DriftLess™

Technology to improve inertial sensors

UDT2014, 11 June 2014
Marcel Ruizenaar, TNO

marcel.ruizenaar@tno.nl

Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Topics

- Problem,
  - Drift in INS due to bias
- DriftLess technology
  - What is it
  - How it works
  - History
- INS integrated navigation
- Field tests/examples
  - Accelerometer bias estimation
  - Airborne test, gyro bias estimation
  - Indoor AGV test, gyro bias estimation
- Conclusions

Drift problem (1/3)

INS based systems use inertial sensors

- Accelerometers measure linear acceleration
- Gyroscopes measure angular velocity
- Inertial sensors have small unknown offsets (biases)

Due to numerical integration, bias results in ever growing error (drift)

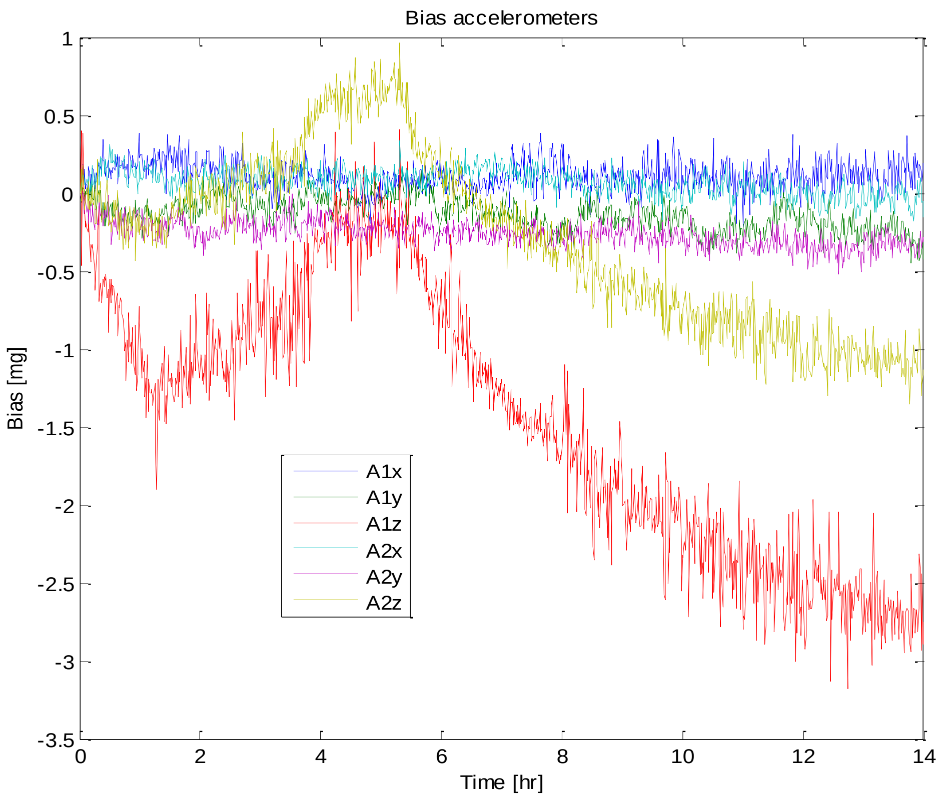
- Drift in attitude estimation.
- Drift in velocity estimation.
- Drift in position estimation.

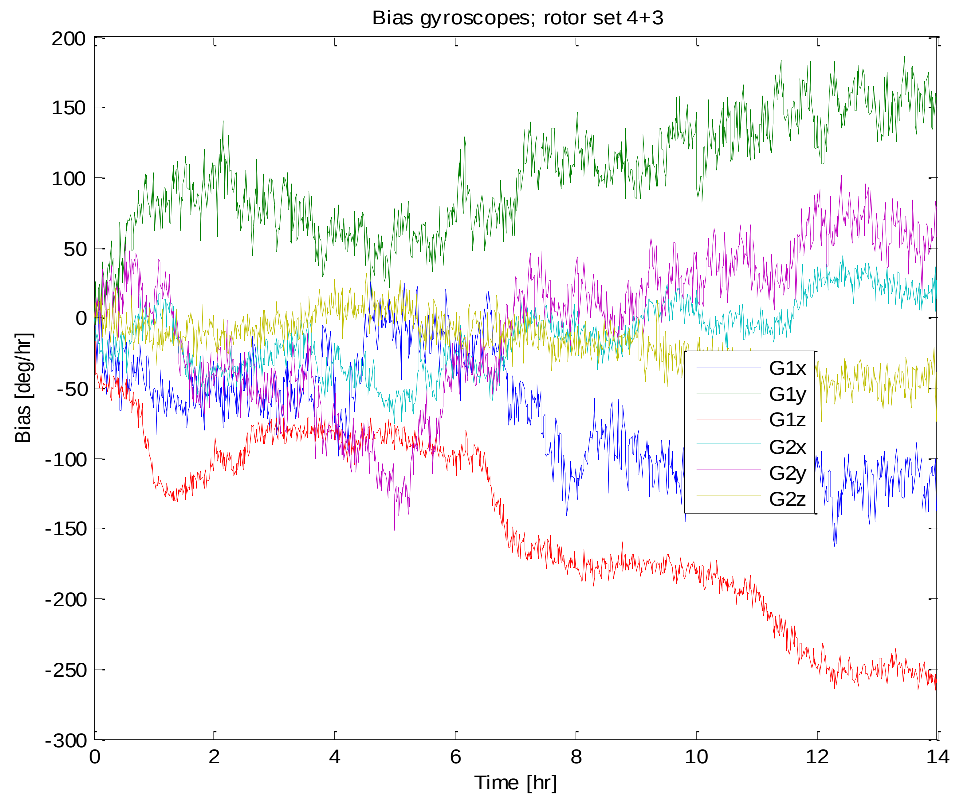
Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Drift problem (2/3): how large is the bias?

