A Low-Cost Internet-of-Things Device for Earthquake Early Warning

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Abstract

A low-cost Internet-of-Things (IoT) device for earthquake early warning (EEW) was presented at the Seismological Society of America (SSA) Annual Meeting in April 2021. This report summarizes recent progress on the device.

The device detected all earthquakes over M 3.0 around Los Angeles, as well as nearby earthquakes down to M 2.3. The waveforms were validated against outputs of a broadband seismometer in the Southern California Seismic Network (SCSN) and accelerometer-based stations in the Community Seismic Network (CSN).

An empirical formula was developed to determine earthquake magnitude based on ground motion amplitude measured by the device, which can be used to estimate magnitude (or effective local impact level) using a single device.

Ten devices of the same design were built and tested, which demonstrated performance consistency. Time syncing accuracy among the devices ranges from low milliseconds on the public internet down to sub-millisecond level on a Local Area Network (LAN).

The devices are being deployed to consumers' homes across Los Angeles to test their performance as a seismic and EEW network.

Device Overview

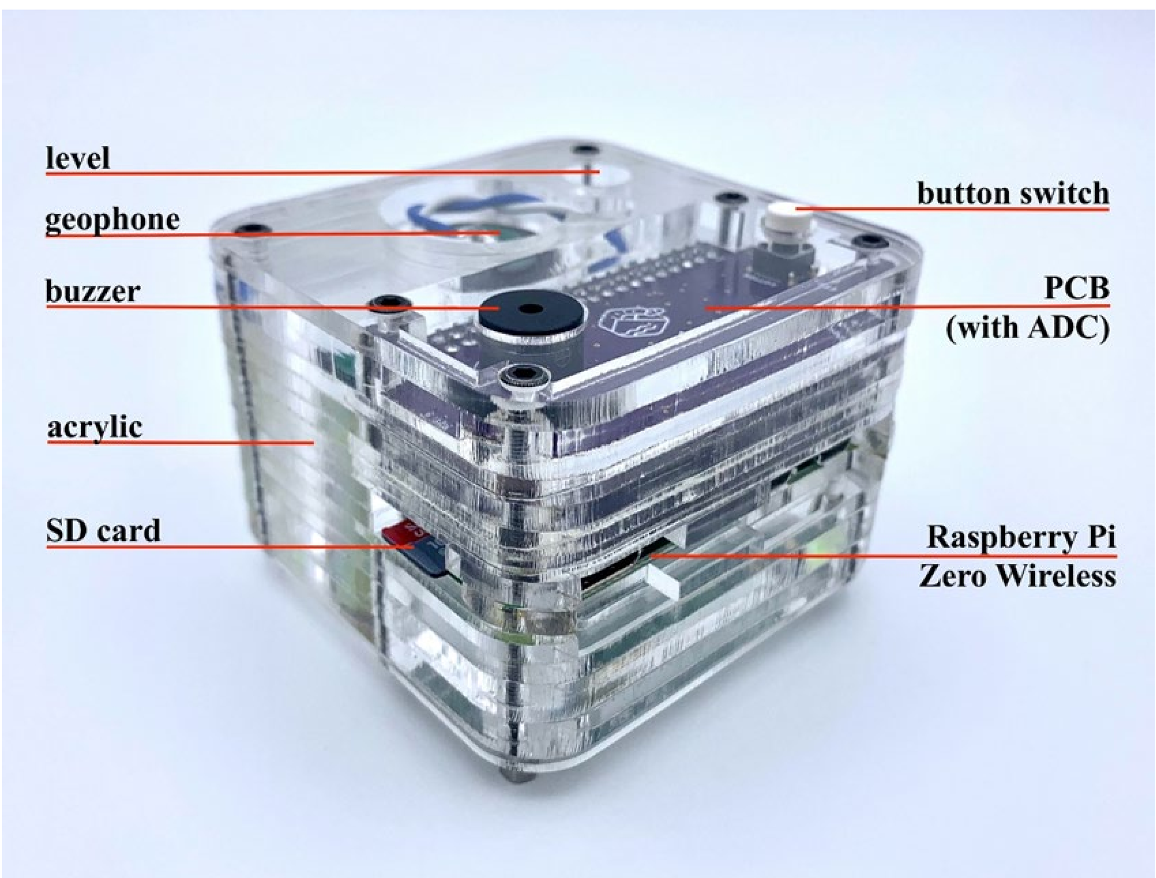


Figure 1: Overview of the low-cost Internet-of-Things EEW device.

