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SEISMIC DATA FROM SMARTPHONES

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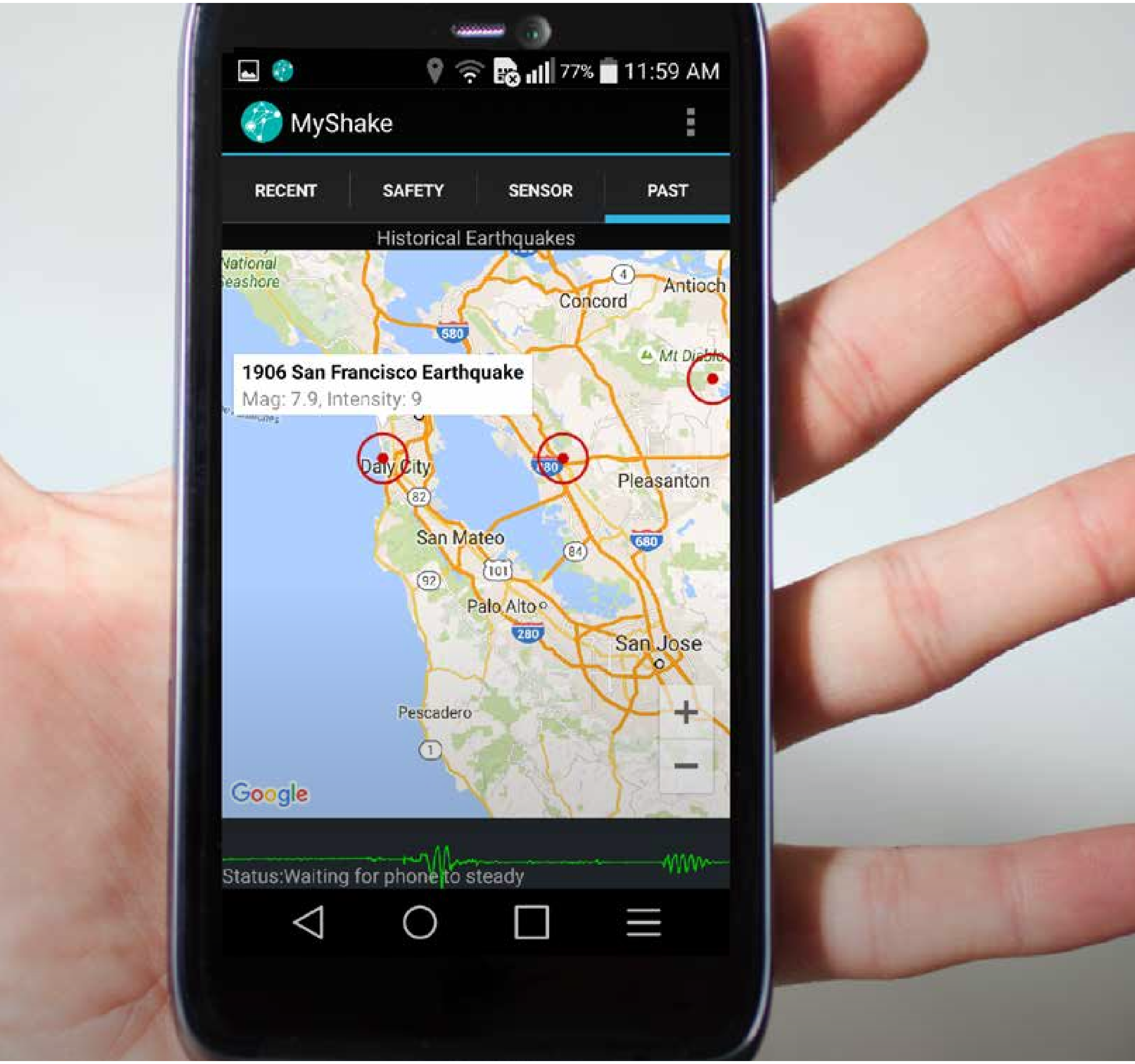
MyShake: Building a Global Smartphone Seismic Network



Increasing the density of earthquake-monitoring instruments at a fast rate and at a low cost is a dream for many researchers who study earthquakes. MyShake, a smartphone application developed by the Berkeley Seismological Laboratory and Deutsche Telekom Silicon Valley Innovation Center, is approaching this goal by turning users' smartphones into portable seismometers. This growing, global, smartphone seismic network will utilize the power of crowdsourcing to quickly and inexpensively spread seismic monitoring to many places around the world.

