Evaluating the Integrability of the Quake-Catcher Network (QCN)

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ABSTRACT

This paper reviews the Quake-Catcher Network (QCN), a distributed computing seismic network that uses low-cost USB accelerometers to record earthquakes, and discusses the potential to incorporate QCN stations with traditional seismic networks. These very dense urban networks could then be used to create a working earthquake early warning system, as has been shown by our preliminary tests of the QCN in Christchurch, New Zealand. Although we have not yet attempted to add traditional seismometers to the QCN or supplement existing seismic networks with QCN sensors, we suggest that to do so would not be difficult, due to the simple nature of our network.

Keywords

Quake-Catcher Network, rapid earthquake detections, earthquake early warning system

INTRODUCTION

Rapid detection and characterization of earthquakes is essential for earthquake early warning systems, which have the potential to alert nearby populations about the approach of potentially damaging seismic waves (*e.g.*, (Allen and Kanamori, 2003, Kanamori, 2005)). In addition, minimizing the time required to estimate the extent and amplitude of ground shaking from an earthquake is necessary for rapid deployment of emergency personnel to affected areas. A dense array of seismometers can reduce the time needed to detect an event and provide higher resolution maps of ground accelerations across a region.

Quake-Catcher Network (QCN) is a new type of seismic network that implements distributed/volunteer computing combined with low-cost micro-electro-mechanical systems (MEMS) accelerometers to record earthquakes (Cochran, Lawrence, Christensen and Chung 2009; Cochran, Lawrence, Christensen and Jakka 2009). Almost any modern computer can become a seismic station provided it has Internet access and either an internal or external MEMS accelerometer. After the initial development costs, the QCN seismic data gathering system costs a fraction of the cost of a traditional network, thus enabling very-high-density seismic monitoring at affordable cost levels. We currently have approximately 2000 sensors running in 67 countries around the world (figure 1). Following the M8.8 Maule, Chile and M*w* 7.1 Darfield, New Zealand earthquakes, we created dense networks in those areas to record the numerous aftershocks. In addition, we have densely distributed sensors in both northern and southern California, as this is the origination of QCN. Although QCN was designed to be a stand-alone network, we have recently shown that our stations can be used in conjunction with traditional seismic networks to create very dense networks.

THE QUAKE-CATCHER NETWORK

QCN uses Berkeley Open Infrastructure for Network Computing (BOINC) open-source volunteer computing system (Anderson and Kubiatowicz, 2002, Anderson, 2004) to utilize idle time on volunteer computers to monitor sensors for strong ground shaking. Accurate timing and location are necessary for reliable earthquake detection and characterization. Since QCN stations are not connected to GPS clocks, we use network time protocol (NTP) to estimate the drift on each participant computer's clock. Clock offsets are estimated every 15 minutes resulting in ±20 msec accuracy (*e.g.*, (Frassetto et al., 2003)).

Almost anyone can be a QCN volunteer, provided they have a computer with internet access. Once the participants receive their sensor, they enter the location of their computer into a Google map interface. The building size, construction type, and sensor location are entered by the user and included in the metadata. This information can later be used when analyzing events to determine the effect of building type, etc. on the recordings. Additional details can be found in (Cochran et al., 2009a, Cochran et al., 2009b).

QCN currently supports five models of three-axis external MEMS sensors (JoyWarrior-10, JoyWarrior-14, MotionNode Accel, O-Navi-12 and O-Navi-16) that are connected to desktop computers via a USB cable (http://qcn.stanford.edu/join-qcn/manualsinstructions). These triaxial MEMS sensors have a dynamic range of ±2 g, resolution of 1 and 4 mg and record accelerations across a wide frequency band (typically 0 Hz < f < 250 Hz) (Cochran et al., 2009b, Farine et al., 2004, Holland, 2003). Time series data are recorded at 50 samples per second. External USB accelerometers are oriented to north and mounted to the floor to ensure adequate coupling to ground motions. In addition, QCN supports two models of laptops (Apple and ThinkPad) with internal MEMS sensors, although these sensors are not used for our rapid earthquake detections due to their lower quality sensors, the sensors being uncoupled with the building (as laptops are usually on desks and will therefore record the movement of the desk more than that of the building), and that the station locations may be inaccurate due to the portability of laptops. Laptop data can be useful, however, for post-event analysis.

