From GNSS to Black Box for Challenging Road Applications

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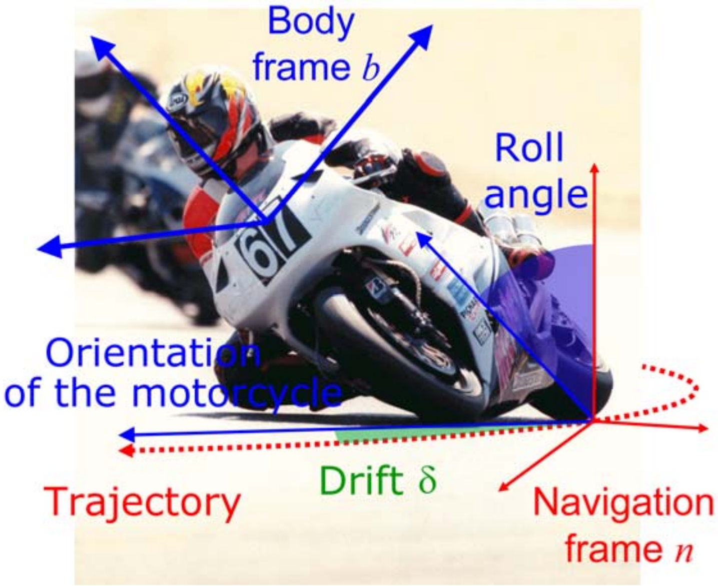
Space for Transport and Mobility

Session Ground Transport

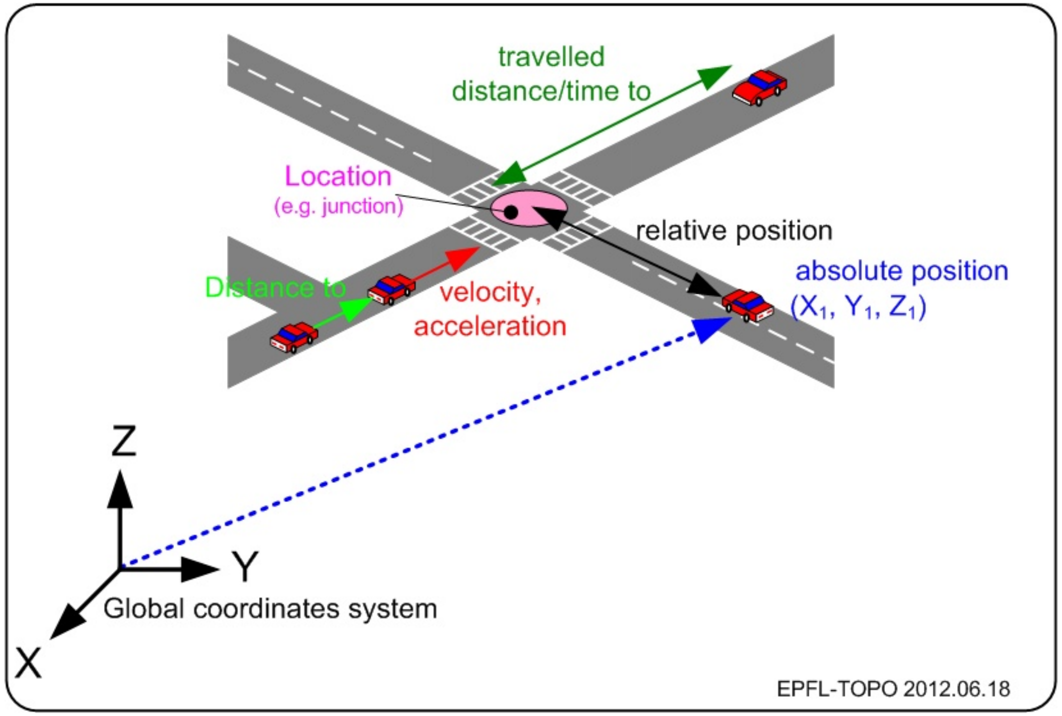
Agenda

- Positioning
  - Parameters
  - Requirements
- Types of Positioning Systems
- GNSS/INS
  - Integration
  - Navigation Performance
- Challenging Applications
  - Trajectory Analysis in Motorcycle
  - Event Data Recorder
- Perspectives

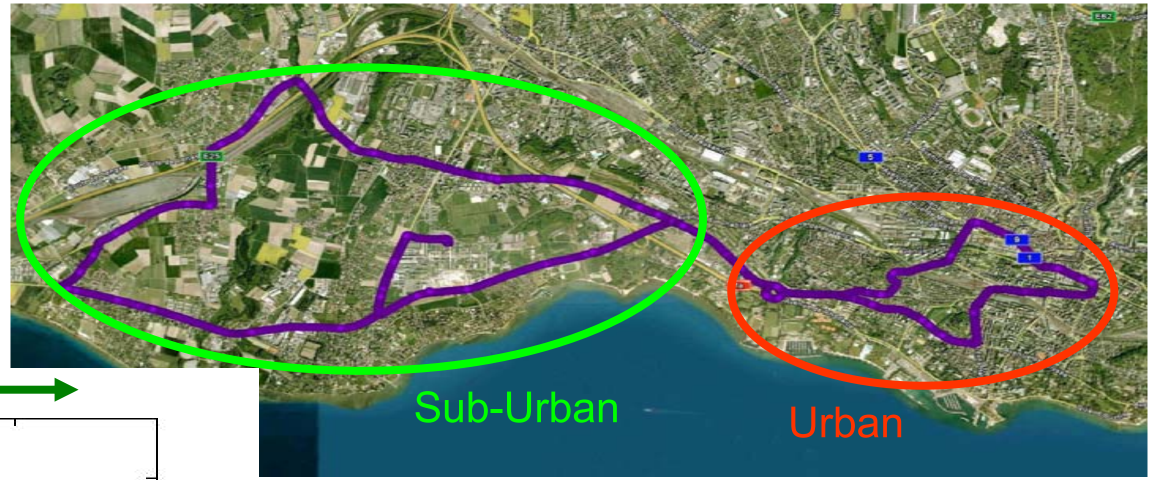


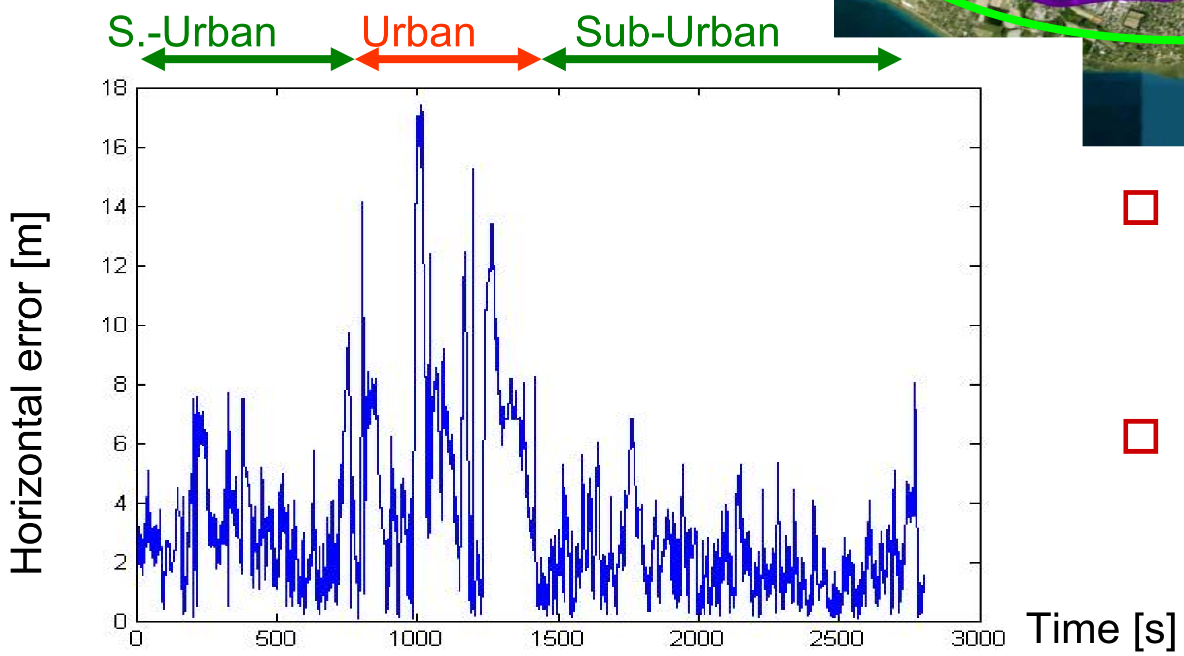
Positioning Parameters

- Fundamental parameters used in positioning
  - Location (specific point, link, area, junction,…)
  - Absolute position (GPS lat/long coordinates)
  - Relative position (distance to vehicle)
  - Time
- Other parameters
  - Velocity, acceleration
  - Orientation, attitude
- Processing
  - Real time (navigation)
  - Post processing (trajectory)