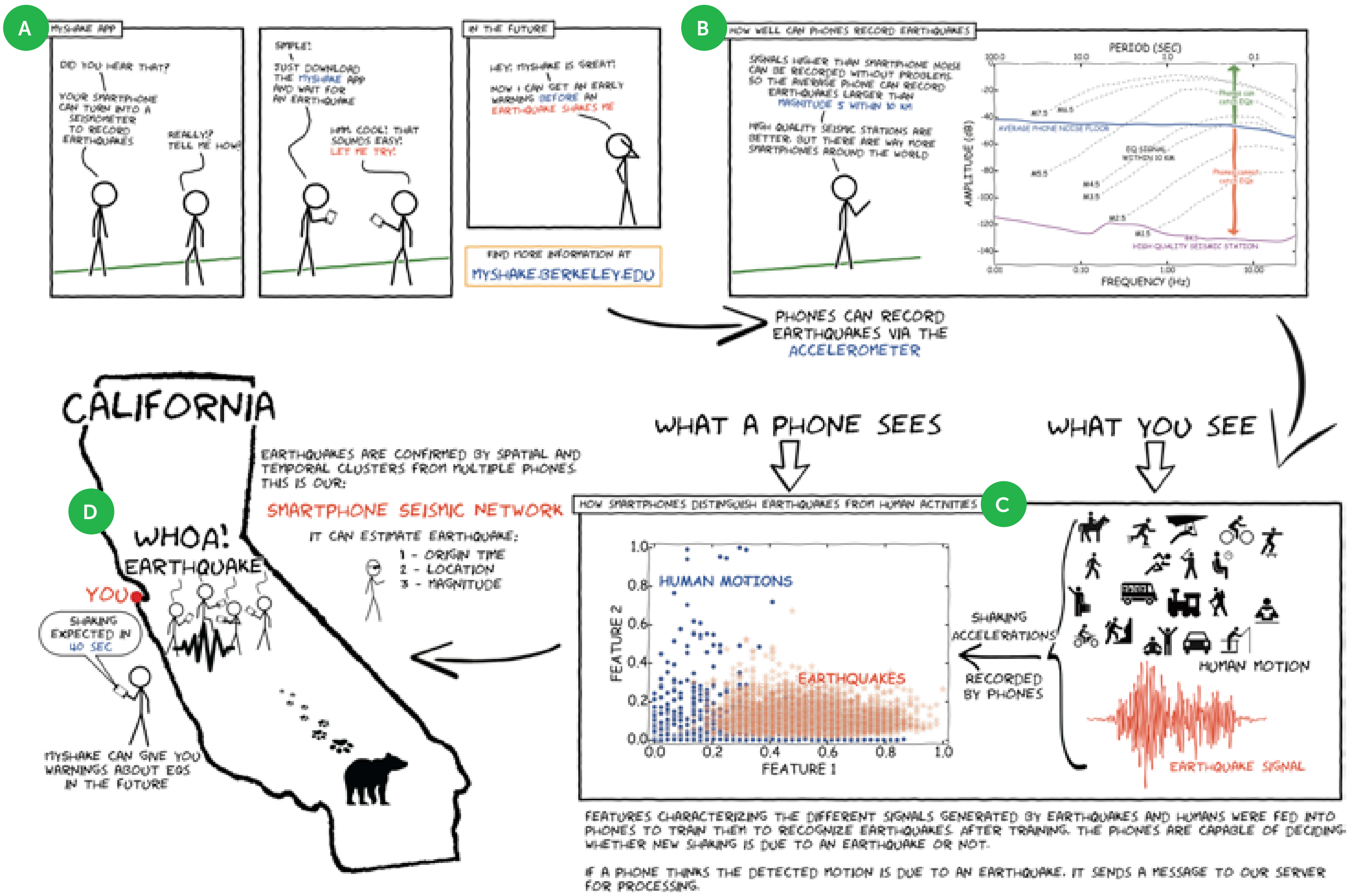


Figure 1. An overview of the MyShake concept.

To turn your smartphone into a seismometer, visit *myshake.berkeley.edu*, download the application, and run it in the background on your Android phone. When people run this app, their many combined phones create a dense network that can detect earthquakes faster and more accurately compared to the existing sparse networks. The recorded data can be used for many applications that current seismic networks cannot support. For example, in places where there are no traditional seismic networks, MyShake can stand alone to provide useful data from earthquakes. But, how can a smartphone become a seismometer and form this global seismic network?

