Using machine learning and satellite radar to detect "silent" earthquakes in the Zagros Mountains, Iran

Project Abstract:

Earthquakes are the single biggest natural hazard facing Iran. 9 out of the 10 deadliest natural disasters in Iran in the 20th Century were earthquakes, including the deadliest individual event on record in the country; a single earthquake in 1990 that killed an estimated 50,000 people. These damaging earthquakes also cause major financial losses of hundreds of millions of dollars, and the combined human and financial losses present a major development challenge to the country.

A significant scientific obstacle that prevents accurate estimates of earthquake hazard, in Iran but also globally, is the unknown importance and frequency of "silent" earthquakes. In regular earthquakes, tectonic faults in the Earth's crust release stress in sudden episodes of slip and cause violent shaking. But in silent or slow earthquakes, these same faults instead slip slowly over hours-to-years, releasing stress without radiating seismic waves. These silent earthquakes can have a major influence on the occurrence of regular earthquakes, and can raise or lower local earthquake hazard. But they are hard to measure, and so it is not known how common they are. Therefore, characterising when and where these silent earthquakes occur is critical for accurately estimating seismic hazard.

The Zagros Mountains in south-west Iran are a region with a large population at risk to earthquakes (>20 million people). And it is also a region where we expect silent earthquakes may be especially common, due to an unusually large mismatch between the numbers of expected and observed regular earthquakes. Two new radar satellites, the Sentinel-1 constellation, afford a major new opportunity to investigate the prevalence of silent earthquakes. But the 1000s of radar images (interferograms) that are generated each day by these satellites preclude manual analysis and require the development of new automatic-detection tools.

This project therefore aims to develop new machine-learning tools to detect silent earthquakes in large, noisy satellite radar datasets, and apply these to radar images over the Zagros mountains. We have developed a novel methodology for this purpose, based on an 'anomaly-detection' approach, which identifies hidden silent earthquake signals as rare 'anomalies' due to the fact they do not conform to the well-characterised spatial-temporal structure of noise in radar data. This method is showing promising preliminary results when applied to both real and synthetic test cases.

This project is interdisciplinary, bringing together geophysicists and artificial intelligence experts to answer a global challenge, and it addresses several of the UN's Sustainable Development Goals. Improved seismic hazard information will strengthen Iran's capacity for risk reduction, and its management of a national major risk to health and life (UN SDG 3). The project and its outcomes will also promote building of resilient infrastructure in Iran (UN SDG 9). And finally, improved seismic hazard information has the potential to reduce injuries, deaths and economic losses caused by earthquakes, and enable resilience to these events (UN SDG 11).

Furthermore, the automatic detection tools developed here could also be used for improving seismic hazard estimates in other developing countries. Iran's vulnerability to earthquakes is not unique, and the countries with the largest relative death tolls from earthquakes are also often the poorest.

Methodology:

In contrast to video data, where an image contains information on the position of objects at a single time acquisition, an individual radar interferogram contains information on the difference in position between two time acquisitions. We therefore take advantage of this uniquely structured dataset by training a model on a sequence of interferograms, constraining the model to learn the spatial and temporal relationship between the signal and the sequence of background noise images from which each image is constructed. Long Short Term Memory cells (LSTMs) [1] are frequently used in similar cases to learn from time dependent data. But to learn both the structure of the input data in space as well as in time, these LSTMs are also applied with convolutions, which are then able to maintain the dimensions of image or video input data. Similar unsupervised or semi-supervised deep learning techniques involving convolutional LSTMs [2] have been used to understand changes and track object movements [3] in video datasets where labelling of features is not possible.

Anomaly detection techniques use reconstruction error as an indicator of sudden or prolonged changes in a sequence. Our model is first trained on a high-quality benchmark dataset from a region in Turkey with no anomalous movements, and is then tested using a similar dataset that has had synthetic earthquake and silent earthquake signals added. The model is also tested on real tectonic deformation signals, and performs well at detecting both synthetic and real ground movements.

Conclusion & Future Work:

Our preliminary experiments show that the trained model has learned the unique spatial-temporal structure of noise in a set of related radar images. The proposed deep learning based methodology has been first trained and tested on a small dataset taken from single location in Turkey, where abundant, high-quality training data are available. We now aim to further improve the model by training with more, and more geographically diverse, data, and then to finally adapt and apply the model to data from the Zagros region of Iran.

Project Information:

Supervisors/partners	Project Duration: 3 Years
Dr Richard Walters, richard.walters@durham.ac.uk	
Dr Noura Al Moubayed, noura.al-moubayed@durham.ac.uk	Project Resources (funded by): Durham University
Prof. Mark Allen, m.b.allen@durham.ac.uk	
Prof. Toby Breckon, toby.breckon@durham.ac.uk	Author: Anza Shakeel
Dr. Mohammad Tatar, mtatar@iiees.ac.ir	

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[2]. Xingjian et al. Convolutional lstm network: A machine learning approach for precipitation nowcasting. In Advances in neural information processing systems, pages 802–810, 2015.

[3]. Ning et al. Spatially supervised recurrent convolutional neural networks for visual object tracking. In 2017 IEEE International Symposium on Circuits and Systems (ISCAS), pages 1–4. IEEE, 2017.

Durham University Palatine Centre Stockton Road Durham DH1 3LE UK
Telephone +44 (0)191 334 2000
www.durham.ac.uk