Real-time earthquake detection using smartphones. Your smartphone.

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It is now widely recognised that there is no way of warning of earthquakes days or even hours in advance. To date, no reliable precursor has been identified and there are reasons for believing none may ever be found.[1]

Nonetheless, nowadays technology can help to mitigate the impact of earthquakes on people. It goes without saying that earthquake-resistant buildings are the best protection against strong earthquakes. Indeed, most earthquake victims are due to the collapse of human-built structures rather than to the earthquake itself. As an example, a magnitude 7.0 earthquake caused more than 100 thousand deaths in Haiti in January 2010. Nearly 6 weeks later, a magnitude 8.8 earthquake (approximately 500 times more powerful) hit central Chile but the death toll was limited to 525 people thanks to safer buildings.

Even when buildings are safe or supposed to be safe, the ability to alert the population even no more than a minute before the quake is actually felt helps to limit casualties. A few seconds are enough to get under a desk if indoors, or to move away from buildings if outside.

There are at least two ways to provide such a forewarning. The first way exploits the earthquake mechanisms. Earthquakes are characterized by primary and secondary waves, with primary waves faster and milder than secondary waves. When primary waves are detected, an alarm is triggered to alert for the arrival of the dangerous waves. The second way implies to detect the earthquake near the epicentre and to use a telecommunications network to alert the population at risk. The physical principle is simple: electromagnetic waves (Internet by extension) travel faster than seismic waves, both primary and secondary.

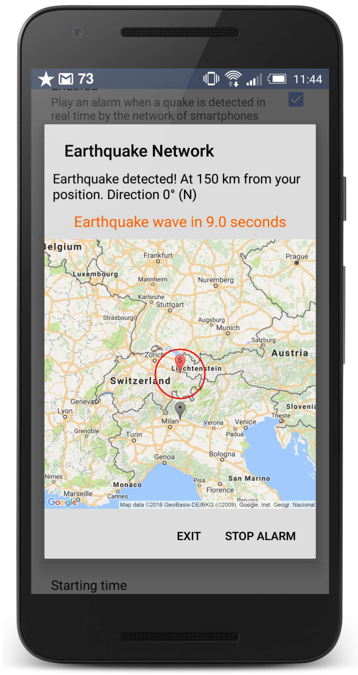
The second approach is at the basis of the so called Earthquake Early Warning (EEW) systems which are operational in several parts of the world, with Japan and Mexico the leading countries. Especially in under-developed and developing countries, however, the diffusion of EEW systems is dampened by the high installation and operating costs which are in the millions of dollars.[2]

A solution to this problem comes directly from the smartphone in your pocket. Smartphones are equipped with accelerometer sensors which can be exploited to detect the shaking induced by earthquake waves. Additionally, smartphones are geolocated and they usually have an always-on Internet connection which is suitable to send data and to receive warnings. Even more important, smartphone ownership and Internet usage are on the rise in both developed and developing countries.

That said, smartphones are far from being seismometers. Although equipped with accelerometers, the low-cost sensor cannot compete with a professional seismometer. Plus, most of the accelerations detected by smartphones are due to background noise (smartphone movements not related to earthquakes). Now, if you still want to detect earthquakes using your smartphone, there are two ways to overcome the above problems. The first option is to bolt down your smartphone on your basement floor and to make it ring when a vibration is detected. Not very convenient and not very useful, as the smartphone is not guaranteed to detect primary waves and the number of false alarms may be very high. The second option is to build a network of smartphones and to rely on statistics. This latter option is at the basis of the Earthquake Network project (www.earthquakenetwork.it).[3] The project implements a crowdsourced EEW system based on a global network of smartphones. People join the network by simply installing the Earthquake Network Android app (https://goo.gl/fVqZnN) and they don't have to change the way they use smartphones.