QCN RAPID EARTHQUAKE DETECTIONS IN CHRISTCHURCH, NEW ZEALAND

There are currently three primary types of earthquake early warning systems available (Allen et al., 2009).

- “Front detection” systems identify an earthquake at one site when the surface waves arrive and provide warning for further locations. While this provides accurate warnings with few false triggers, as front detection requires detection of strong shaking surface waves this type of warning is only useful for detection earthquakes at large distances, such as in Taiwan and Mexico.
- “Onsite” or “single-station warning systems detect seismic energy at a single location and provide warning of coming ground shaking at the same location. As only one station is needed to provide a warning, this system works very quickly. However, this method does not often provide accurate characterization of an earthquake (magnitude, location, predicted ground shaking, etc.) and is susceptible to false triggers. Examples of onsite warning systems include Japan and China.
- “Regional” warning systems use a network of stations with onsite processing to determine the earthquake parameters from the first few seconds of the *P*-wave and predict the expected ground shaking. Regional warning, such as the ElarmS network in California, requires a few stations and is very fast, but can be less reliable than front-detection as only the initial *P*-wave, not surface waves (strong shaking) is used.

The Quake-Catcher Network’s early warning system uses a regional network of stations, however processing is done by a main server. When the signal-to-noise ratio at a given station rises over a given threshold, a trigger is recorded and the computer then sends a small packet of data to our servers including peak acceleration at the time of the trigger and station information. When that trigger is received, the server then correlates triggers within 100 seconds and 200km radius of the original trigger. If other triggers are found, the wave moveout is checked to determine if the wave is traveling at a reasonable seismic velocity from a single source. If the number of triggers exceeds a given threshold (usually 7 stations), a detection is registered and a webpage is created for that event.

The location and magnitude are then estimated using only the peak acceleration at the time of the trigger. The detection algorithm does not discriminate between *P*- or *S*-waves, so the triggers used may include different wave phases. The starting location is set to the location of the first trigger. We then perform a grid search of possible locations and iterate to find the best fitting hypocenter. Next, the magnitude is estimated using a vector sum of the peak ground acceleration at the time of the trigger and an empirical distance-magnitude relationship. Finally, a map of estimated shaking is created (figure 2), which extrapolates shaking recorded at the stations to all other locations.

Unlike other early warning systems, the Quake-Catcher Network is very unique in that is does not need to wait for the earthquake to progress in order to start calculating an earthquake’s parameters. Using our dense network in Christchurch, New Zealand, we find that first detections by our network are made within 7-10 seconds of the earthquake origin time. This includes sending the data to our server and processing time. Preliminary testing of our earthquake rapid detection has proved to be very successful. 90% of earthquakes are within 1 magnitude of GNS reported value, and over 50% are within 0.5 magnitude, which is excellent as our estimates are based on the initial trigger information alone. Because of the density of stations in our network, we have been able to make up for the fact that our sensors are of slightly lower quality than traditional seismometers. And because our sensors so inexpensive ($50-$150 instead of a traditional seismometer, which may cost thousands of dollars), we have shown that we can create a working seismic network for a significantly lower cost.

COMPARING QCN WITH A TRADITIONAL SEISMIC NETWORK

Immediately following the September 3, 2010, M*w* 7.1 Darfield earthquake, 192 CodeMercenaries JWF14 USB accelerometers were installed in and around Christchurch, New Zealand as part of the Quake-Catcher Network. 140 of those sensors were within the main city center, with station-to-station spacing of approximately 1.6km (Cochran et al., 2011) Volunteers were asked to host sensors for a minimum of two months. Many of the sensors were returned at the end of this time period, and approximately 40-50 sensors remained in the region by February, 2011.

