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# Movement Detection with GPS in the Velocity Domain: G-MoDe+

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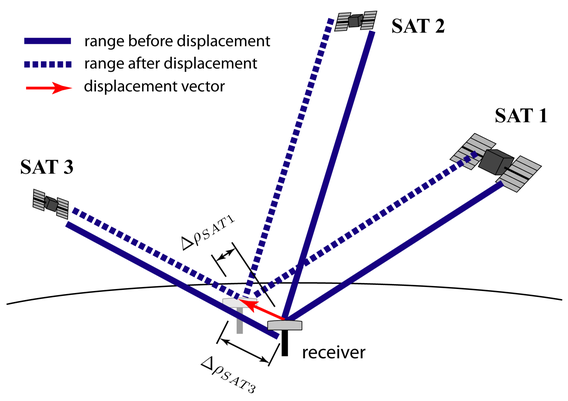
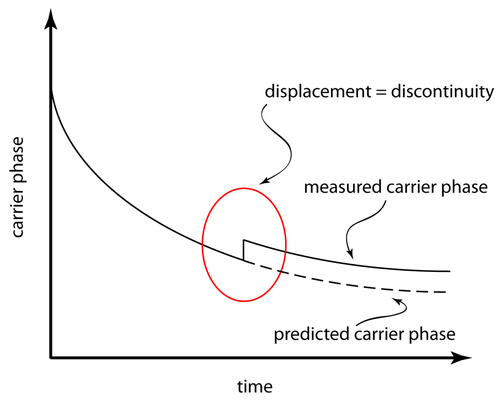
- **Idea of G-MoDe+:** Expand G-MoDe® (GPS Movement Detection) algorithm (developed at IGP) for detecting small and rapid movements of a single frequency GPS receiver towards detecting movements at (triggered) sensor wake-up

## Principle of G-MoDe

- Introduce a displacement term Δρ in the GPS observation equation in the range domain and predict observations in a Kalman Filter
- Estimate displacement vector based on 'observed – predicted' residuals Δρ from measurements to multiple satellites