Positioning Parameters

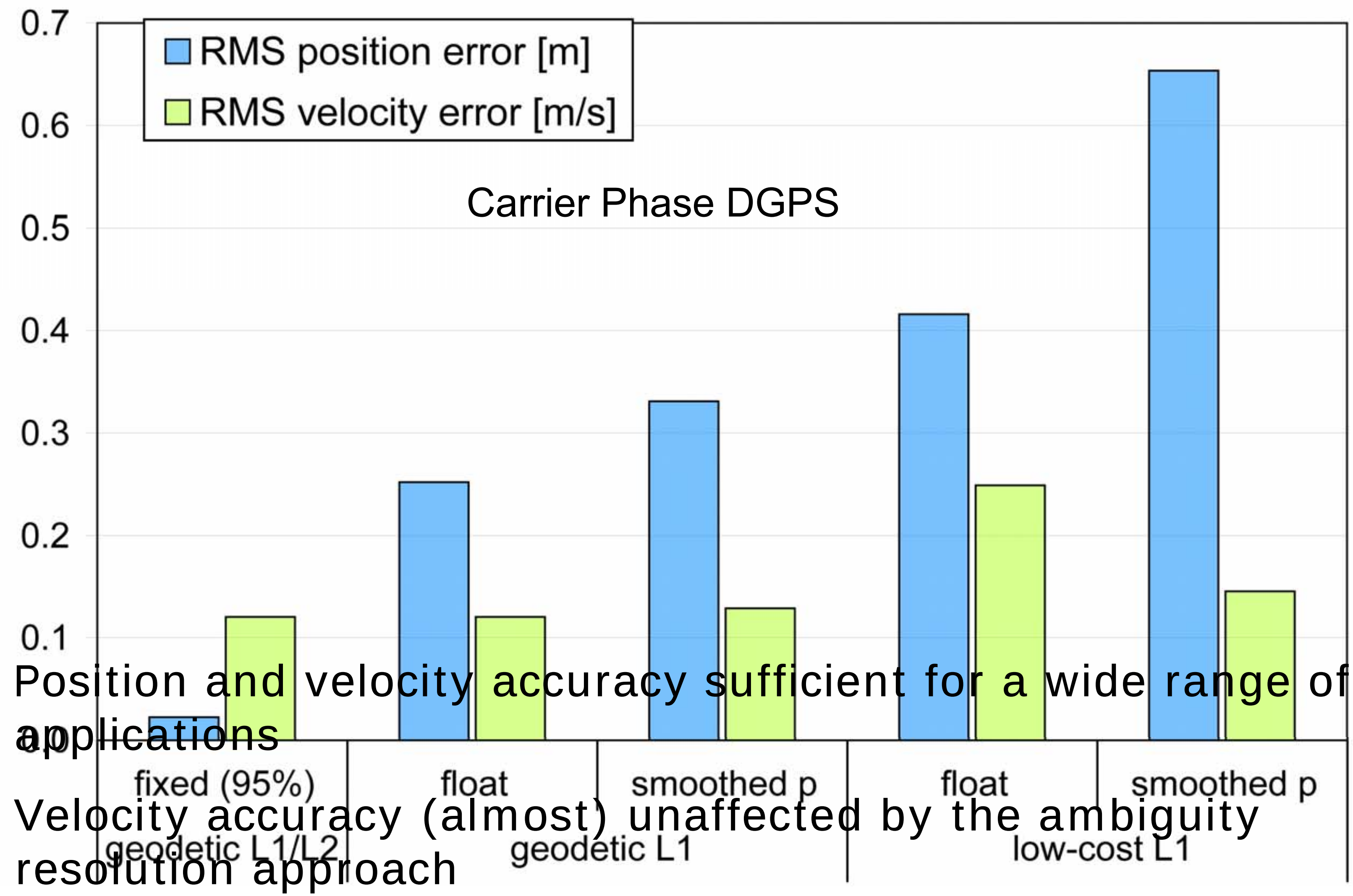




- GNSS issues
  - Outages
  - Bias
  - Interferences
- Necessity to combine GNSS signals with other navigation sensors

- Horizontal error: GPS “low cost” vs reference trajectory (0.1m)

Positioning Parameters



→ Position and velocity accuracy sufficient for a wide range of applications

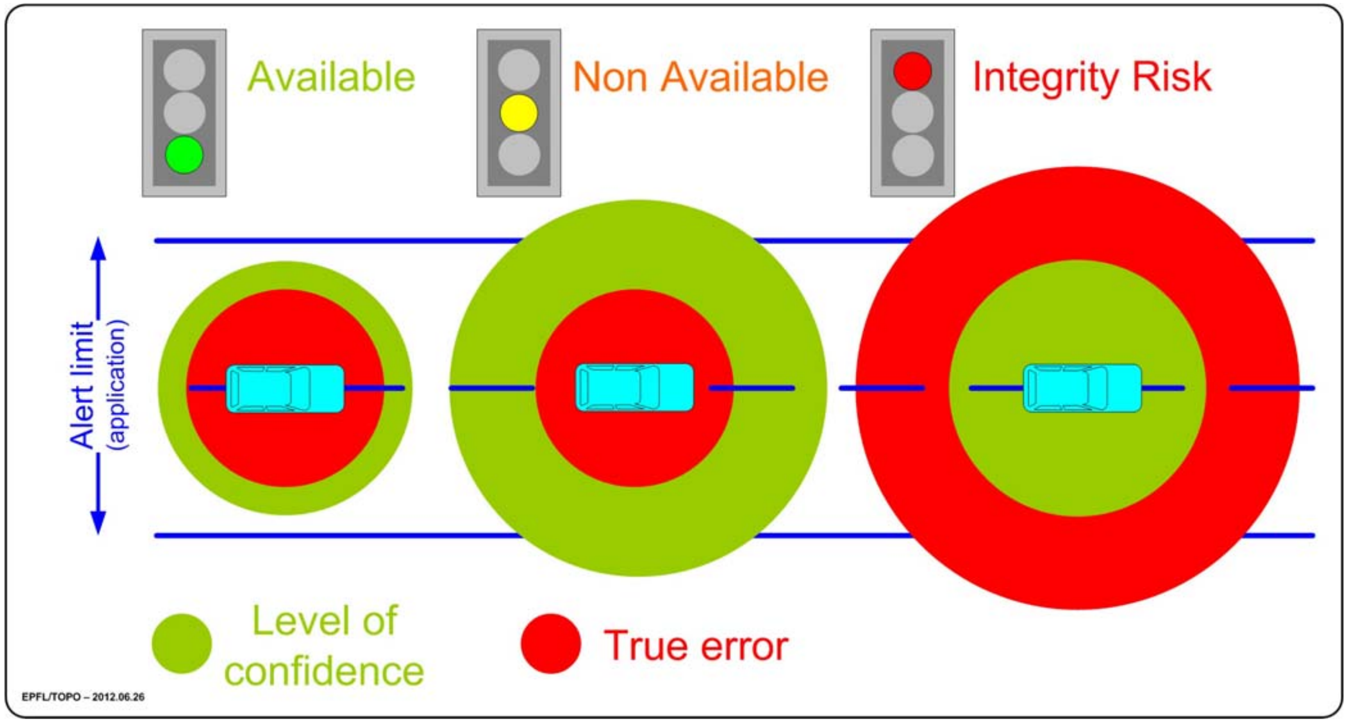
→ Velocity accuracy (almost) unaffected by the ambiguity resolution approach

Requirements on Positioning

- Fundamental requirements
  - Accuracy: measure of the difference between the estimated position of a vehicle and its true position
    - Which road, which lane, where in the lane?
  - Integrity: measure of the trust that can be placed in the correctness of the information supplied by the positioning system
    - Is the position information usable or not?
  - Continuity: capability of the system to perform without unscheduled interruptions during the intended operation
  - Availability: percentage of the time that the positioning service is usable and is delivering the required accuracy, continuity and integrity

- More specific requirements
  - Resistance to interferences
  - Privacy
  - Synchronization between mobiles
  - Others

Requirements on Positioning

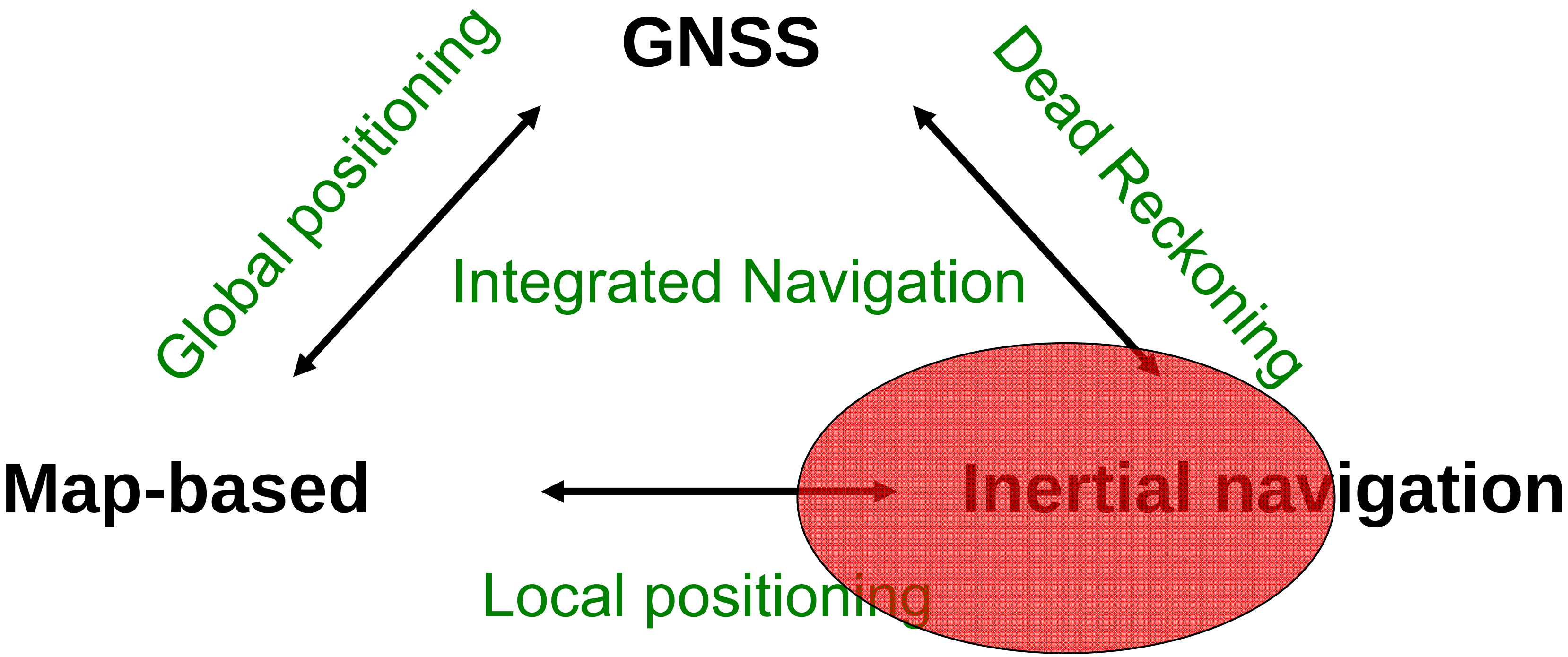


- Available: True error < Level of Confidence < Alert limit
- Non available: True error < Level of confidence > Alert limit
- Integrity Risk: True error > Level of confidence
- Key challenge: estimation of the correct level of confidence

Types of Positioning Systems

- **Satellite navigation (GNSS)**
  - GNSS: satellite-based positioning, provide a 3D position (lat, long, altitude) in a global reference system (WGS84)
- **Terrestrial radio navigation**
  - WLAN, RFID, Bluetooth: 2D position relatively to fix points (access points) or to a local reference system
- **Dead reckoning (DR)**
  - Magnetic heading, barometric altimeter, odometers: measure the spatial motion of the user with respect to the environment
- **Feature matching**
  - Map matching (or image matching) : provide positioning relatively to map (image) features in a mapping reference system
- **Inertial navigation (INS)**
  - Accelerometers, gyroscopes: dead reckoning navigation system, comprising an IMU and a navigation processor. Measurements of specific forces and angular rate

