MEMS Accelerometers Mini-Array (MAMA) Initial results and lessons learned

Ran N. Nof1, Angela I. Chung2, Horst Rademacher2, Lorinda A. Dengler2, Mark A. Hemphill-Haley2, Richard M. Allen2

1. Geological Survey of Israel, Jerusalem, Israel; 2. Berkeley Seismology Lab, University of California Berkeley, Berkeley, CA; 3. Geology Department, Humboldt State University, Arcata, CA

1. Background

Most operational earthquake early warning systems (EEWS) consider earthquakes to be point-sources and have difficulty providing prominent and robust source locations and magnitudes, especially at the edge of the seismic network or where seismic stations are sparse. Mini-arrays have the potential to reliably estimate hypocentral locations by beam-forming (FK-analysis) techniques. They can also characterize the rupture dimensions and account for finite-source effects, leading to more reliable estimates of ground motions for large magnitude earthquakes. In the past, the high price of multiple seismometers has made creating arrays cost-prohibitive. Here, we present a setup of two mini-arrays of a new low-cost (~$150) seismic acquisition unit based on high-performance MEMS accelerometers around conventional seismic stations deployed at UC Berkeley (UCB) and Humboldt State University (HSU) campuses. The expected benefits of using such MEMS Accelerometer Mini-Arrays (MAMA) include decreasing alert times, improving real-time shaking predictions and mitigating false alarms.

2. The Challenge

A significant problem faced by EEWS is the correct characterization of earthquakes that occur at the edge of or outside of the seismic network. Due to poor azimuthal coverage, location estimate errors can be considerable.

3. The Solution

Combining multiple MAMA may make it possible to robustly estimate the epicenter of an earthquake based on just two arrays instead of the current requirement of 4 stations. This would decrease the time needed for point source EEWS to issue an alert, especially where the seismic network is sparse.

4. New MAMA Device

We have developed a new low-cost (~$150) device. This unit consists of a printed circuit board (PCB) bearing four analog MEMS accelerometers (±g range) and a 34-bit ADC. The RPi serves as a datalogger and is capable of providing online access to the 100 samples per second data streams via an onboard webserver. The device can be used as a single low-cost station or be part of an array and is more sensitive than the available off-the-shelf sensors currently available (Figs 2 & 3).

5. MAMA Deployment

The first MAMA deployment, BRK MAMA, was at the UCB campus and the second, ARC MAMA, at the HSU campus (Fig 4). MAMA devices were placed in basement or ground floor rooms (Fig 5). We note that using this method the coupling to the ground is not ideal, but it’s a very quick, low-cost and non-invasive method, suitable for offices and occupied urban areas. Communication with the nodes is done via Wi-Fi or Ethernet.

6. Results

Both ARC and BRK MAMA data were collected at BSU data center. Using the UGSs ANSS catalog, for events Mw > 2.5 within a 110 km radius from the MAMA center, we automatically process the waveforms from the MAMA and compare the PPSD. For the events using M6 analysis (Figs 6 & 7), we used an automatic processing scheme, 4 out of 23 events were identified by the BRK MAMA and 6 out of 33 events were identified by the ARC MAMA between March 9th, 2017 and August 1st, 2017. Of the identified events, we successfully calculate BAZ for 3 and 4 events at the BRK and ARC MAMA, respectively. Figure 8 shows the BAZ and event identification threshold with respect to magnitude and distance. We have been able to calculate BAZ for earthquakes with magnitudes as low as Mw 2.7 at 20 km distance.

7. Conclusions

Though still noisier than class-A strong-motion devices (e.g. Episensor), our low-cost device significantly improves our capability to obtain useful signals of small magnitude events and allows us to test our approach without needing significant events to occur in the MAMA vicinity.

As demonstrated, MAMA can be used to rapidly obtain the BAZ of an event. Combining multiple MAMA may make it possible to robustly estimate the epicenter of an earthquake based on just two arrays. This would decrease the time needed for point source EEWS to issue an alert. Implementing MAMA in real-time and incorporating it into EEWS will allow for the better estimation of earthquake magnitudes and shaking intensity distributions.

Acknowledgments

Ran N. Nof was funded by a fellowship from the Geological Survey of Israel (GSI), at the Ministry of Energy and Infrastructure (MEI). Additional support was provided by the National Science Foundation (NSF) Graduate Research Fellowship and the Raymond and Beverly Sackler Fund for Earthquake Research in Jerusalem. Physical design, testing and RPi software were developed by Yuval Yaron and Ran Nof. This research was supported by the United States National Science Foundation (NSF) grant CBET-1503139, NSF Cyber-Physical Systems (CPS) Research Challenge Program.

References