- **Low cost:** < $100 to make
- **Small size:** 7 x 7 x 5 cm^3; about the size of a Rubik's cube
- **Low power consumption:** ~620 mW at steady state
- **Ground motion sensing:** a vertical geophone
- **High speed:** 100 samples per second
- **High precision:** 32-bit analog-to-digital converter (ADC)
- **Single board computer:** Raspberry Pi Zero W
- **Wireless:** Wifi & Bluetooth connection
- **Remote control:** via smartphone or computer
- **Packaging:** consumer-friendly; stacked acrylic layers
- **On-site alert:** onboard buzzer alarm
- **Regional alert:** text message to local subscribers

Performance Comparison with SCSN & CSN

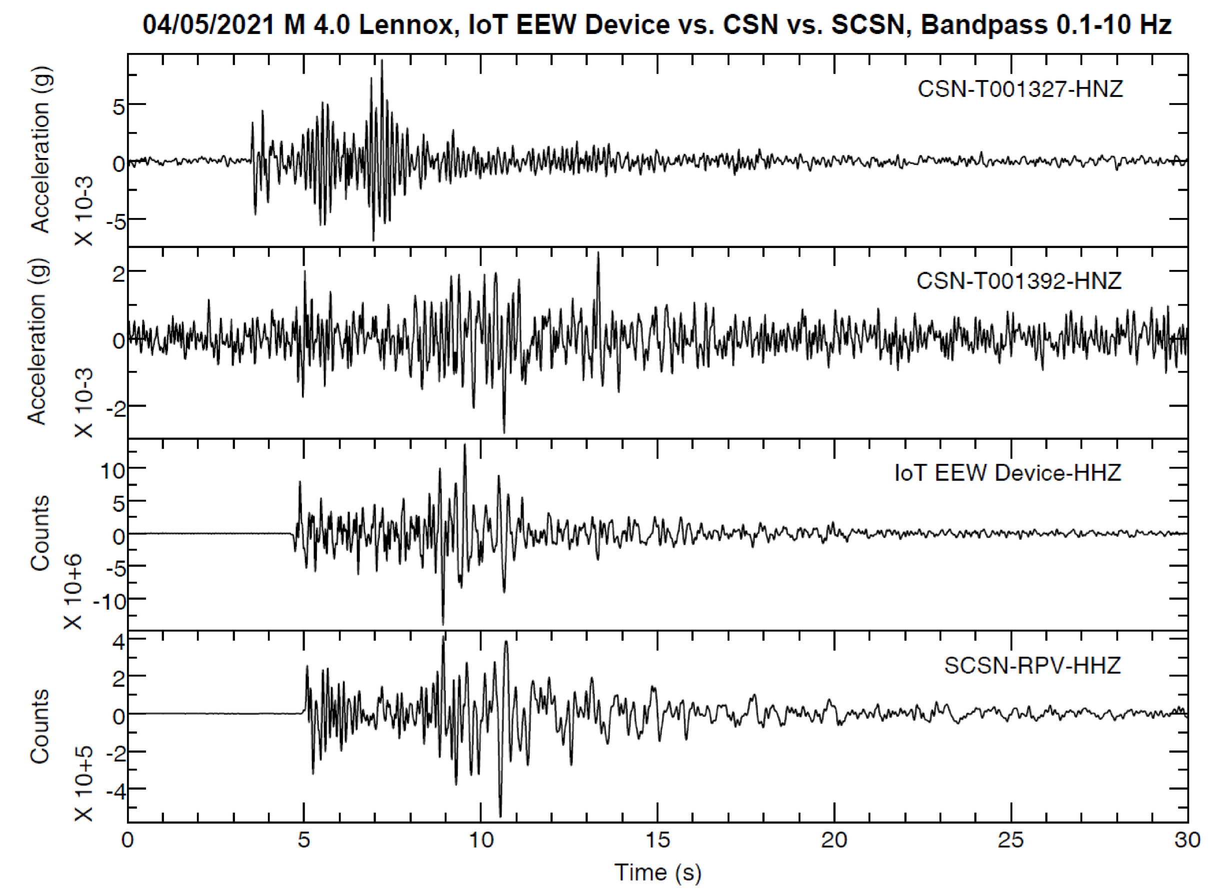


Figure 2: Comparison of the IoT EEW device with selected CSN and SCSN stations, for the M 4.0 earthquake in Lennox, California on April 5, 2021. The horizonal axis shows seconds after 11:44:02 UTC.

- **Validated device's waveform:** the device's output is consistent with waveforms captured by SCSN and CSN.
- **Demonstrated high sensitivity:** the device showed high signal-to-noise ratio, was more sensitive than the CSN stations, and was similar to the performance of SCSN's broadband seismometer in this comparison.