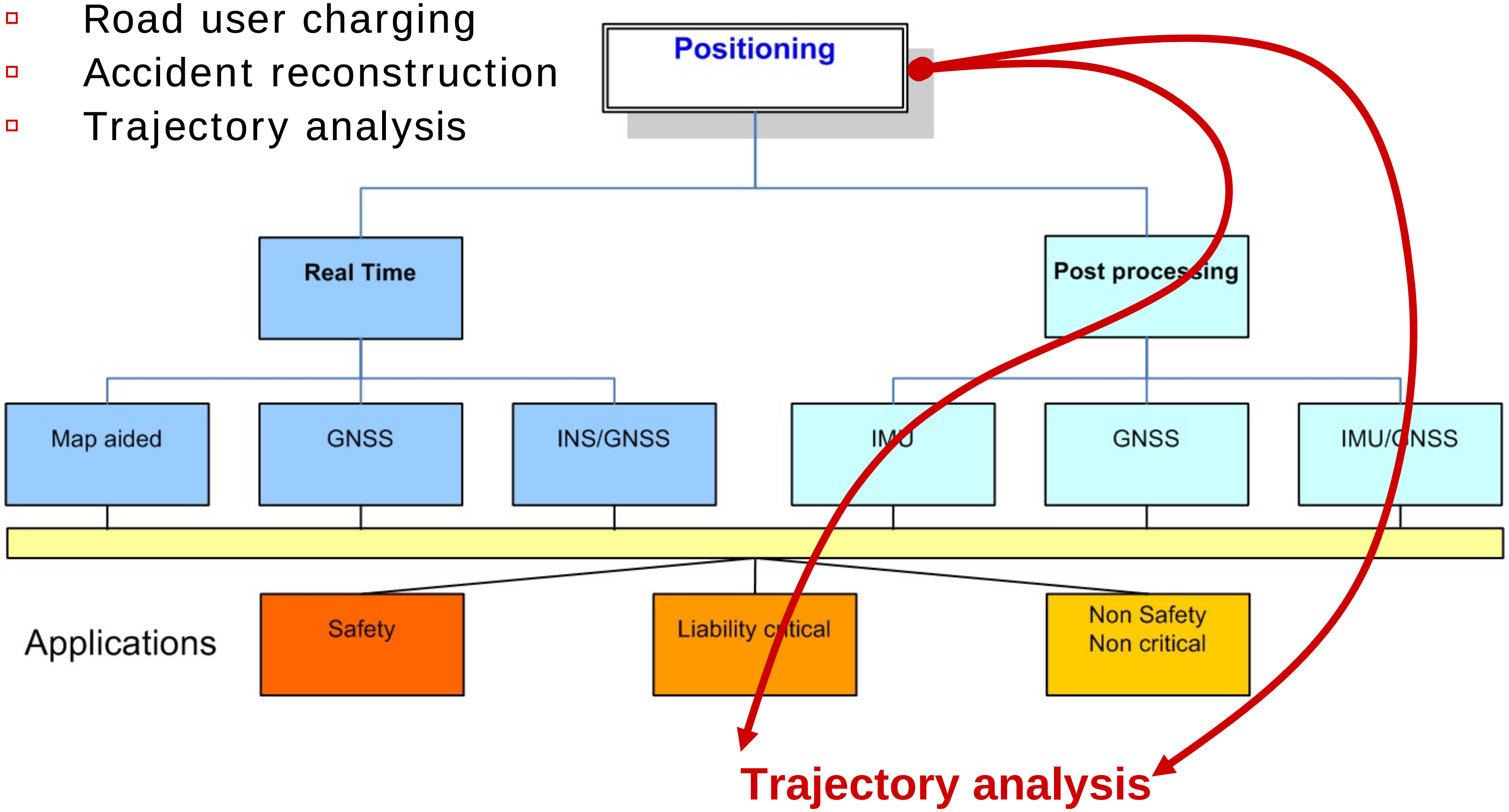
Types of Positioning Systems



- Most of applications are based on global/local positioning and are linked to onboard digital maps
- >> **Strong dependencies on hard/soft infrastructures**

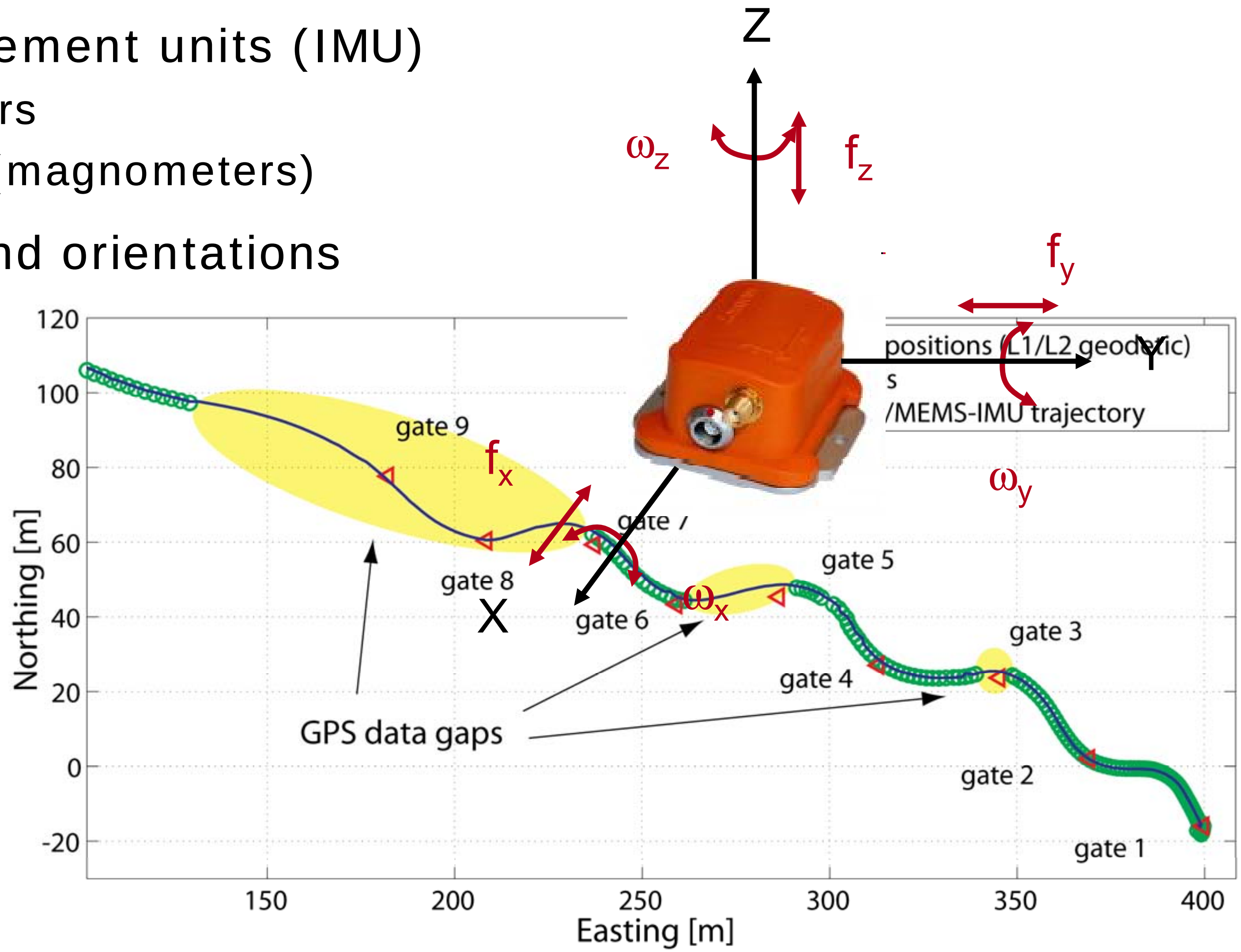
Types of Positioning Systems

- Concept of **black box** for precise trajectory recording
  - Independent from vehicle (onboard) sensors
  - Applications
    - Road user charging
    - Accident reconstruction
    - Trajectory analysis



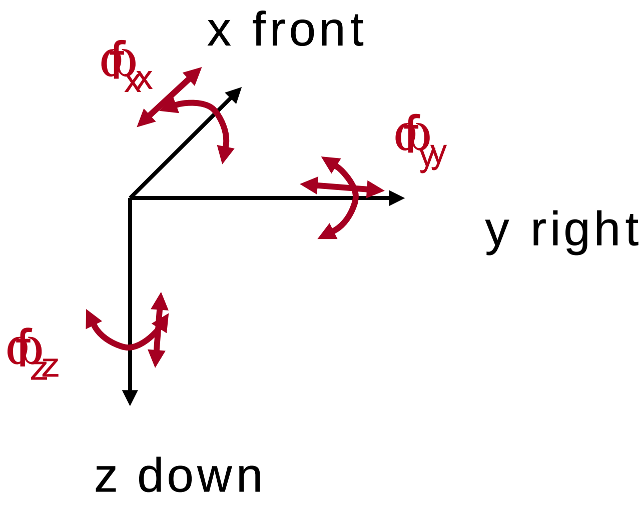
GPS/INS integration

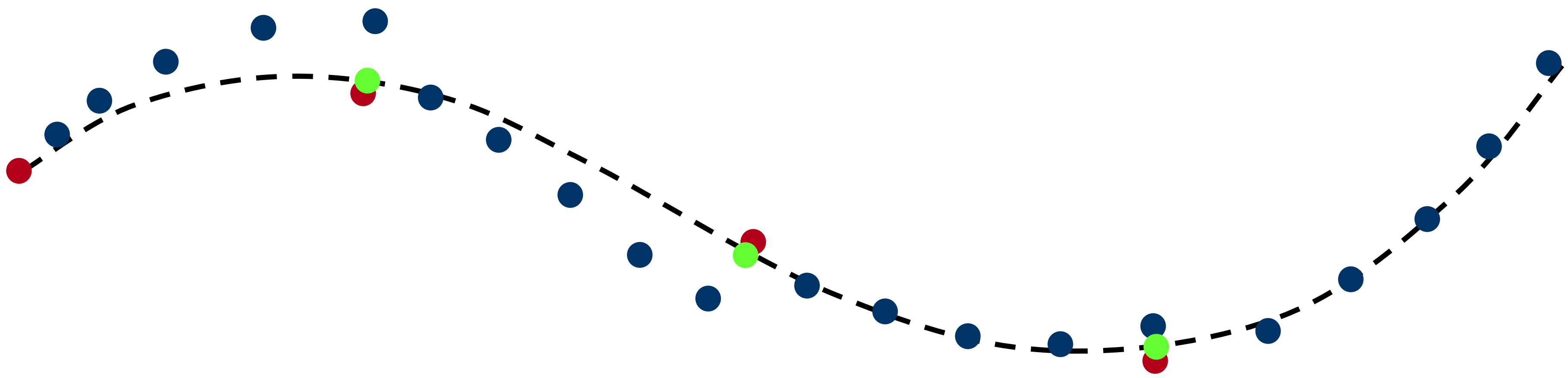
- Inertial measurement units (IMU)
  - Accelerometers
  - Gyroscopes, (magnometers)
- Accelerations and orientations
- High data rate
- GPS data gaps



GPS/INS integration

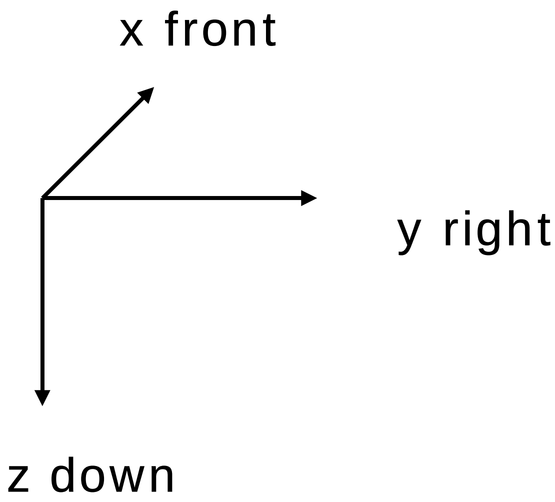
- GPS coordinates
- Reference trajectory
- Strapdown inertial navigation
- Updated coordinates