MyShake Methodology

Let's take a closer look at your smartphone. It's called "smart" because it has an onboard processing unit to make it a portable computer, and it has sensors inside. A smartphone contains a MEMS (microelectromechanical systems) accelerometer, gyroscope, magnetometer, barometer, and so on; it also has GPS to obtain a precise location, and a built-in communication unit to enable it to interact with the world. All these components can work as part of a seismometer.

The accelerometer can monitor the movement of the ground. The processing unit can parse recorded data from the accelerometer to determine whether this motion is due to an earthquake or from human activities. The communication unit can send the data back to the central processing center (CPC) in the cloud for further confirmation of the magnitude, origin, and time of the earthquake. The smartphone device contains all the necessary parts for a seismometer, and maintenance is supported by the user, i.e., they charge the phone and ensure it works properly. Of course, there are limitations. The accelerometers inside the smartphones are less sensitive than the high-quality sensors used in the scientific world. Test results for a range of phones show that the noise floor — the amplitude of noise signal on the accelerometers when the phone is stationary — will hide signals from earthquakes smaller than approximately magnitude 5 at a distance of 10 km from the phone (Figure 1B). Thus, to record the same earthquake, either the phones must be much closer to the source, or we must stack (combine) many phone recordings to improve the signal-to-noise ratio to improve the quality of the waveforms. So it's a trade-off between quality and quantity, but with a smartphone in almost every pocket, we have the luxury of quantity.

Creating a global smartphone network is more than just turning phones into seismic recording systems. After recording one day's worth of phone motions, you will encounter a variety of non-earthquake signals. Ordinary human activities like picking up the phone from a desk, walking, running, roadway traffic, or passing trains, make the detection of earthquakes through smartphones much more challenging. Therefore, we need a way to distinguish between earthquakes and these other movements. MyShake's unique Artificial Neural Network (ANN) model was developed by using past earthquake records and a set of human activity data to classify earthquake-like movements captured on a single phone.

To explain the classifier, consider for a moment how your brain learned to distinguish between an apple and an orange when you were young. When an apple or orange was given to you, you could sense some features, such as their different colors, textures, smells, and taste. We stored these different features in our memory to characterize the object. When given another object, we compared the features of this new object with the ones in our mind to determine whether we were looking at an apple or an orange. Our parents then confirmed whether our classification was correct or not. If we were wrong, we updated the features we memorized, and used the new set of features to identify the object the next time we encountered it.

This is the same learning process employed by MyShake. Training a smartphone to recognize an earthquake involves identifying the features that best characterize the difference between earthquakes and human activities, and using them to decide whether the incoming data is an earthquake or not. A group of 75 volunteers helped the MyShake team by collecting four months of human activity data. Shake table test data and simulated earthquake data were also used to provide the earthquake training data to the algorithm. The shake table is a large platform that can simulate the movement of an earthquake in three dimensions. From these data, different features were extracted and examined to find the ones that best capture the difference between earthquake and non-earthquake movements. The features that are currently used in MyShake are differences in the dominant frequency content and the amplitude of the time domain signal. In Figure 1C, Feature 1 and Feature 2 characterize frequency and amplitude, respectively. We can see most of the human activities are either large amplitude with small frequency content, or broader frequency content with small amplitude. This contrasts with earthquakes that have relatively broader frequency content with medium amplitudes.

MyShake Public Release

After many tests and validations, the MyShake application was released to the public on February 12, 2016, and has since been downloaded more than 250,000 times. MyShake users are currently distributed over six continents, especially in regions where earthquake hazards are high. Figure 2 shows the world

Figure 2. MyShake users light up the world.