GeoNet is GNS New Zealand's real-time earthquake monitoring network, which currently has 180 strong motion seismometers throughout New Zealand (http://www.gns.cri.nz/Home/Our-Science/Natural-Hazards/Earthquakes/Earthquake-Monitoring). A recent study by (Cochran et al., 2011) compared peak ground motion and full waveform characteristics of the data recorded by QCN sensors with that recorded by nearby existing GeoNet stations. The peak ground accelerations, velocities, and displacements recorded by QCN and GeoNet networks were found to be comparable, and a clear decay of peak acceleration with distance could be seen (figure 2). A few QCN stations showed unusual peak accelerations, which could be due to either local site effects or possibly problematic stations (such as incorrectly installed sensors leading to poor station to ground coupling). Overall, QCN sensors were shown to be highly compatible with the Geonet traditional seismic network and, we hope, could be used to supplement and fill in gaps of existing strong-motion networks.

This study shows how well the Quake-Catcher Network stations deployed in Christchurch, New Zealand following the M*w* 7.1 Darfield mainshock performed compared to the traditional GeoNet strong motion. By utilizing MEMS sensors and distributed computing techniques it is possible to provide reliable records of strong ground motion at greatly increased station densities.

DISCUSSION

In order to create a fully functional and useful earthquake early warning system, there are several things that must be addressed. The network must have a dense enough distribution of sensors to rapidly detect seismic waves before substantial damage has occurred. Furthermore, the detection system must be able to handle the large number of triggers associated with a substantial seismic event.

As mentioned above, the Quake-Catcher Network uses sensors that are attached to volunteers' computers. Due to their low-cost and easy installation (usually taking 10-15 minutes, with most volunteers capable of installing their own sensors), the network is really only limited by the location and number of volunteers. We have found that schools are excellent places to install the sensors as they tend to be fairly evenly spaced out from one another geographically, there is often at least one computer left running most, if not all day, and the sensors can be used in conjunction with our educational activities to teach K-12 students about geophysical concepts (http://qcn.stanford.edu/learning-center).

In more rural areas, or locations where it is difficult to find suitable volunteers, we have begun exploring stand-along QCN stations. These units consist of a USB sensor attached to a low-cost tablet, or other simple computer, that is connected to an existing internet connection. With a complete station costing approximately $200USD, an additional station can be added to a dense QCN network for a fraction of the cost of a traditional seismometer.

In order to determine the scalability of QCN, Benson et al. created EmBOINC, an emulator of BOINC projects to study QCN simulations with up to 1,000,000 sensors (Benson et al., 2012). They found that QCN servers could efficiently detect earthquakes using large numbers of sensors without crashing the main servers.

Based on our current research, incorporating traditional seismic stations into the QCN network appears to be possible to do with relative ease. Provided the existing system is capable of sending real-time information to a QCN server, the biggest obstacle to overcome is making minor adjustments to the triggering algorithm in order to accommodate higher quality seismometers. Conversely, due to the simple output of our sensors, we theorize that QCN stations could be integrated with a traditional network without many complications, provided that the existing network can be modified to use the trigger information sent by QCN sensors.

We are keen to point out that incorporating QCN into an existing traditional network, or traditional sensors into QCN is still very much in the preliminary testing stages. While the prospect of integrating traditional and non-traditional networks is very exciting, much work remains to be done in this field. The Quake-Catcher Network is a highly adaptable network with the potential to create an early warning system unlike any other. In order to do so, however, the network must be expanded dramatically, particularly in areas of greatest seismic hazard, and rigorously tested.