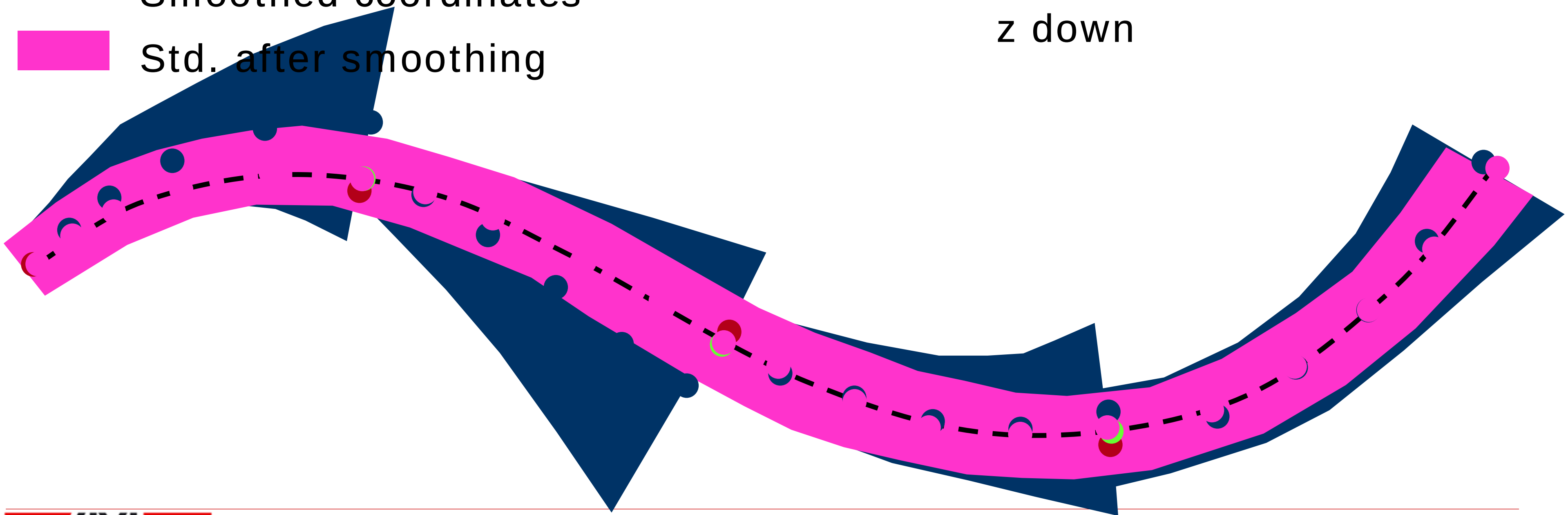




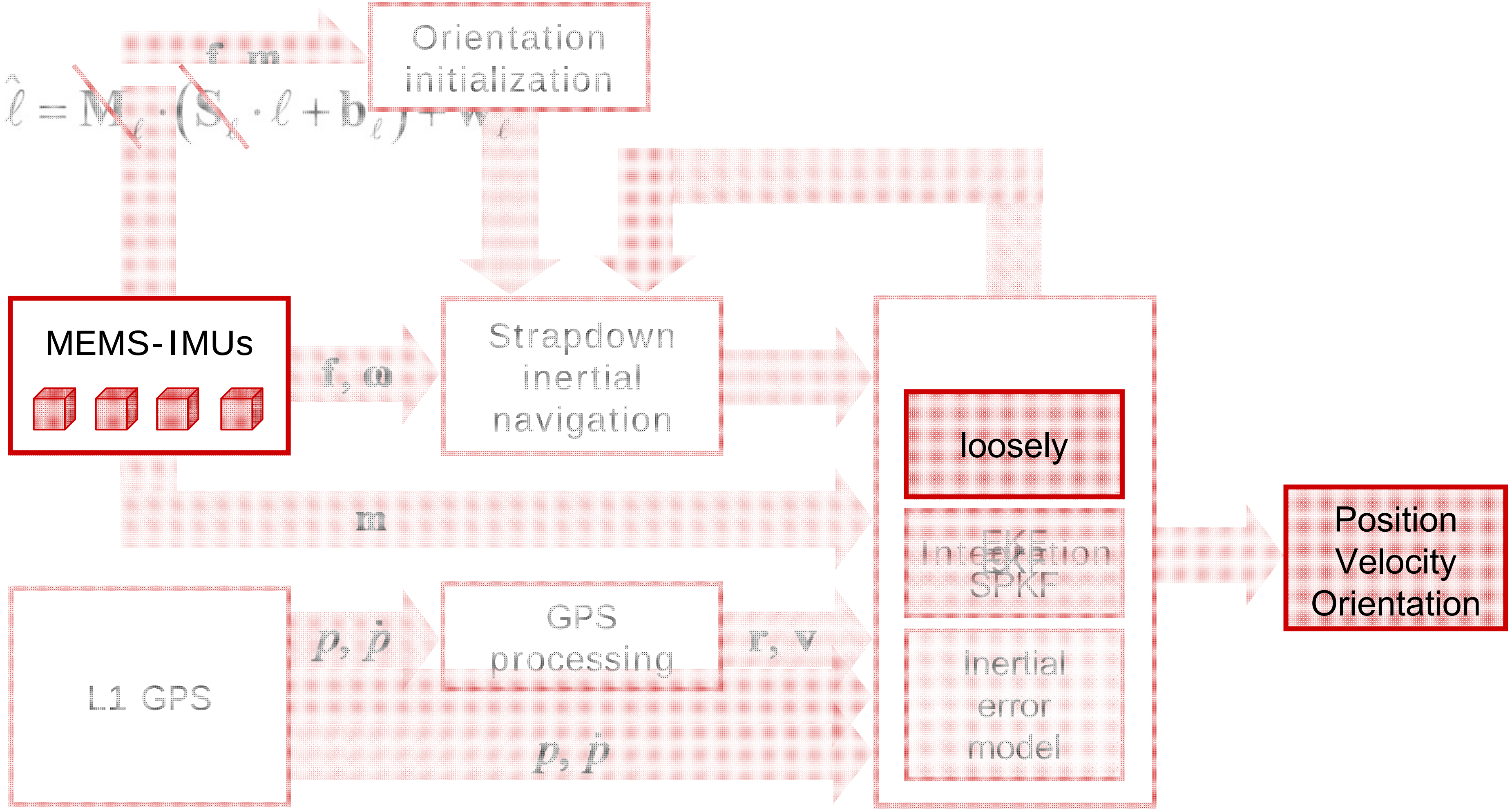
GPS/INS integration

- GPS coordinates
- Reference trajectory
- Strapdown inertial navigation
- Updated coordinates
- Std. after forward processing
- Smoothed coordinates
- Std. after smoothing

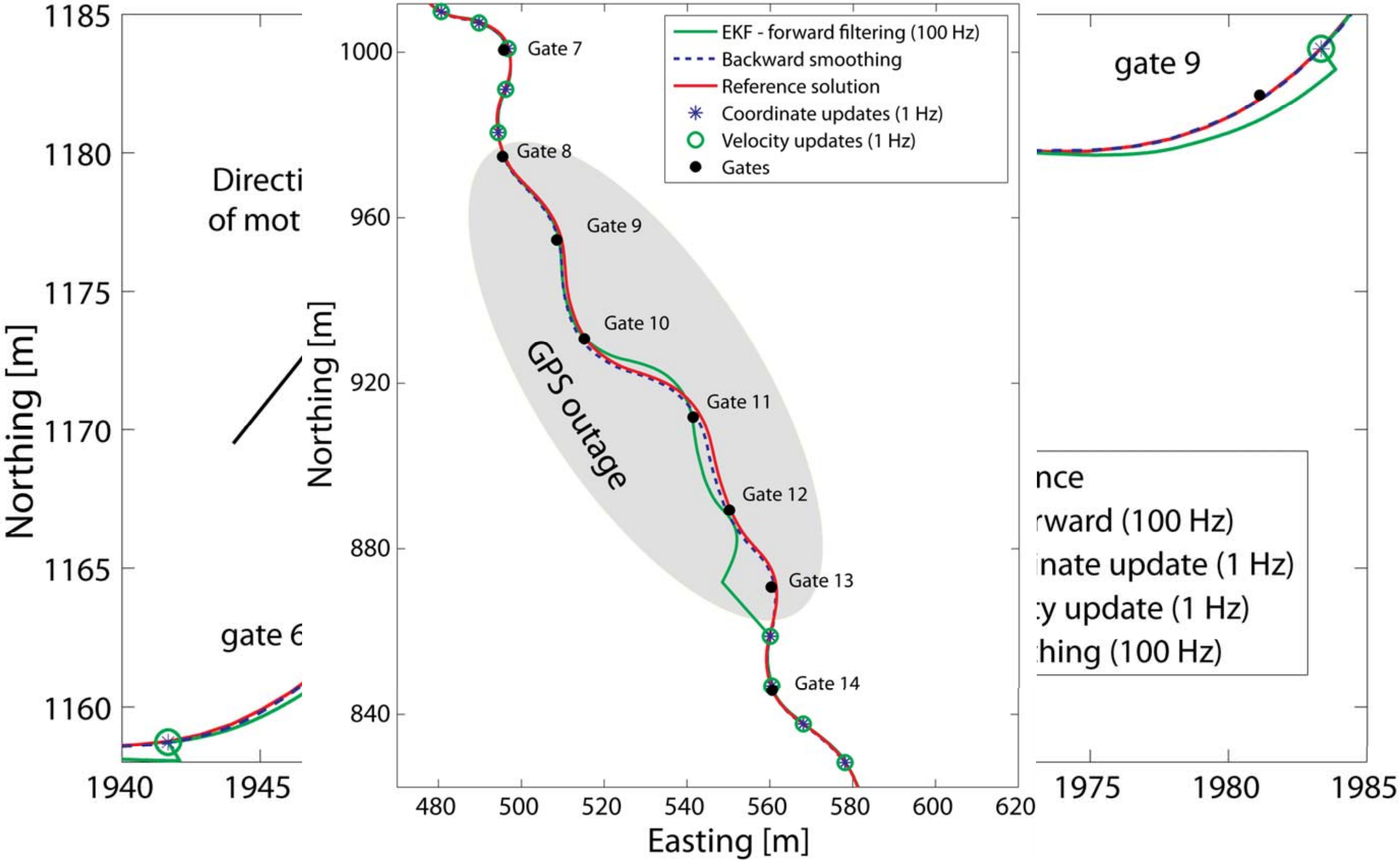




GPS/INS integration



DGPS/MEMS-IMU navigation performance



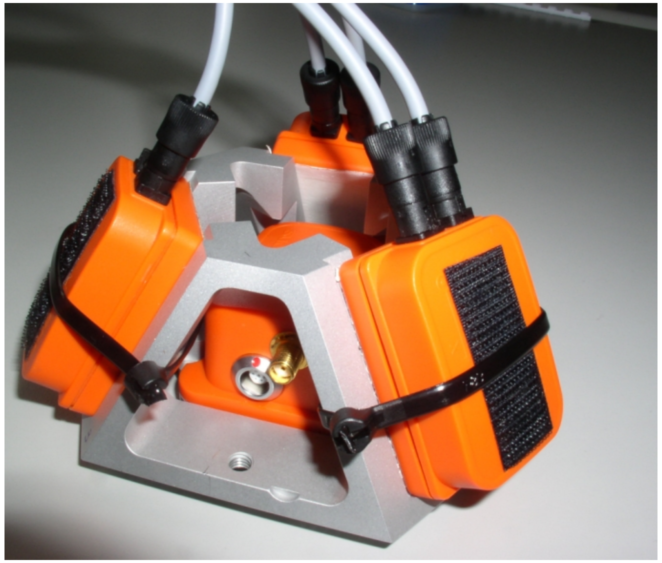
DGPS/MEMS-IMU navigation performance

- Typical DGPS/MEMS-IMU performance:

  0.1-0.8 m, 0.2 m/s, 1-2 deg

→ Improve orientation accuracy

- Ideal geometry: 4 MEMS-IMUs in skewed configuration

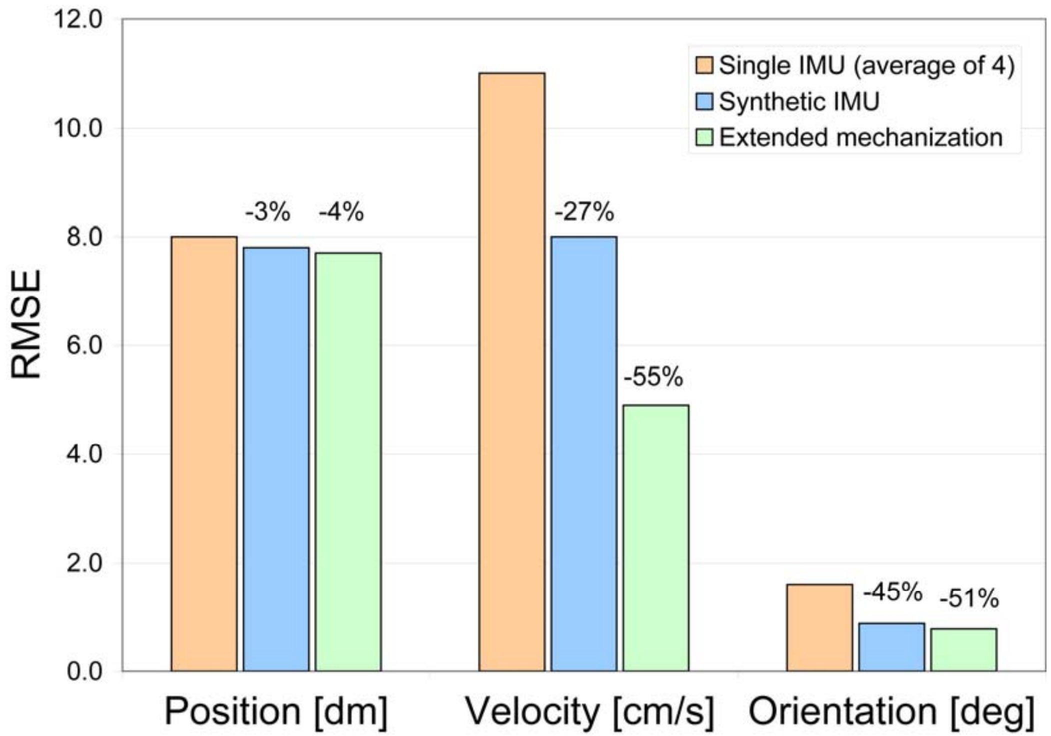


DGPS/MEMS-IMU navigation performance

- RMSE: 3-55%
- Orientation error < 1°
- Extended mechanization performs better than synthetic IMU

Filtering strategy

- Average of 4 IMUs
- Synthetic IMU
  - Not stochastically optimal
- Extended mechanization
  - Estimation of individual sensor errors



Challenging Applications

- Applications
  - Trajectory analysis in **motorcycling**: estimation of drift angle, lateral slipping of tires
  - Event Data Recorder (EDR): pre-crash recorder of speed
- Goal
  - Robust positioning system (real time or post processing)
  - Accurate estimation of trajectory
    - position, velocity, acceleration and orientation
  - Adequate estimation of errors
  - Autonomous
  - Low cost & easy to mount system
- Why motorcycling?
  - High dynamic, vibrations
  - Many degrees of freedom
  - Small vehicle