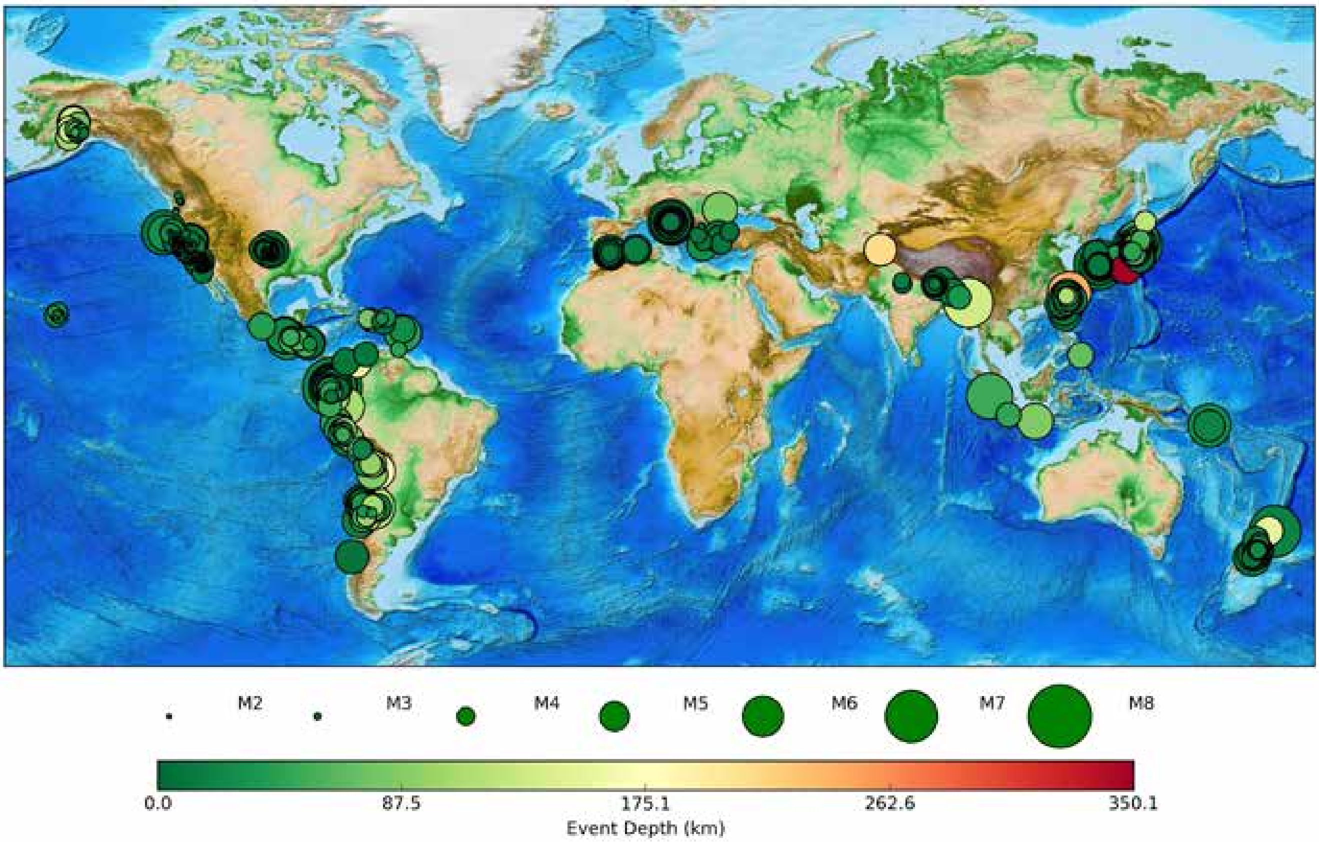


Figure 3. **MyShake earthquake recordings between launch and February 12, 2017.**