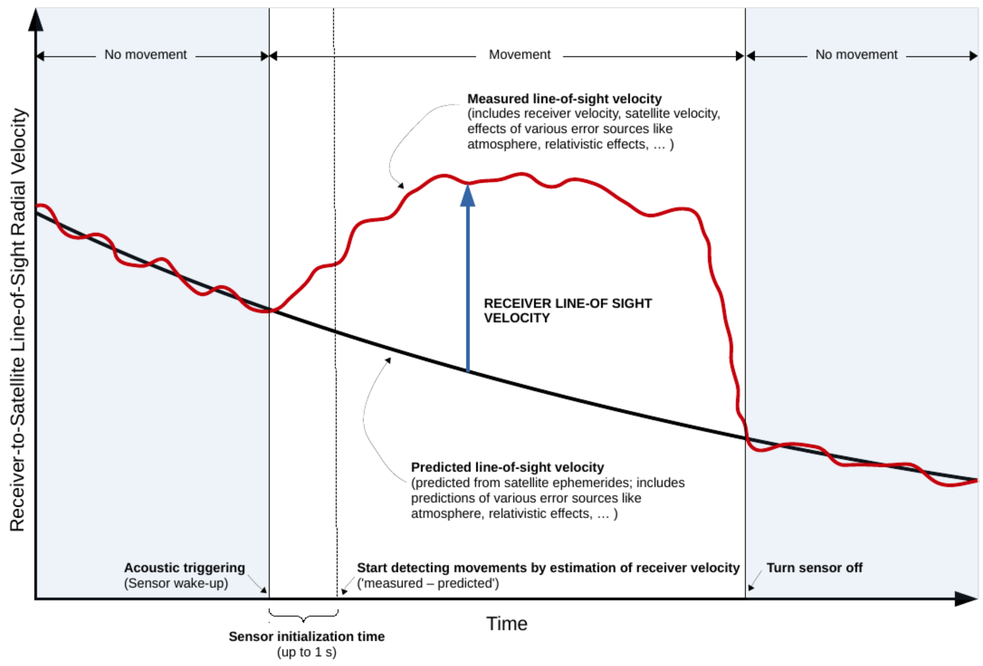


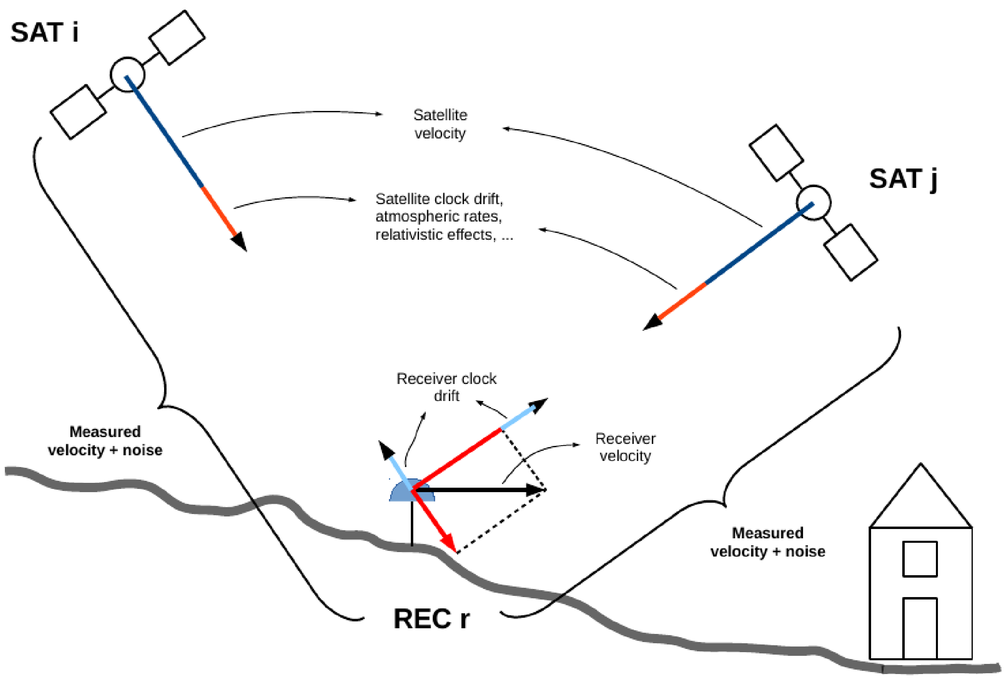

## Idea of G-MoDe+

- Movement detection by estimation of receiver velocity vector based on 'observed–predicted' satellite-receiver line-of-sight (LOS) velocity

Idea Of G-MoDe+: GNSS Movement Detection Right From Sensor Wake-up




- Concept based on prediction of contributing effects (analytical and empirical models) to observation equation in the velocity domain




## Observation Equation and Workflow

$$\lambda D^i + \dot{\epsilon}^i = -\vec{v}_r\vec{e}_i + \vec{v}_s\vec{e}_i + c\dot{d}T - c\dot{d}t^i - \dot{d}Ion^i + \dot{d}Trop^i + \dot{d}Mult^i + \dot{d}Rel^i$$

| $\lambda D^i + \dot{\epsilon}^i$ | $-\vec{v}_r\vec{e}_i$ | $\vec{v}_s\vec{e}_i$ | $c\dot{d}T$ | $-c\dot{d}t^i$ | $-\dot{d}Ion^i$ | $+\dot{d}Trop^i$ | $+\dot{d}Mult^i$ | $+\dot{d}Rel^i$ |
|---|---|---|---|---|---|---|---|---|
| Measured LOS Velocity + noise | Receiver LOS Velocity | Satellite LOS Velocity | Receiver Clock Drift | Satellite Clock Drift | Ionospheric Rate | Tropospheric Rate | Multipath Rate | Relativistic Effects |

