In 2007, Guillaume and Geiger presented a new method for the detection of small and rapid movements of a single GPS receiver called G-MoDe (GPS movement detection). The method is based on the prediction of single differences of carrier phase measurements between pairs of satellites by using appropriate filter methodologies. By assuming that the effects which do have an impact on the measurements (orbit trajectory, atmosphere, clocks, etc.) vary slowly at a sub-second resolution, an antenna displacement can be detected, if the predicted phase differs significantly (95%) from the measured phase. The results indicated that quick horizontal movements above the 5 [mm] level are detectable with a GPS receiver.

In order to apply the G-MoDe algorithm it is necessary to have continuous measurements available for the purpose of system identification and initialization for a proper time interval even before an antenna displacement occurs. However, within the scope of X-Sense II such an algorithm should already be applicable at an event-driven (triggered) start-up of the sensor, in order to prove if there is happening something and if further measurements should be collected for a precise point positioning.

To achieve this, a possible solution could be not to track the phase, but its time derivative, the Doppler frequency, which is linear related to the radial velocity of a moving object.

In this case, this corresponds to the receiver-satellite line-of-sight (LOS) velocity, for which an analytical expression can be derived by a time derivation of the GPS phase observation equation (after conversion to [m]). By applying this time derivation, the various effects which affect the phase measurements enter the velocity observation equation only by their gradients, which vary very smoothly. Another benefit is, that effects like satellite velocity, tropospheric effects (dry part) or relativistic effects can very well be modeled. They can be used for an error model for a sequential least squares adjustment or they can serve as a deterministic sensor control input in a filter for the tracking of satellite velocities, in order to estimate the velocity of a moving receiver.

Conclusions

Based on the concept of G-MoDe and on the work of Zhang et al. (2008) and Serrano et al. (2004), the goal is to expand the G-MoDe algorithm towards a real-time monitoring tool to detect hazardous events almost instantaneously on a triggered startup with a low-cost GPS equipment.

The results stated in previous works already indicate promising results to reach an accuracy at the sub-centimeter per second level. To reach such an accuracy it is necessary to account for the various error sources affecting the velocity measurements. The most unpredictable part is assumed to come from the atmosphere. Multipath effects are also assumed to have a small influence; however, in a non or slowly changing atmosphere environment they can possible be accounted for with a multipath mask.

Preliminary tests with a shake table together with a geodetic two-frequency receiver already indicate that very small movements at the cm/s level can be detected in the GPS velocity data. In a next step, such measurements have to be collected for single frequency low-cost GNSS receivers to assess the quality of the Doppler measurements and their predictability by modeling the contributing effects.

References


![Figure 1: Concept of G-MoDe displacement detection](image1)

**Concept of G-MoDe**

An expanded version of the phase observation equation (with the displacement $\tau$ added) forms the observation equation for the receiver-satellite LOS velocity. After derivation w.r.t. time it reads:

$$Φ(t) + \epsilon = \nabla i(t) \cdot \nabla t + \epsilon (t)$$

$$\Phi = \text{single phase differences of the incoming observations [m]}$$

$$i = \text{single phase differences estimated with the Kalman Filter [m]}$$

$$\epsilon = \text{correlated noise [m]}$$

$$\nabla = \text{unknown displacement vector [m]}$$

$\dot{i}$, $\dot{t}$ = receiver – satellite unit vector

By step-wise tracking and predicting the function $\dot{i}$, for the next epochs, it becomes possible to detect a movement w.r.t. the incoming observations (figure 1). In a next step, the differences ‘observed – predicted’ can be formed and the equation can be solved for the displacement in a least-squares sense.

**The Idea of G-MoDe+**

An expanded version of the phase observation equation (with the displacement $\tau$ added) forms the observation equation for the receiver-satellite LOS velocity. After derivation w.r.t. time it reads:

$$Φ(t) + \epsilon = \nabla i(t) \cdot \nabla t + \epsilon (t)$$

$$\Phi = \text{single phase differences of the incoming observations [m]}$$

$$i = \text{single phase differences estimated with the Kalman Filter [m]}$$

$$\epsilon = \text{correlated noise [m]}$$

$$\nabla = \text{unknown displacement vector [m]}$$

$\dot{i}$, $\dot{t}$ = receiver – satellite unit vector

The terms on the right-hand-side correspond to receiver velocity, satellite velocity and the time gradients of receiver clock, satellite clock, ionospheric effects, tropospheric delay, multipath and relativistic effects. $\tau$ is the time between the emission of the signal at the satellite to the reception at the receiver. As for eq. (1), single differences can be formed (eliminates receiver clock effects) and the G-MoDe concept can be adapted. (Serrano et al, 2004) developed an algorithm for the solution of eq. (2) in an sequential least squares adjustment for $\tau$. They accounted for satellite orbits and various errors by using a priori models. For a GPS L1 low-cost receiver in a static case they arrived at an accuracy of better than 1 cm/s (figure 2).

**References**