Continuous Nine-Month Earthquake Testing

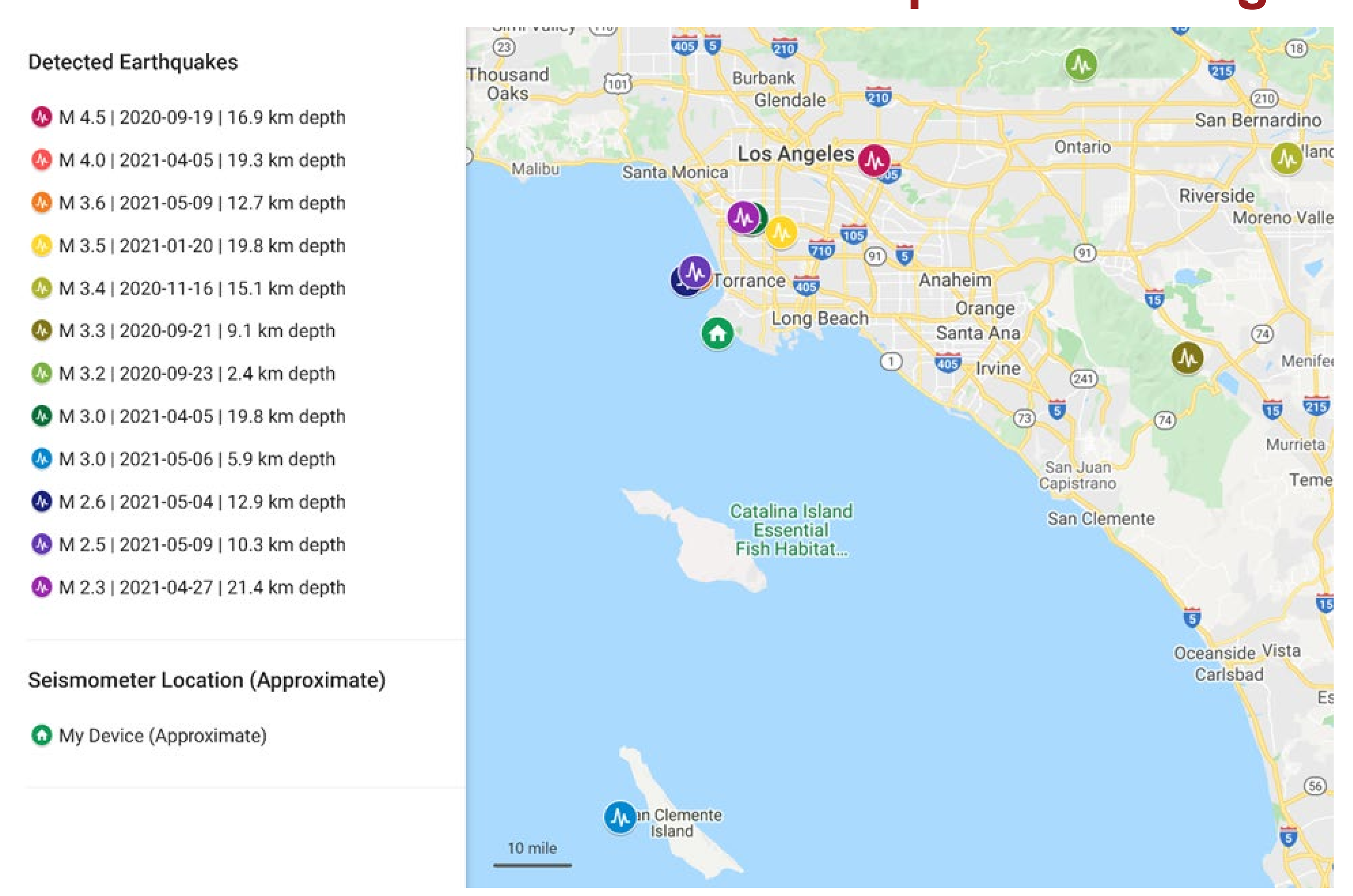
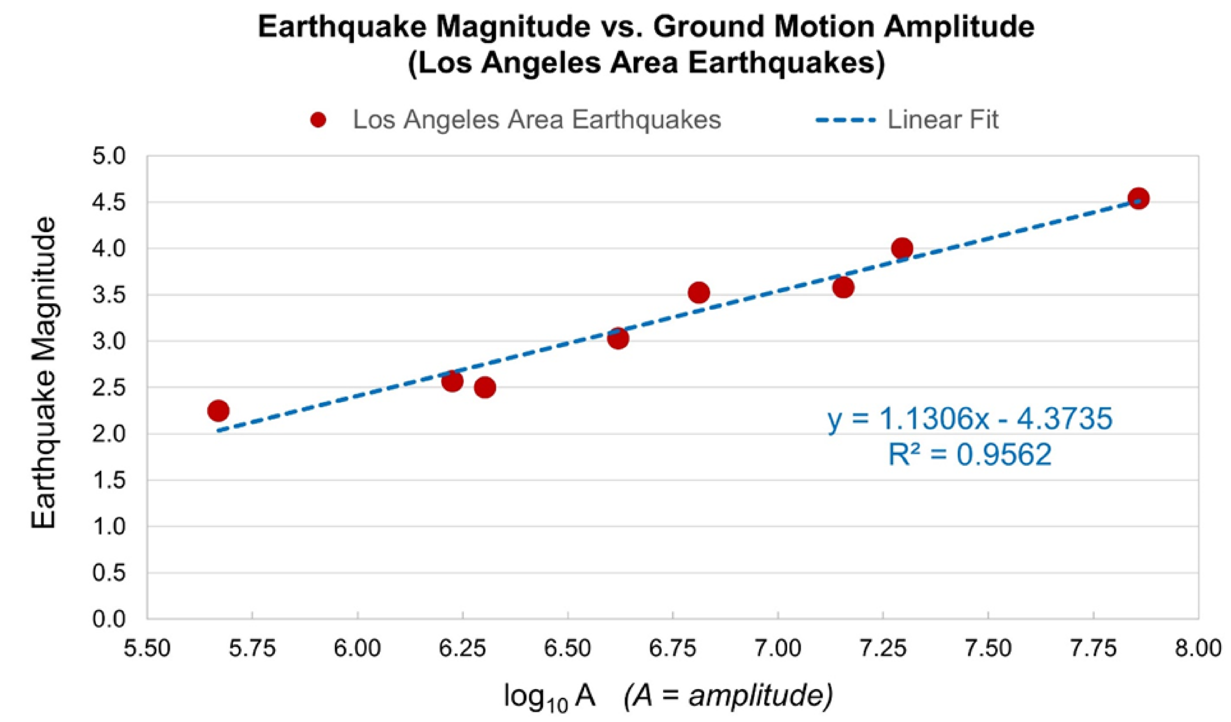


