Benefits from receiver clock modeling: from PPP-based GPS seismology to Navigation in harsh environment
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Introduction
In the last years, progress has been made to enable high rate (>1 Hz) applications for GNSS in Earth observation. In addition to new receiver designs (up to 100 Hz), especially high-rate satellite products from the IGS and its analysis centers are now available with a data rate of up to 5 s. Geophysical and atmospheric studies (e.g., volcano monitoring, tsunami prediction, and especially studies of co- and post-seismic displacements) benefit from these developments opening up new temporal scales for analyses.

However, high correlations between the parameters of up to 0.99 occur depending on the elevation cut-off angle. This yields a significant degradation of positioning in the vertical direction and masks many valuable geophysical or atmospheric features.

Our Solution: Clock modeling improving parameter estimates by incooperation of external clock information.

Concept of clock modeling
If
• the GNSS receiver is driven by a stable oscillator,
• its accumulated time error due to random frequency fluctuations of the oscillator $\sigma_\omega$ (in terms of the Allan deviation) is smaller than the GNSS receiver noise $\sigma_r$ (e.g., 1% of the wavelength) over a significant time interval $\tau_w$, i.e.,
\[ RMS(\tau_w) = \frac{\sigma_r}{\sigma_\omega} < 1 \]
then
• the temporal variation of the receiver clock offset can be in a physically meaningful way - constrained over intervals $\tau_w$ where (1) is met.
• Within this interval the receiver clock error can be described by a linear or quadratic polynomial, since the random oscillator fluctuations cannot be resolved by GNSS observations because they are below the receiver noise.

Application of clock modeling to the Chile 2010 Earthquake

GPS Data and analysis concept
• 1 Hz GPS data of the IGS station CONZ made available by BKG
• 3 hours data before and after earthquake included for reliably estimating the float carrier phase ambiguities
• GPS receiver (CONZ) connected to well-maintained hydrogen maser frequency standard
• processed with PPP software developed at Institut für Erdmessung
• linearly interpolated 5 s GPS satellite clocks, provided by CODE. (Bock et al. 2009)
• epoch-wise independent receiver clock offsets or piece-wise linear segments (5 min) intervals.

Mainshock

Fig. 3: Kinematic PPP position estimates and receiver clock error during the main shock of the 8.8 magnitude 2010 Chile earthquake (a) using epoch-wise clock estimation, (b) using clock modeling taking the h-masser performance at CONZ into account

Benefits: less jumps, continuous and reliable time series

Application of clock modeling to the Chile 2010 Earthquake

Aftershock

Fig. 4: Kinematic PPP position estimates and receiver clock error during a 6.9 magnitude aftershock (a) using epoch-wise clock estimation, (b) using clock modeling taking the h-masser performance at CONZ into account

• Vertical station displacements hidden in the noise of the kinematic height estimates (Conventional PPP solutions Fig.5(a))
• High mathematical correlation (here about 89.6%) expressed by the similarity of the vertical position time series and the epoch-wise receiver clock offsets (cf. arrows, Fig.5(a))
• Tightly constraining the receiver clock according to the physical clock performance, the signature of the earthquake becomes clearly visible also in the height component (Fig.5(b))
• The standard deviation of height time series is improved by 37% from 12 mm to 7.5 mm.

Application of clock modeling to code-based navigation

Fig. 5: Kinematic code-based position estimates and receiver clock error during a kinematic test drive (a) Test trajectory (b) receiver set up with three identical receivers,
(c) Results with internal clock, (d) Results from clock modeling

• Clock modeling with two states (offset, drift) Kalman model.
• Again, the noise of the height component is reduced (Static positioning up to 23%, kinematic positioning up to 50%).
• Height component less vulnerable w.r.t. systematics, since correlations between the parameters are reduced.
• Availability improved, since positioning with only three satellites in view is possible.
• Vibrations may degrade the results.

Conclusions

• The usage of highly stable GNSS receiver oscillators allows to improve the accuracy of kinematic vertical position estimates by a factor of 2-3.
• Co-seismic few mm vertical displacements of a stand-alone GPS receiver connected to a hydrogen maser frequency standard can be detected using the PPP approach with enhanced clock model.
• More accurate height variations can be derived from Precise Point Positioning using IGS orbit and clock products. This is interesting for high-frequency deformation monitoring such as GPS seismology.
• Chip-scaled atomic clocks together with clock modeling improve the availability, continuity and precision of code-based navigation solutions in harsh environments.

References:
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