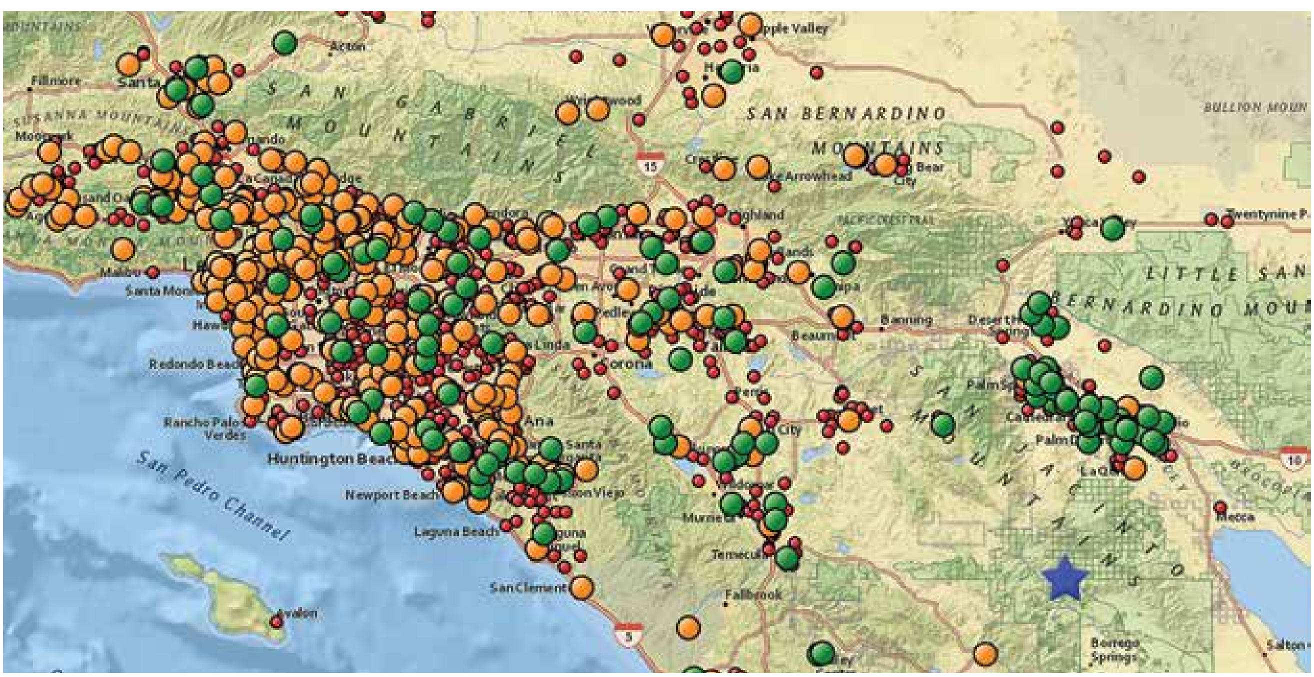


Figure 4. **MyShake phones during the Borrego Springs earthquake.**

lit up with MyShake users. Coverage is so good that we can see the outlines of the continents and countries. On a typical day, there are about 10,000 active MyShake users around the globe monitoring the occurrence of earthquakes.

Figure 3 shows the locations of the 505 earthquakes recorded by at least one MyShake user between launch and February 12, 2017. Each circle in Figure 3 is an earthquake; the larger the size of the circle, the larger the magnitude of the earthquake. The colors of these circles represent the depth of the recorded earthquake. The MyShake seismic network recorded earthquakes with magnitudes ranging from M2.5 to M7.8, with the deepest earthquake recorded in Japan at a depth of 350 km. Many recorded earthquakes are from California, Oklahoma, Alaska, and Hawaii in the U.S., and Chile, Ecuador, Italy, Morocco, Nepal, Japan, Taiwan, and others. For smaller earthquakes, around M2.5, the recordings typically come from phones nearest the epicenter (within 5 km). But for a M5.0 earthquake, the recordings come from large distances, up to 200 km on some of the phones.

A great example of MyShake detecting moderate earthquakes at large distances is the M5.2 Borrego Springs earthquake in California on June 10, 2016, at 08:04:38 UTC (Coordinated Universal Time). The dots on the map in Figure 4 show the locations of the phones that were running MyShake at the time of the event, with the blue star indicating the earthquake's epicenter. Red dots indicate phones that were active, but not monitoring the ground motion, due to human activities in the vicinity of the phone. The orange colors represent phones that were actively monitoring ground motions, but didn't detect the earthquake due to various reasons, including the low-quality sensors within the smartphones, specific site response, and so on. The green dots are phones that detected the earthquake and sent a message and data back to the CPC.

