earthquakes (with an available seismic bulletin) and a range of urban sources. A denoising algorithm will be then trained on both the broadband seismometer and Raspberry Shake data. The trained denoising algorithm will then be applied to both datasets and the event detected using from the broadband and Raspberry Shake data will be compared.

The trained Raspberry Shake denoising algorithm will then be applied to U.K. Raspberry Shake data from urban environments. Any events found via this process will be examined and compared with known BGS bulletins or events of opportunity.

Relevant Literature

- Anthony, R. E., Ringler, A. T., Wilson, D. C., and Wolin, E. Do low-cost seismographs perform well enough for your network? An overview of laboratory tests and field observations of the OSOP raspberry shake 4D, *Seismol. Res. Lett.*, 90, 219–228, 2019.

- Calais, E., Boisson, D., Symithe, S., Momplaisir, R., Prépetit, C., Ulysse, S., Etienne, G. P., Courboulex, F., Deschamps, A., Monfret, T., Ampuero, J.-P., de Lépinay, B. M., Clouard, V., Bossu, R., Fallou, L., and Bertrand, E. Monitoring Haiti's quakes with Raspberry Shake, *Eos, 100*, 2019.
- Díaz, J., Schimmel, M. Ruiz, M., and R. Carbonell, R. Seismometers within cities: a tool to connect Earth Sciences and Society. *Front. Earth Sci.*, 8:9, 2020.
- Green, D., Bastow, I.D., Dashwood, B., and S.E.J. Nippress, S.E.J. Characterizing Broadband Seismic Noise in Central London. S*eismological Research Letters*, 88 (1), 113–124, 2015
- Tibi, R., Hammond, P., Brogan, R., Young, C.J., and Koper, K. Deep Learning Denoising Applied to Regional Distance Seismic Data in Utah. *Bulletin of the Seismological Society of America*, 111(2), 775–790 2021.
- Yang, L., Liu, X., Zhu, W., Zhao, L., Beroza, G.C. Toward improved urban earthquake monitoring through deep-learning-based noise suppression. *Sci Adv.*, 8(15), 2022.