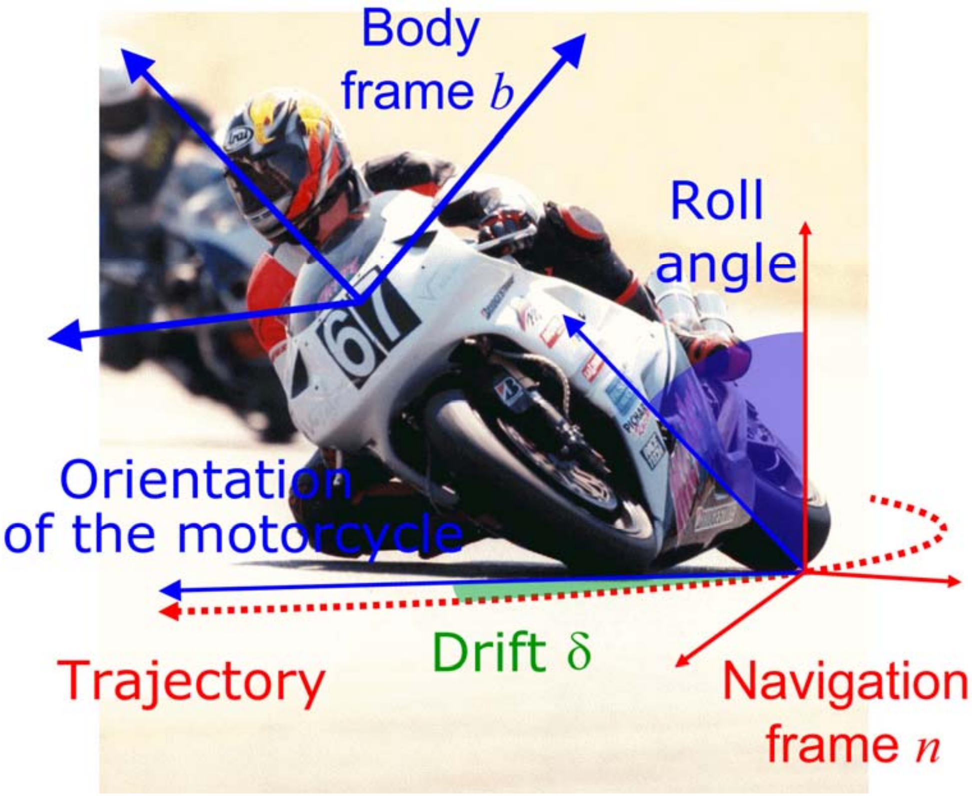
Challenges

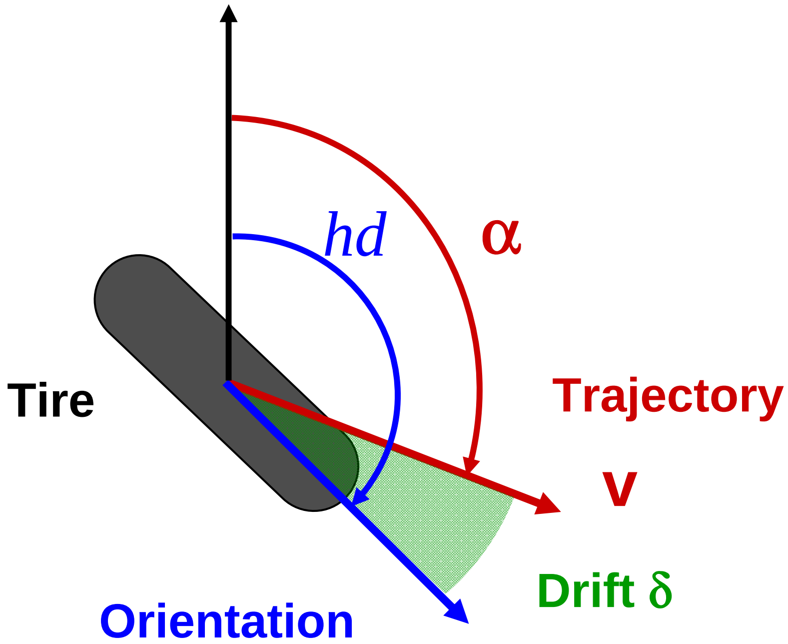
Smart setup of sensors

Almost 3D trajectory

Miniaturization of sensors

Trajectory analysis in motorcycling



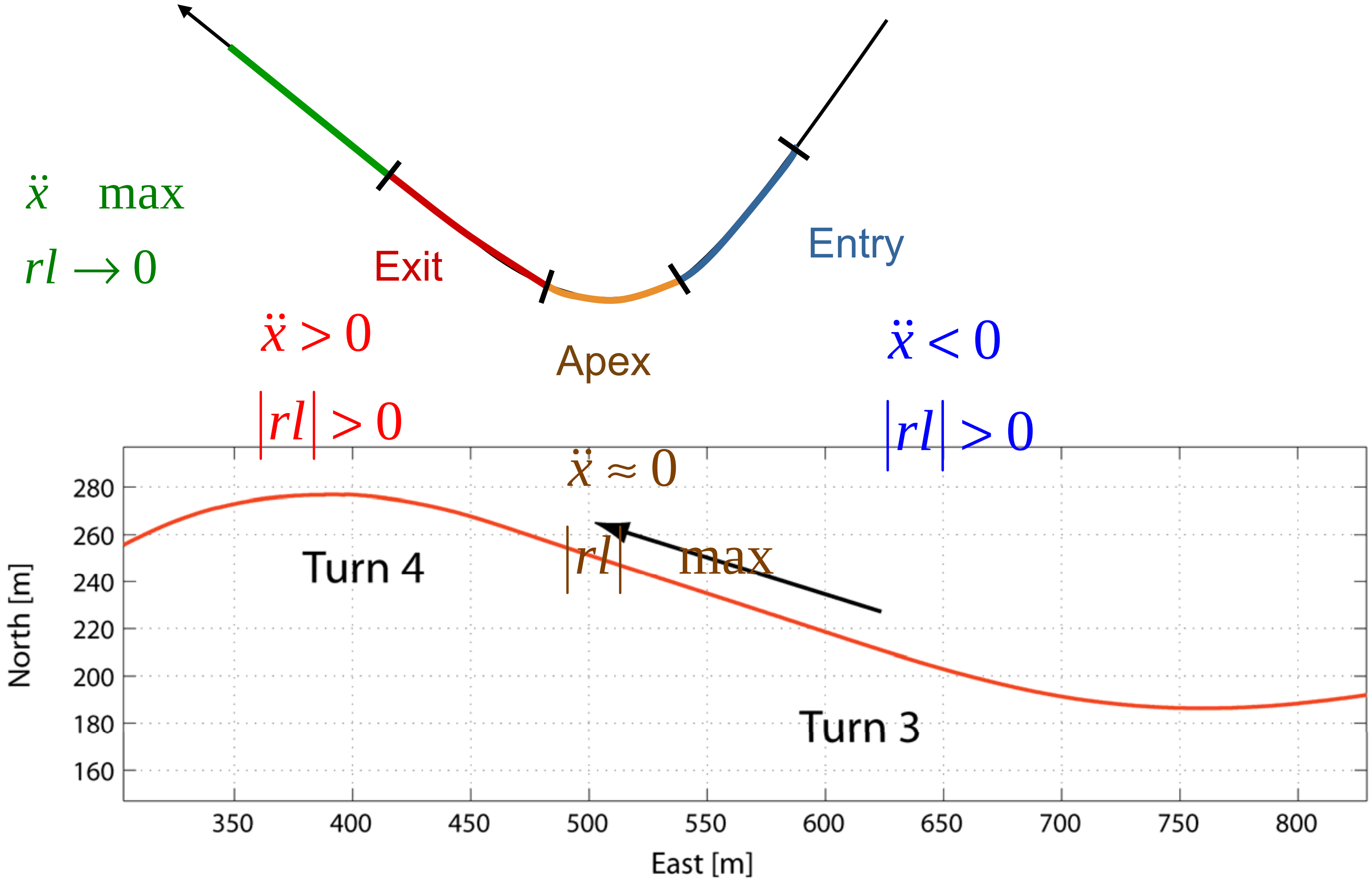


$$\tan(\alpha) = \frac{\mathbf{v}_{North}}{\mathbf{v}_{East}}$$

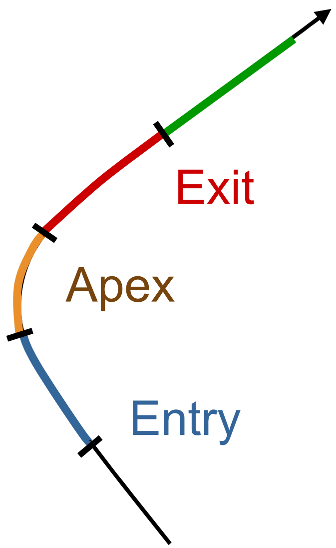
Lateral slipping of tires

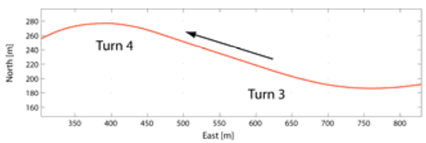
$$\delta = hd - \alpha$$

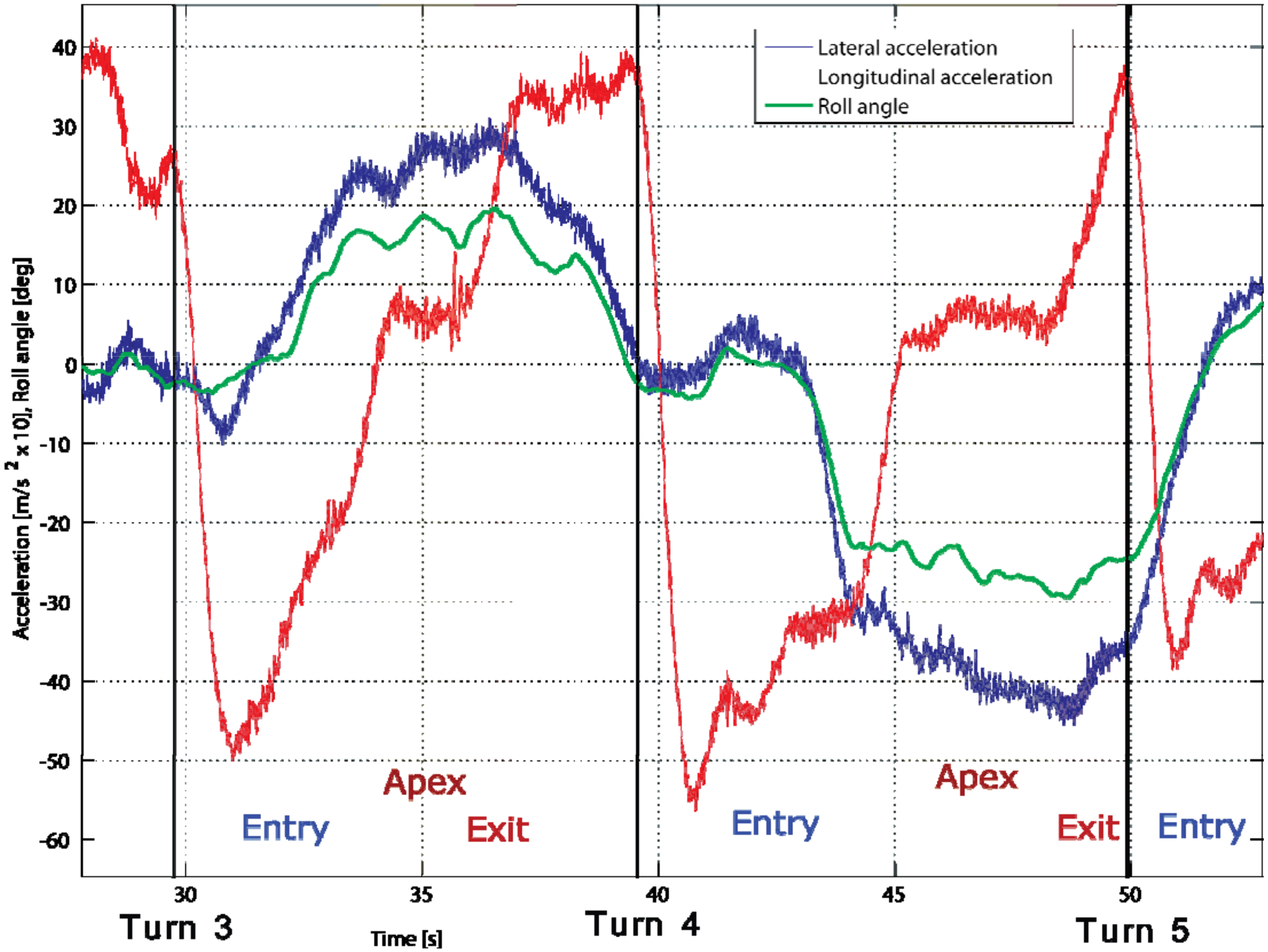
Trajectory analysis in motorcycling



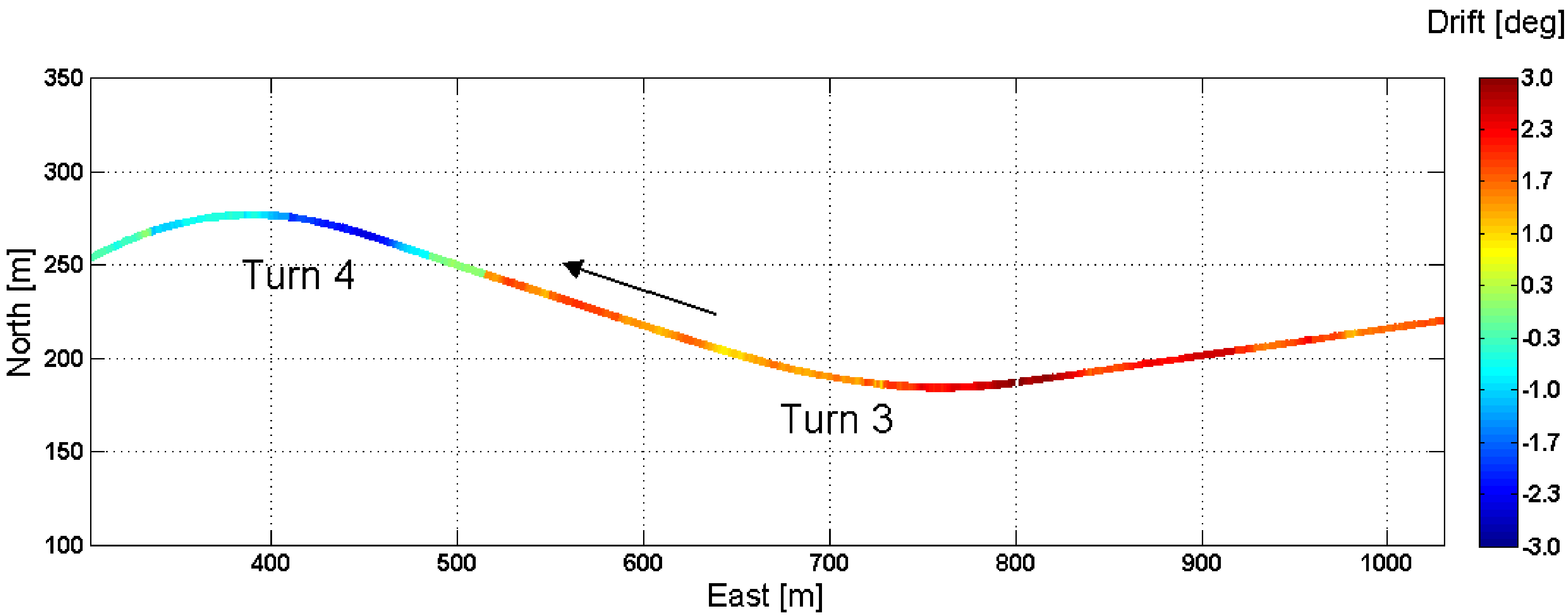
Trajectory analysis in motorcycling







Trajectory analysis in motorcycling



Lateral slipping (drift) of tires

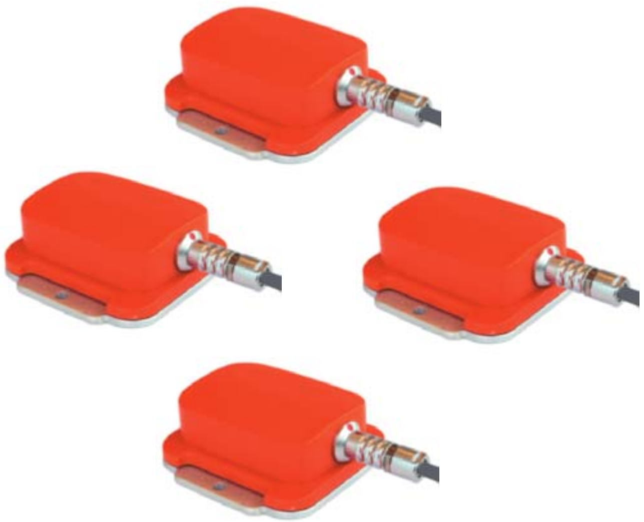
Motorcycle – Event Data Recorder

- **Objective:**
  - Developement of tools for motorcycle accident reconstruction
  - Event Data Recorder (EDR)
  - Associated with off-line Event-Analyzer