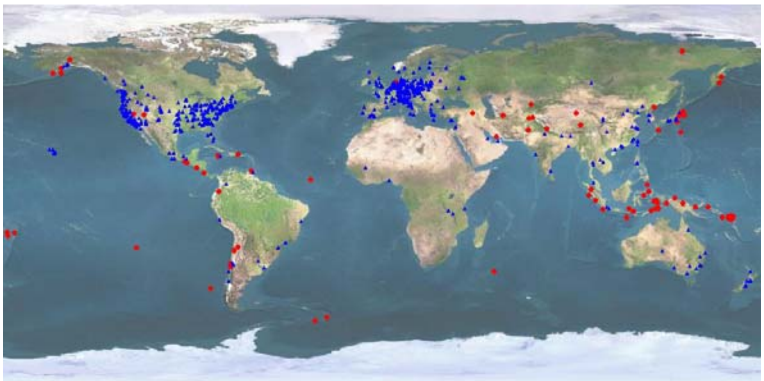

Figure 1: Map of the current distribution of QCN stations around the world.

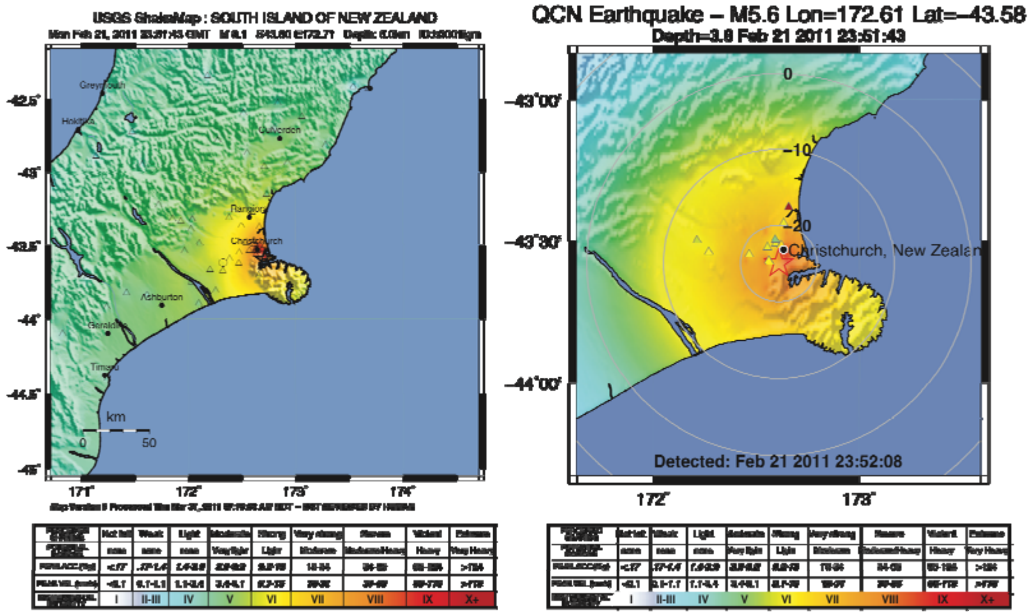

Figure 2. (Left) USGS ShakeMap produced after shaking has ceased. (Right) QCN shaking intensity estimate map produced 7 seconds after event origin

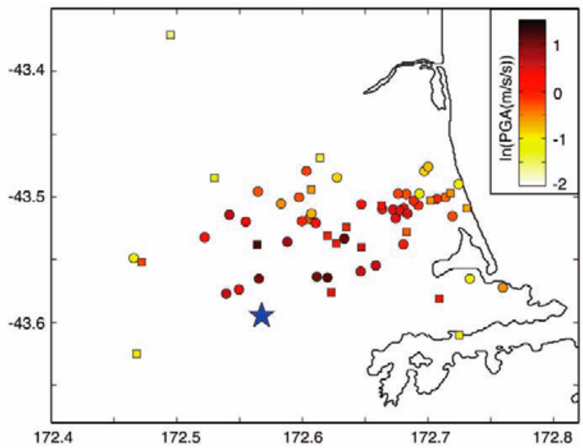

Figure 3. From (Cochran et al., 2011) Peak horizontal ground acceleration (PGAH) recorded by QCN (circles) and GeoNet (squares) stations during a M5.1 aftershock on October 18, 2010 (blue star). The stations are colored by observed PGA. Note that a few (<3) of the QCN stations have IP-based locations that are not very accurate. Those data included here for completeness; although the location quality is included in the metadata so the data could be excluded.