Figure 3: All earthquakes detected by the device from Sep 2020 to May 2021. All dates are UTC. Map credit: Map data ©2021 Google, INEGI.

- **Nearby earthquakes:** 8 earthquakes in the Los Angeles metropolitan area were detected, ranging from M 2.3 to M 4.5 and epicenter distance from ~13 to 40 km.
- **More distant earthquakes:** 4 earthquakes were detected with magnitude of M 3.0 to M 3.4 and epicenter distance from ~80 to 110 km.

Empirical Formula to Estimate Earthquake Magnitude



$$Magnitude = 1.1306 \times \log_{10} Amplitude - 4.3735$$

Figure 4: For all 8 earthquakes in the Los Angeles area detected by the device from Sep 2020 to May 2021, this chart shows a linear relationship between earthquake magnitude and $\log_{10}$ of the ground motion amplitude detected by the device.

- **8 nearby earthquakes:** linear relationship with R^2 value of 0.9562. This empirical formula can be used to estimate nearby earthquake magnitude based on a single device.
- **4 more distant earthquakes:** R^2 value drops to 0.8604. The same magnitude formula leads to an error ranging from -0.2 (M 3.0 vs. M 3.2 per USGS) to -0.5 (M 2.5 vs. M 3.0 per USGS). This means magnitude for distant earthquakes is underestimated, which can help minimize false alarms.

Time Syncing for Networked Devices

Figure 5: many devices of the same design were built and tested as a network.

- **Chrony:** is used as the system tool for the implementation of the Network Time Protocol (NTP)
- **Time syncing on the public internet:** low milliseconds offset among the devices when publicly-available NTP time servers were used
- **Time syncing on Local Area Network (LAN):** sub-millisecond offset when all devices were synced to the same time server hosted on the same LAN

Conclusion & Future Work

- This low-cost IoT device for EEW has been demonstrated to have high sensitivity, provide on-site alert, and warn regional subscribers
- A number of these devices have been built and are being deployed in users' homes across the Los Angeles metro area to test their performance as a seismic and EEW network
- Other applications for the device are being explored such as earthquake and seismology education

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