- **Constraints:**
  - Autonomy : no need for infrastructure
  - No position (e.g. GPS) to respect privacy

Motorcycle – Event Data Recorder

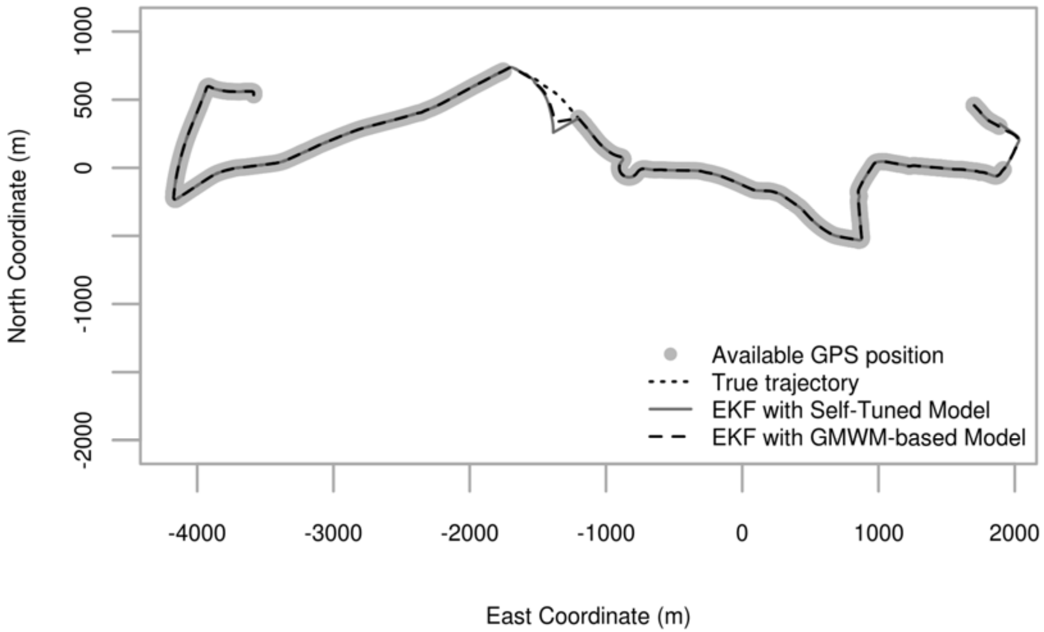
- Specifications of EDR (black box)
  - Almost independent from onboard vehicle sensors
  - Redundant inertial measurement units (IMUs)
    - Higher reliability
    - Direct sensor noise estimation
    - (Fault detection and isolation)
  - Better positioning accuracy



- Trajectory reconstruction
  - Velocity (longitudinal)
  - Acceleration (lateral, longitudinal)
  - Relative positioning

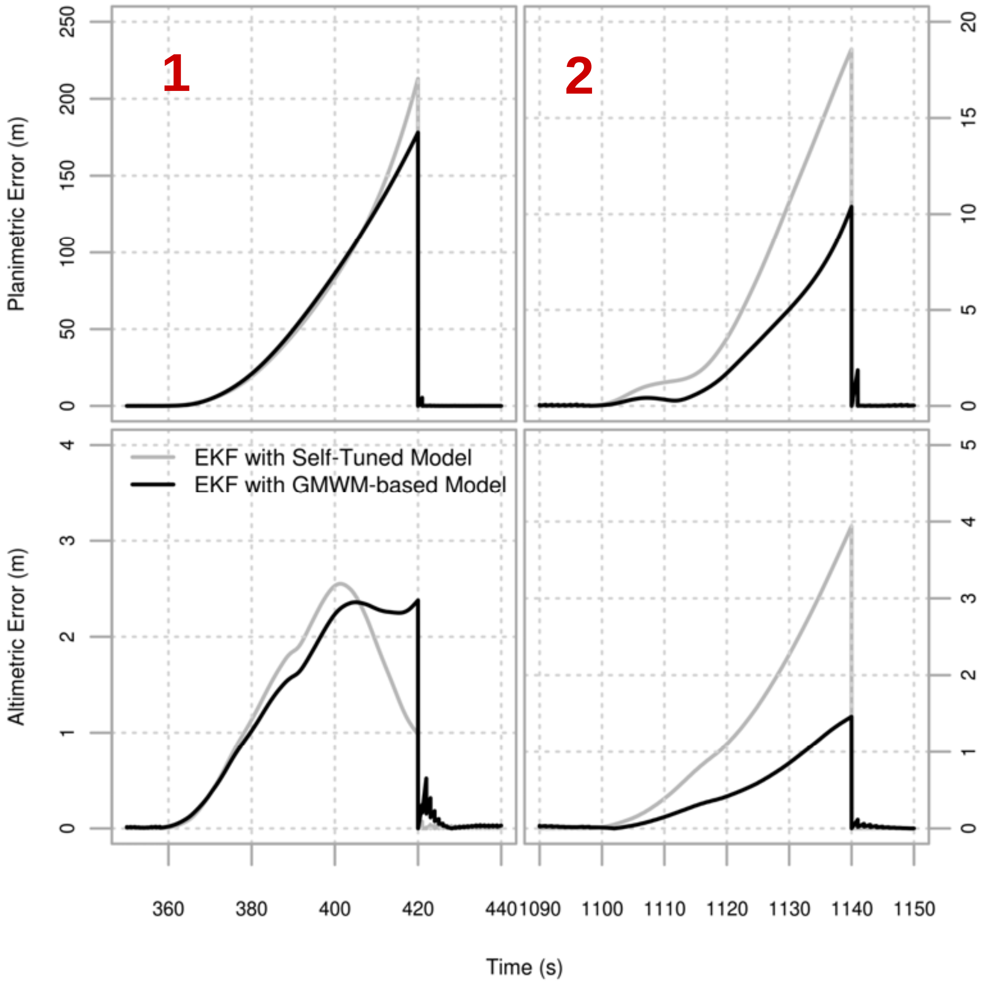
Motorcycle – Event Data Recorder

- Test 1 "Urban trajectory"
- Goal: assessment of low cost IMU/GPS with different filtering strategies
- Specifications
  - By car, 7 km
    - Urban, semi urban
  - Reference
    - IXSEA Airins navigation grade IMU @100Hz
    - GNSS Javad Delta C-DGNSS @10Hz
    - $\sigma_{horizontal}$: 10 cm
  - GNSS outages
    - 30-60 sec



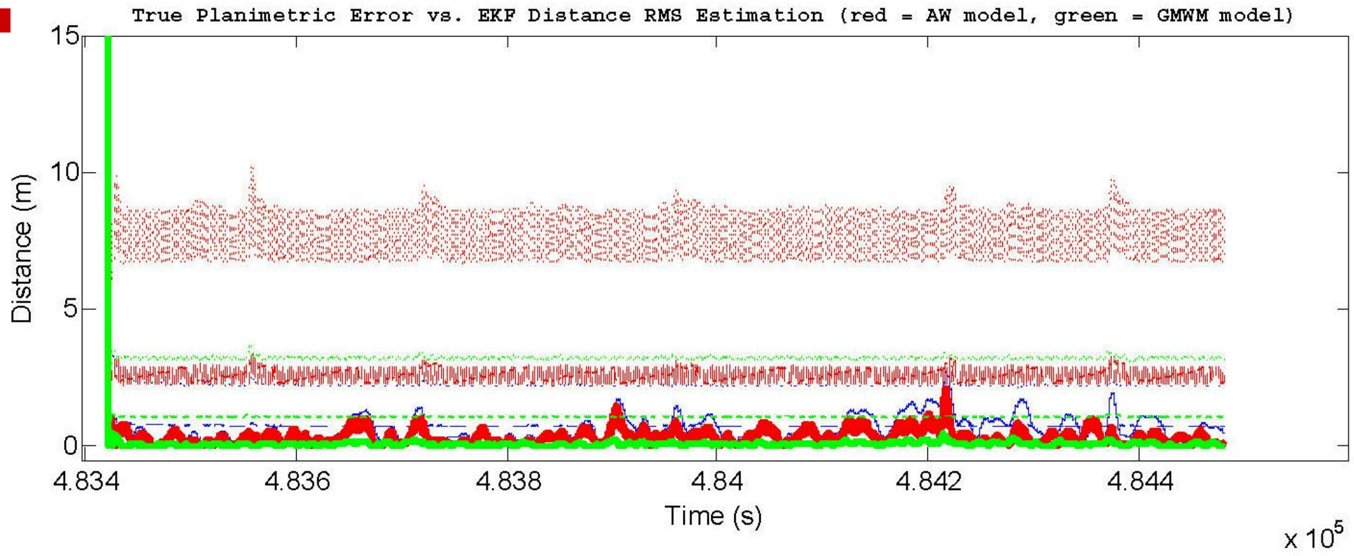
Motorcycle – Event Data Recorder

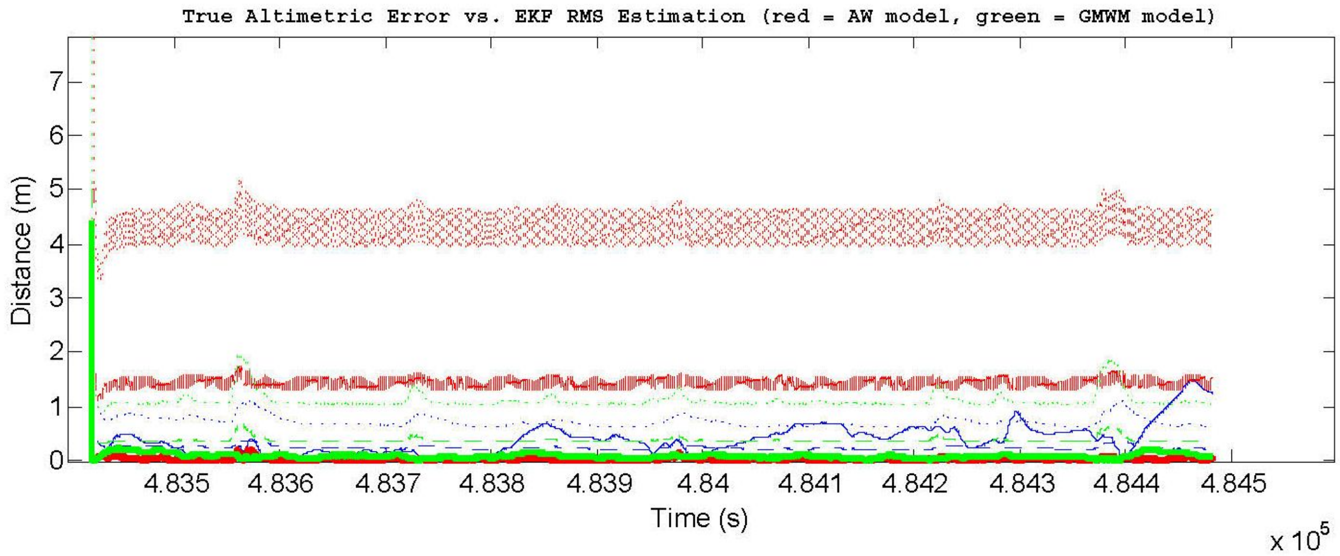
- Improved stochastic IMU signal modeling
  - GPS outages
- New estimation method
  - Generalized Method of Wavelet Moments (GMWM)
  - Designed for complex models
- Comparison of models
  1. Similar performances
  2. GMWM model is significantly better
  - According to the dynamic of the vehicle, the impact of filters is changing drastically