The app enables the accelerometer only when the smartphone is charging and it is not being used. This allows a reduction in the number of false detections and, more importantly, to save battery. When the smartphone acceleration exceeds a threshold, a signal is immediately sent to a central server. Thanks to an algorithm based on a statistical approach, the server decides in real time whether an earthquake is occurring. If that is the case, a warning is issued toward the smartphone network and people are alerted by an alarm.

Intuitively, the system works since the detection problem is moved from the very unreliable smartphone to a dense network of smartphones. Indeed, the only natural event that can shake a large number of smartphones in the same area at around the same time is an earthquake (or a large meteor entering the Earth's atmosphere, but let's stick to earthquakes).



Earthquake warning on smartphone

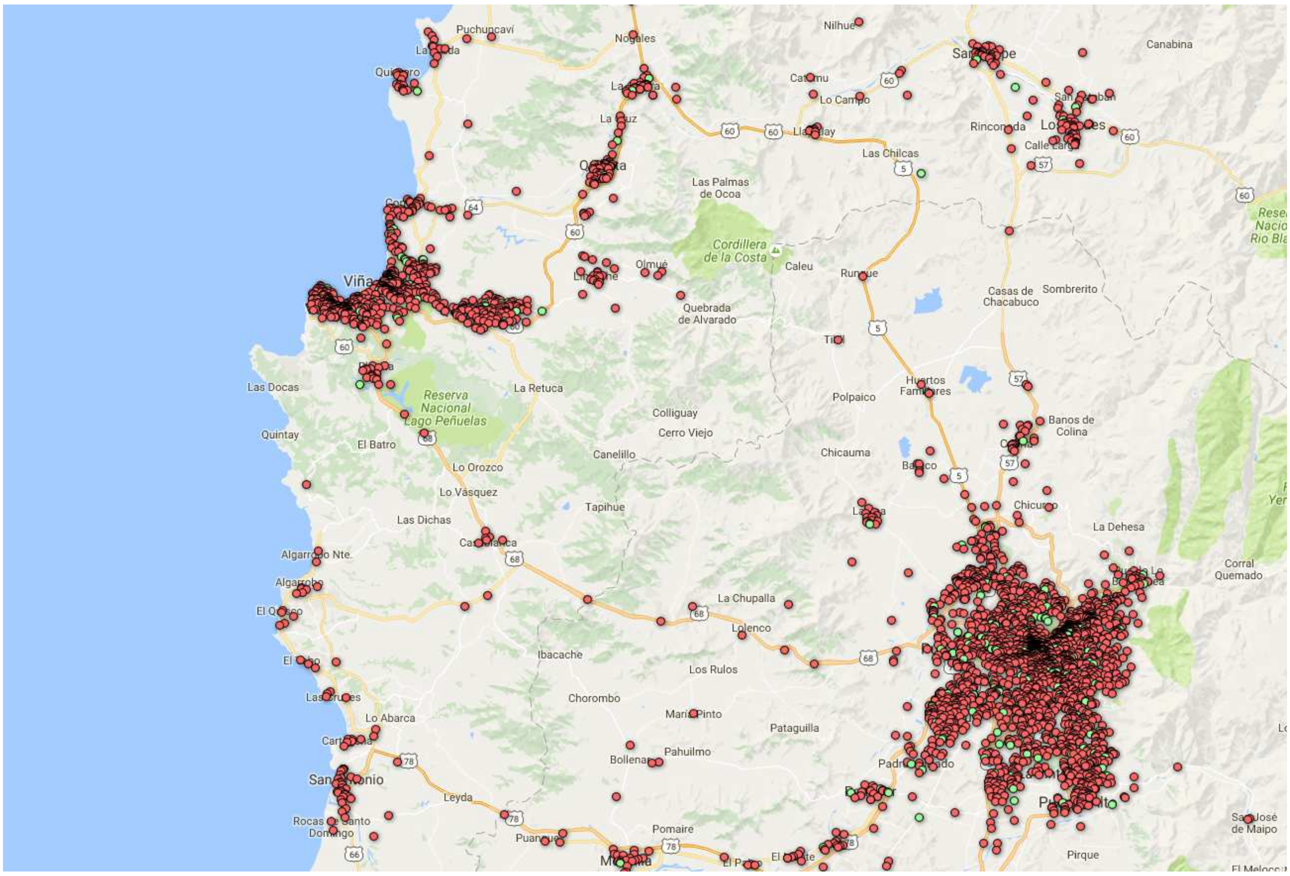
The idea is simple but how many smartphone signals make an earthquake? And how sure are we that an earthquake is really occurring? This is where statistics will come into play. First of all, there exists a trade-off between false alarm probability and detection delay that has to be balanced. Secondly, the detection problem is complicated by the fact that the network is constantly changing. Since the smartphones are in the thousands and they are all sending data to the server, their state is asynchronously updated only every 30 minutes. When an earthquake strikes, smartphones that are supposed to be on may have been turned off, or their position in space may have changed. These scenarios increase the probability of false detection and the probability of missed detection.