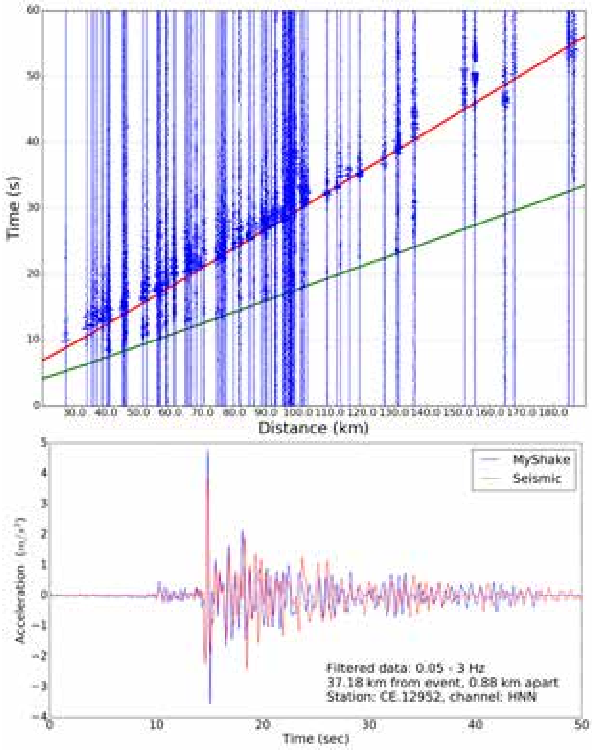


Figure 5. **Waveform recorded during the Borrego Springs earthquake.**

On a typical day, there are about 10,000 active MyShake users around the globe monitoring the occurrence of earthquakes.

The top panel from Figure 5 shows the horizontal component of the acceleration waveforms recorded by the phones and sorted by distance (the amplitudes are scaled so that the lower-amplitude distant waveforms are as visible as the recordings closer to the source). The green and red lines in Figure 5 are the estimated compression and shear (P- and S-) wave arrival times, respectively, for the Borrego Springs earthquake. The P-wave energy tracks the green line well and appears in the recordings from distances around 90 km. The S-wave energy, which is most interesting for structural engineering, is apparent from waveforms collected at distances up to 200 km.

Traditional seismic networks also recorded the Borrego Springs earthquake, and we can compare the performance of the MyShake app with data from these seismometers. The bottom panel from Figure 5 shows the waveforms recorded by MyShake (in blue) overlaid with those from seismic station CE 12952 (in red). The MyShake phone and the seismic station are about 1 km apart, and both are approximately 37 km from the epicenter. While the traditional seismic instrument is bolted to a fixed location on the ground, we are not able to determine what environment the cellphone was in at the time (e.g., on a desk, on the floor, in a dock). Nevertheless, the waveforms correlate remarkably well, which indicates that MyShake data could be useful for many applications, including structural dynamics.

Other MyShake Uses

One way MyShake could contribute to the structural engineering community is by estimating the natural frequency of a building's response during an earthquake using the recorded waveforms. To test this theory, we ran an experiment atop the 9-story Millikan Library on the Caltech campus. The roof of the building houses a large shaker that can input sinusoidal forces to the building with tunable frequencies in any horizontal direction. We placed many phones on the roof to test whether MyShake could record the imposed low-amplitude sinusoidal waveforms and estimate the natural frequency of the building. Testing of these results is ongoing. If these results are promising, it may be possible to progress further into this application by analyzing ambient noise profiles in buildings.

The MyShake team is also working toward using the network and its recorded data sets to provide earthquake early warning alerts to the public. The basic principle of an earthquake early warning system is to detect an earthquake as it begins and send information about the approaching ground motions to people before the shaking arrives. These systems take advantage of the fact that electronic signals

MyShake may provide a valuable dataset to study the human response to an earthquake, and thereby improve training for earthquake readiness.

travel faster than seismic waves (speed of light versus speed of sound in rock). Using a network of phones that might include multiple devices in each city block near the epicenter, we can detect the earthquake quickly and alert other users who are further away from the epicenter. The amount of advance-warning time depends on how far the user is from the epicenter and the speed at which the system can send the message. The larger the epicentral distance and the quicker the transmission of data, the more warning time people will receive. The more phones that are located near the epicenter, the faster the detection and the earlier the warning time. The data recorded by MyShake can also provide a detailed map of shaking intensities with a higher resolution than from traditional seismic stations. Data could come from phones on each city block, rather than the more regional scale of current networks. This type of information can be useful for correlating with post-earthquake observations.

Future Potential

Beyond the seismology and engineering communities, MyShake may have many interesting applications in other fields as well. The seismic data collected may sometimes contain human activities. When the user feels the earthquake and then grabs the phone, the phone will record the movements of that person during the earthquake. This may provide a valuable dataset to study the human response to an earthquake, and thereby improve training for earthquake readiness. In addition, phones running MyShake during earthquakes could also provide a record of the user's last location, which could be helpful for rescue teams. Additional functionality providing the capability of sending quick notification to friends or relatives after the earthquake is also a possibility.

The MyShake global smartphone seismic network is still in its infancy. There are many challenges to address before it will issue accurate earthquake early warnings, or be demonstratively useful for broad scientific applications. But the potential of this network is already clear. If you have any comments or suggestions, please contact the authors. GS

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