REFERENCES

1. Allen, R. M., Brown, H., Hellweg, M., Khainovski, O., Lombard, P. and Neuhauser, D. (2009), Real-time earthquake detection and hazard assessment by ElarmS across California, *Geophysical Research Letters*, 36.
2. Allen, R. M. and Kanamori, H. (2003), The Potential for Earthquake Early Warning in Southern California, *Science*, 300, 786-789.
3. Anderson, D. P. (2004), BOINC: A System for Public-Resource Computing and Storage, 5th IEEE/ACM International Workshop on Grid Computing. November 8, 2004, Pittsburgh, USA.
4. Anderson, D. P. and Kubiatowicz, J. (2002), The world-wide computer, *Scientific American*, 286, 40-47.
5. Benson, K., Schlachter, S., Estrada, T., Taufer, M., Lawrence, J. F. and Cochran, E. S. (2012), On the Powerful Use of Simulations in the Quake-Catcher Network, *Future Generation Computing Systems*, 00, 1-19.
6. Chung, A. I., Neighbors, C., Belmonte, A., Miller, M., Sepulveda, H. H., Christensen, C., Jakka, R. S., Cochran, E. S. and Lawrence, J. F. (2011), The Quake-Catcher Network Rapid Aftershock Mobilization Program Following the 2010 M8.8 Maule, Chile Earthquake, *Seismol. Res. Lett.*, 82, 526-532.
7. Cochran, E. S., Lawrence, J. F., Christensen, C. and Chung, A. I. (2009a), A Novel Strong-Motion Seismic Network for Community Participation in Earthquake Monitoring, *IEEE Instr. & Meas.*, 12, 8-15.
8. Cochran, E. S., Lawrence, J. F., Christensen, C. and Jakka, R. (2009b), The Quake-Catcher Network: Citizen science expanding seismic horizons, *Seismological Research Letters*, 80, 26-30.
9. Cochran, E. S., Lawrence, J. F., Kaiser, A., Fry, B., Chung, A. I. and Christensen, C. (2011), Comparison between low-cost and traditional MEMS accelerometers: a case study from the M8.1 Darfield, New Zealand, aftershock deployment, *Annals Of Geophysics*, 54.
10. Evans, J. R., Jr., R. H. H., Kunding, C., Camina, P. and Rogers, J. A. (2005), TREMOR: A wireless MEMS accelerograph for dense arrays, *Earthquake Spectra*, 21, 91-124.
11. Farine, M., Thorburn, N. and Mougenot, D. (2004), General application of MEMS sensors for land seismic acquisition, is it time?, *The Leading Edge*, 23, 246-250.
12. Frassetto, A., Owens, T. J. and Crotwell, P. (2003), Evaluating the Network Time Protocol (NTP) for Timing in the South Carolina Earth Physics Project (SCEPP), *Seismological Research Letters*, 74, 649-652.
13. Gledhill, K., Ristau, J., Reyners, M., Fry, B. and Holden, C. (2011), The Darfield (Canterbury, New Zealand) Mw 7.1 earthquake of September 2010: A preliminary seismolocial report, *Seismol. Res. Lett.*, 82, 378-386.
14. Holland, J. (2003), Earthquake data recorded by the MEMS accelerometer, *Seismological Research Letters*, 74, 20-26.
15. Kanamori, H. (2005), Real-Time Seismology and Earthquake Damage Mitigation, *Annu. Rev. Earth Planet. Sci.*, 33, 195-214.
16. Wald, D. J., Quitoriano, V., Heaton, T. H., Kanamori, H., Scrivner, C. W. and Worden, C. B. (1999), TriNet "ShakeMaps": rapid generation of peak ground motion and intensity maps for earthquakes in southern California, *Earthq. Spectr.*, 15, 537-555.