To keep both probabilities under control, a statistical approach is adopted.[4] For the sake of simplicity, let's consider a small geographic region like the area of a city. As first thing, the number of signals sent by the smartphone network to the server under the no-earthquake hypothesis is modelled. Arrivals are described by a Poisson process characterized by a time variant intensity function which depends on some covariates. For instance, the number of signals in any given interval of time is higher at night when people go to sleep and their smartphone is somewhere charging. Additionally, you may want to model specific behaviours of the smartphone owners. If many people set their morning alarm at 7:00 AM and vibration is enable, you can expect a large number of signals around that time, which are not to be confused with an earthquake. Using historical data, model parameters are estimated by Poisson regression.

The model on the process intensity function is used to define a real time detector based on a likelihood approach. At each signal arrival, a generalized likelihood ratio test to assess whether the number of signals in the last 30 seconds reflects the intensity function is carried out. If the test statistic exceeds a threshold, then an earthquake is detected. The threshold is estimated in such a way that the probability of false alarms is below a desired value, say one false alarm per year. Considering only arrivals observed during no-earthquake periods, the distribution of the test statistics is assessed and its right tail is modelled through a generalized Pareto distribution. The threshold is then obtained as the quantile of the Pareto distribution that guarantees the required mean time between false alarms.

Controlling type I error is important since many false alarms reduce the effectiveness of the warnings when real earthquakes are occurring and they may induce people to leave the network. During the last two years, both the EEW systems of Japan and Mexico generated false alarms, triggering panic and causing unnecessary evacuation from buildings. EEW systems based on seismometers are more susceptible to this problem as the number of instruments is relatively small and a false detection at a seismometer may produce a false alarm. On the other hand, a network with a high number of smartphones is expected to be more robust against false alarms as the probability that a large number of devices detect a vibration at around the same instant is low.

When the Earthquake Network app was released in 2013, the ability of detecting earthquakes using smartphones was not yet proven. It took 5 months for the network to spread enough to detect the first earthquake in real time. When it did, the Earthquake Network project was started. As of the end of September 2016, the project relies on more than 150 000 smartphones and the app has exceeded 1.2 million downloads. During the last 3 years, more than 300 earthquakes have been detected by the network, most of them in the earthquake prone areas of Central and South America.



Smartphones of the Earthquake Network project in the Santiago and Valparaíso area, Chile.

As the network increases in the number of smartphones, new technical and statistical challenges are to be faced. For instance, a higher number of active smartphones implies a higher network sensitivity, which leads to the detection of mild earthquakes. However, EEW systems should only alert for earthquakes that are likely to be dangerous, and the problem of estimating the earthquake magnitude in real time has yet to be solved.

Whether or not the Earthquake Network project has so far saved lives it is not easy to say. Nonetheless, its usefulness is recognised by the global population who is keen to join this citizen science project with their smartphones. New challenges are still to be faced, but in time they will be solved with the help of statistics and with the help of the people joining the network. Additionally, the Earthquake Network project shows us nicely how statistics can be exploited in the emerging field of crowdsourced data analysis.

References

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