| | Error Terms | Modelling in Doppler Measurements | Magnitude Estimated | |
|---|---|---|---|---|
| Satellite Orbit | Broadcast Ephemeris | Yes | ±1mm/s per axis | High Predictability |
| Satellite Clock | Satellite Clock Correction | Yes | Negligible | |
| | $L_1$-$L_2$ Correction | No | Negligible | |
| Relativity | Orbit Eccentricity | Yes | Several cm/s | |
| | Sagnac | Yes/No** | Several mm/s | |
| | Second-order Doppler Effect | Yes | Over 2.0 cm/s | |
| | Secondary Relativistic Effects | No | Negligible | |
| Atmosphere | Ionospheric Correction | Yes | mm/s to cm/s | Limited Predictability |
| | Tropospheric Correction | Yes | mm/s to cm/s | |
| Receiver | Receiver Site Displacement | No | Negligible | |
| | Receiver Clock | As an unknown to be estimated | | |

**Table:** Estimated magnitude of receiver-satellite LOS velocity components [Zhang, 2008]

ALGORITHM WORKFLOW:

(0) Convert Doppler measurements $D^i$ to LOS velocity (observations to > 4 satellites)

(1) Model contributions to observation equation → 'Predicted'

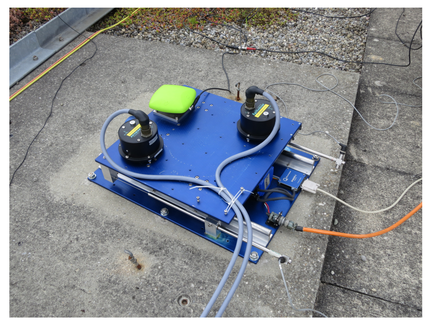
(2) Create 'Observed – Predicted' residuals

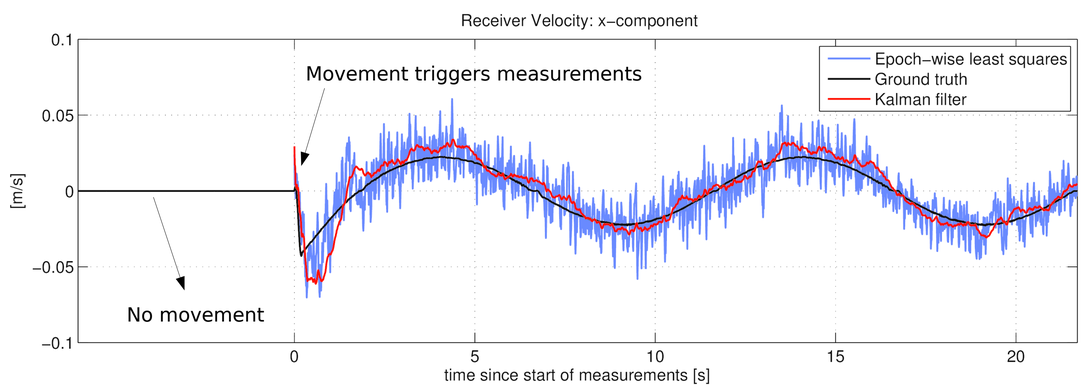
(3) Estimate receiver velocity vector $\vec{v}_r$ in a Kalman filter
→ Estimates of unknows (rec. velocity, rec. clock drift, … )

(4) Statistical testing of estimates to prove movement
→ Detect movement

## Preliminary Results

Shake table experiment of an oscillation with an amplitude of 0.05 meter and a period of 10 seconds, measured with a JAVAD dual frequency receiver. Instrumental setup (right), results and ground truth (bottom)






- In this case study, small movements can be tracked with Doppler measurements of a high-grade GPS receiver
- Next: Statistical proof and further tests with low-grade receivers

**Reference:** Zhang, J.; Zhang, R.; Grenfell, R.; Deakin R.; On Real-Time Precision Velocity Determination for Standalone GPS Users, Survey Review, 366-378 2008