Six-degree-of-freedom Seismogeodesy using Android GNSS, accelerometer and gyroscope data for Rapid Earthquake Response

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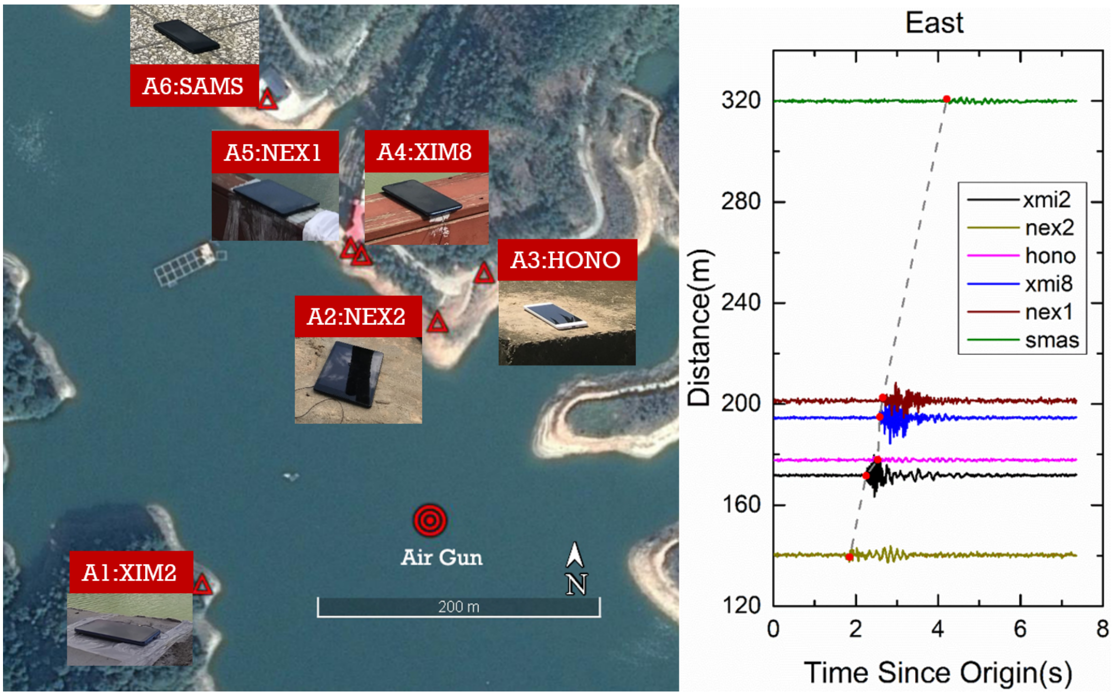
Rapid earthquake response increases the resistance of the humankind to destructive earthquakes. In this paper, we investigated the low-cost smartphone platforms producing raw GNSS, accelerometer and gyroscope data, and inspected if we could tightly couple all of them to compute real-time six-degree-of-freedom (6-DOF) seismogeodetic solutions for a prototype crowdsourcing earthquake sensor. We tested the noise level of the embedded accelerometers/gyroscopes and GNSS chipsets within Android smart devices (e.g., Nexus-9 and Xiaomi-Mi8). The dynamic range of accelerometers was about 60 dB, only half of that of a survey-grade accelerometer (e.g., Kinemetrics Episensor). However, they could still record a M5 earthquake at a distance of 10 km or less. GNSS pseudorange noise was about 1-3 m, about 10 times larger than that of geodetic receivers; the carrier-phase noise was about 0.05 cycle, fortunately only 3-5 times the geodetic receiver phase noise. Based on broadcast satellite ephemeris, the real-time GNSS horizontal and vertical velocity could reach an accuracy of 0.3 cm/s and 0.7 cm/s, respectively. We thus further reported a new method to estimate coseismic displacements and rotations simultaneously, which combined accelerometer/gyroscope and raw GNSS data from Android smart devices in real time without any additional corrections from nearby reference GNSS stations. A comparison was made with eentec R2 rotational seismometers. Moreover, it is well-known that accurate displacements are a prerequisite to rapidly determining the earthquake magnitude, the velocity waveforms are critical to computing the epicenter location and the rotations can be used to assess earthquake-induced differential deformation of structures. Airgun experiments in Yunnan and Fujian provinces of China under controlled conditions showed that the horizontal displacement accuracy for smart devices was about 2-3 cm. The seismic waveforms from smartphones were transmitted to a simulated warning center in real time for further analysis, where we successfully estimated the location and magnitude of airgun experiments. The epicenter location estimate had an error of only 17 m.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A5:NEX1
A4:XIM8
A3:HONO
A2:NEX2
A1:XIM2
Air Gun
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Distance(m)
Time Since Origin(s)