Motorcycle – Event Data Recorder

- GNSS/IMU
  - No GNSS gaps
- GMWM model
  - Very small true errors
  - Realistic error estimation
- EKF self-tuned model
  - Small true errors
  - Conservative error estimation

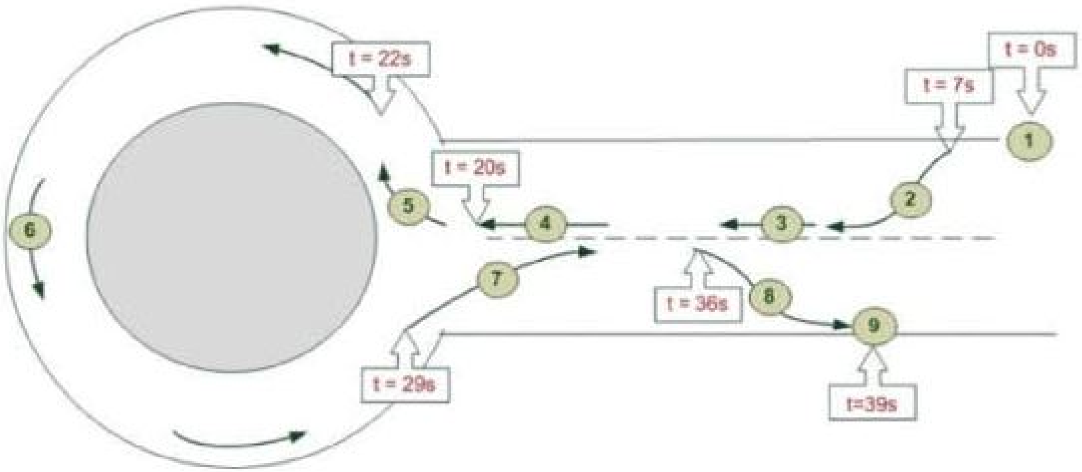




Motorcycle – Event Data Recorder

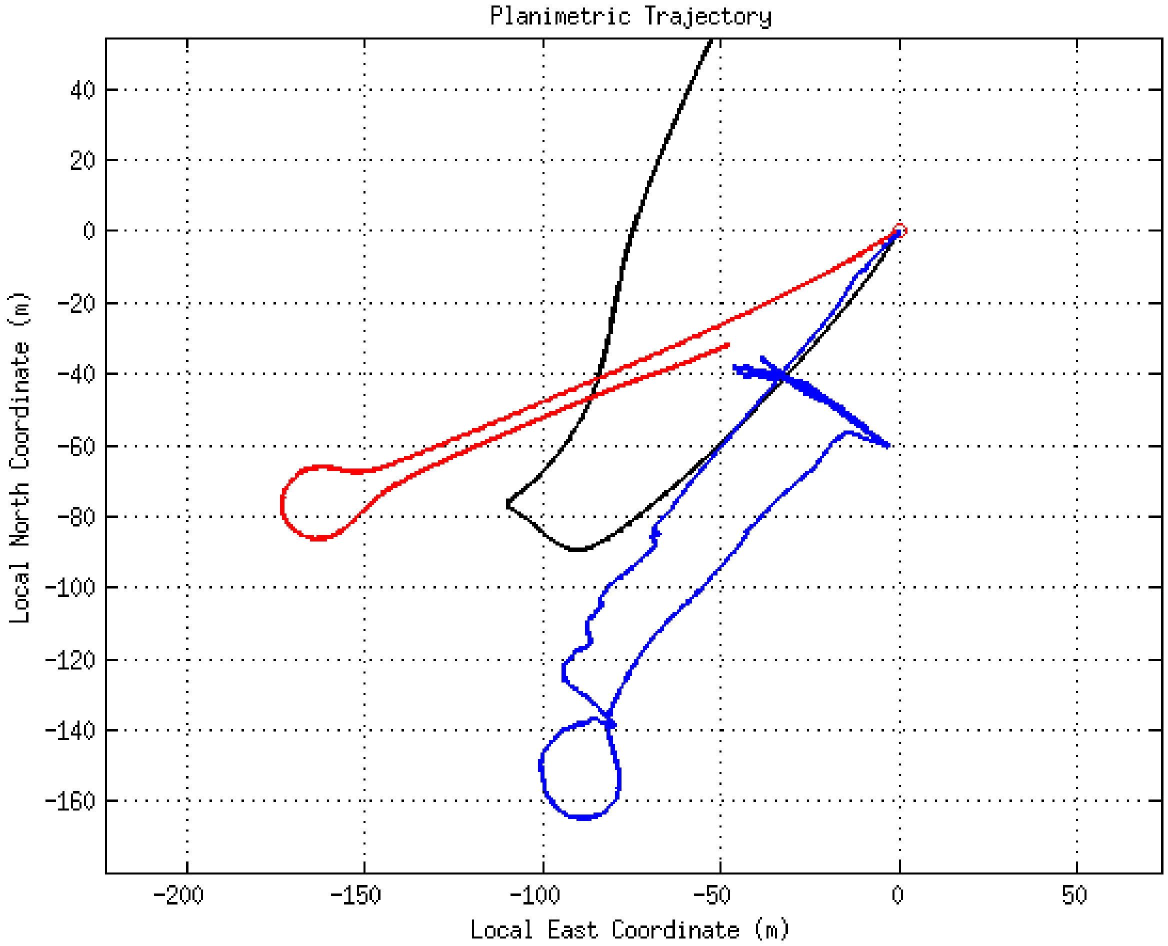
- Test 2 "Round-about"
- Sensors: GPS L1, IMU, odometer
- Specific "sensors" of motorcycle
  - Motor-spin estimation using voltage measurements of MCs generator
  - Status of engaged gear

- **Test trajectory in a round-about**



Motorcycle – Event Data Recorder

- Trajectory
- Red: GPS/IMU
  - Reference trajectory
- Blue: IMU (Hidden Markov Model) with ZUPT
- Black: IMU only



Motorcycle – Event Data Recorder

Speed estimation based on IMU combined with other sensors

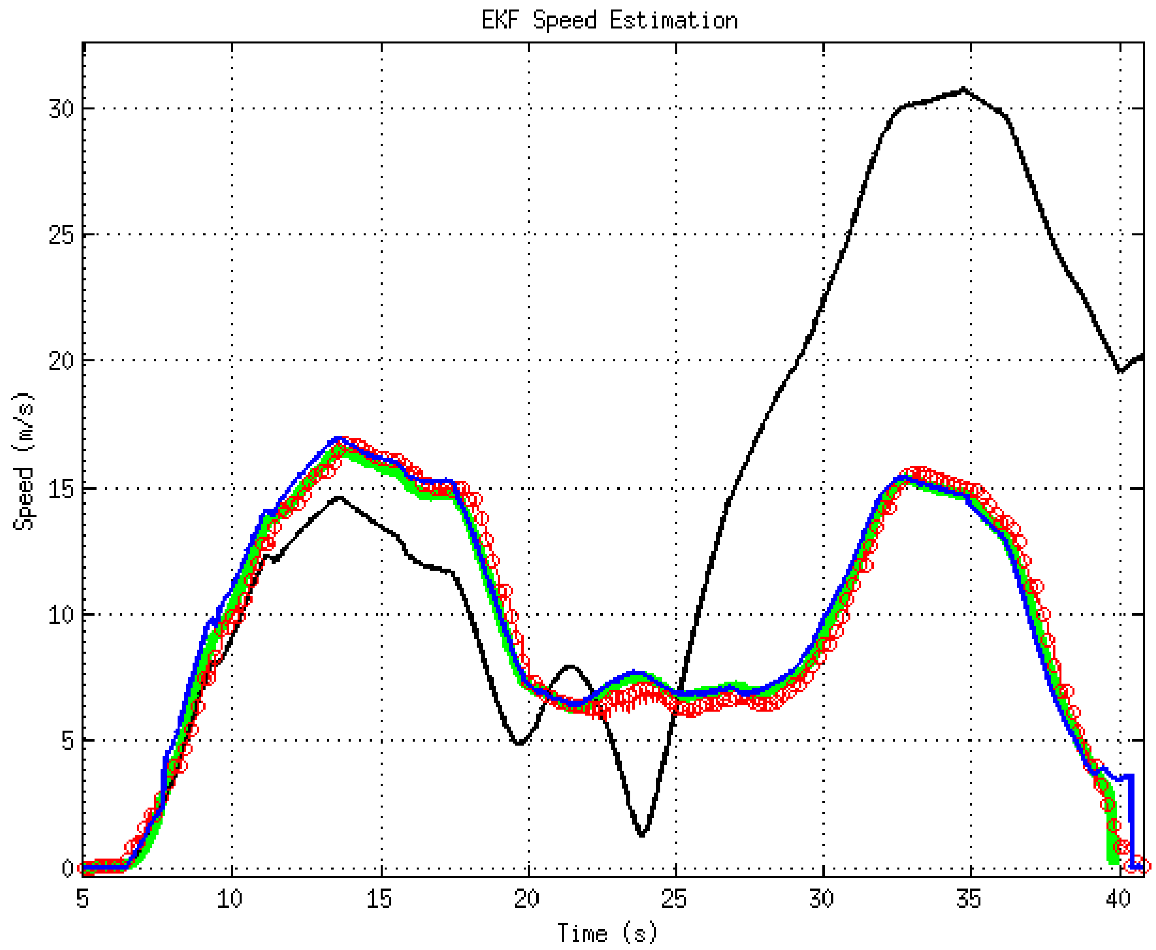
- Red: GPS/IMU

o Red: Speed GPS

- Blue: IMU (Hidden Markov Model) with ZUPT

- Green: Odometry

- Black: IMU only



Conclusions

- Growing demand on reliable positioning systems
  - Road transport is a challenging domain for navigation
  - Each application has specific requirements
  - Design of particular solutions
  - ➢ **Towards a generic platform for positioning?**
- Integration of MEMS based sensors
  - Development in post-processing mode useful before real time implementation
  - Risk when “manual” tuning of filters !
  - Development of estimators able to model complex signals (e.g. GMWM), which provide confidence intervals
  - Use of additional basic information (ZUPT, motor-spin)
  - ➢ **Sensors error/noise estimation is crucial**
- Towards GNSS/INS board (deeply coupled)
  - Use of IMU raw measurement for GNSS data acquisition

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Thank you for your attention !

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