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地震観測に向けた高頻度出力 GPS 受信機の特性比較実験
Performance Comparison of High-Rate GPS Receivers for Seismology

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High-rate GPS observations with higher than once-per-second sampling are getting increasingly important for seismology. A number of reports have shown that high-rate GPS receivers are capable of capturing the ground vibration due to earthquakes. Unlike a traditional seismometer which measures short period vibration using accelerometers, the GPS receiver can measure its antenna position directly and record long period seismic wave and permanent displacements as well. The high-rate GPS observations are expected to provide new insights in understanding the whole aspects of earthquake process.

The ground vibration due to an earthquake is composed of a wide spectrum of frequencies. In general, the seismic energy in frequency spectrum decreases toward higher frequency, and the corner frequency is around several to tens of hertz depending on the earthquake magnitude. In order to grasp such a wide frequency range, the GPS receiver is required to provide higher data sampling rate. The receiver also needs to maintain lock to the GPS signals under high acceleration and high jerk environment due to the earthquake.

In this study, we investigated dynamic characteristics of the high-rate GPS receivers capable of outputting the observations at up to 50Hz. This higher output rate, however, doesn't mean higher dynamics range of the GPS observations. Since many GPS receivers are designed for low dynamics applications, such as static survey, personal and car navigation, the bandwidth of the loop filters tend to be narrower in order to reduce the noise level of the observations. The signal tracking loop works like a low-pass filter. Thus the narrower the bandwidth, the lower the dynamics range. In order to extend this dynamical limit, high-rate GPS receivers might use wider loop bandwidth for phase tracking. In this case, the GPS observations are degraded by higher noise level in return.

In addition to the limitation of the loop bandwidth, higher acceleration due to earthquake may cause the steady state error in the signal tracking loop. As a result, kinematic solutions experience undesirable position offsets, or the receiver may lose the GPS signals in an extreme case.

In order to examine those effects for the high-rate GPS observations, we made an experiment using a GPS signal simulator and several geodetic GPS receivers, including Trimble Net-R8, NovAtel OEMV, Topcon Net-G3A, and Javad SIGMA-G2T. We set up the zero-baseline simulation scenario in which the rover receiver was vibrating in a periodic motion with the frequency from 1Hz to 10Hz around the reference station. The amplitude of the motion was chosen to provide up to 10G acceleration to emulate high frequency and high acceleration earthquake motion.

The simulation results showed that the amplitude was too small when the frequency was higher than 5Hz, and kinematic solutions were buried under the noise level. The jerk was also too high in such high frequency region, and no receiver was capable of maintaining signal lock. Many receivers lost signal under the acceleration higher than 4G. We also found that the accuracy of high-rate GPS observations was independent of sampling rate of the receivers, and the 50Hz sampling rate provides better resolution to the kinematic solutions.

Our experiment suggested that, in the given environment and receiver sets, higher sampling interval was recommended to measure the ground motion in higher resolution. On the other hand, the dynamic characteristics of the signal tracking loop put a limit on the frequency and the acceleration of the antenna motion, and it would be quite difficult to capture the ground vibration with higher than 5Hz in frequency and 4G in acceleration. We will further continue our experiments to find the optimal configurations of the high-rate GPS receivers to monitor seismic events.