Example bias of low-cost MEMS gyroscopes/accelerometers (MPU6050)

- 14 hour of measurement data
- At constant temperature
- Turn-on bias already removed → In-run bias variations





Marcel Ruizenaar, marcel.ruizenaar@tno.nl

TNO innovation for life

Drift problem (3/3)

How big is the problem, using typical low-cost MEMS sensors?

	Integration time 10 seconds	Integration time 30 seconds
5 mg accelerometer bias	2.5 m	23 m
200 deg/hr gyro bias (~1 mrad/s) *	10 mrad/0.6 deg 1.7 m	30 mrad/1.7 deg 45 m

$$P_{drift} = \frac{1}{2} b_a t^2$$

$$P_{drift} = \frac{1}{6} b_g g_0 t^3$$

*1 mrad (~0.05 deg) attitude error → 1 mg acceleration error

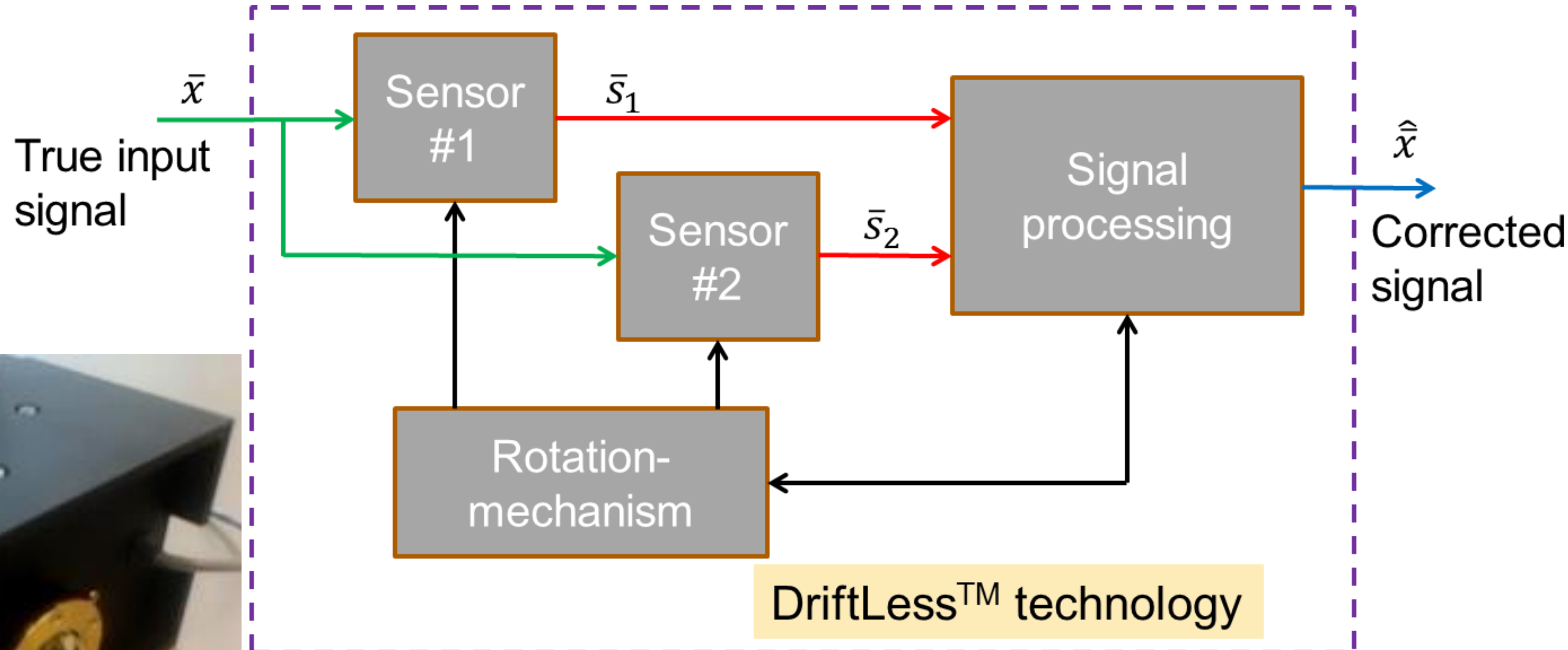
- Correcting the bias of the gyros has major priority!!!
- Very limited use of MEMS based INS-only systems

DriftLess technology (1/3)

- Estimates biases of sensors that measure a vector quantity
  - Inertial sensors (accelerometers & gyroscopes)
  - Magnetometers
  - Other sensors
- 1D, 2D or full 3D
- Almost independent of temperature
- Bias estimation and compensation continuously during use/operation.
- All fixed and varying biases removed, leaving only white noise (theoretically).
- Bias compensation of all sensors can be combined in a single set-up.
- Patent pending TNO-technology

Marcel Ruizenaar, marcel.ruizenaar@tno.nl

DriftLess technology (2/3): basic principle



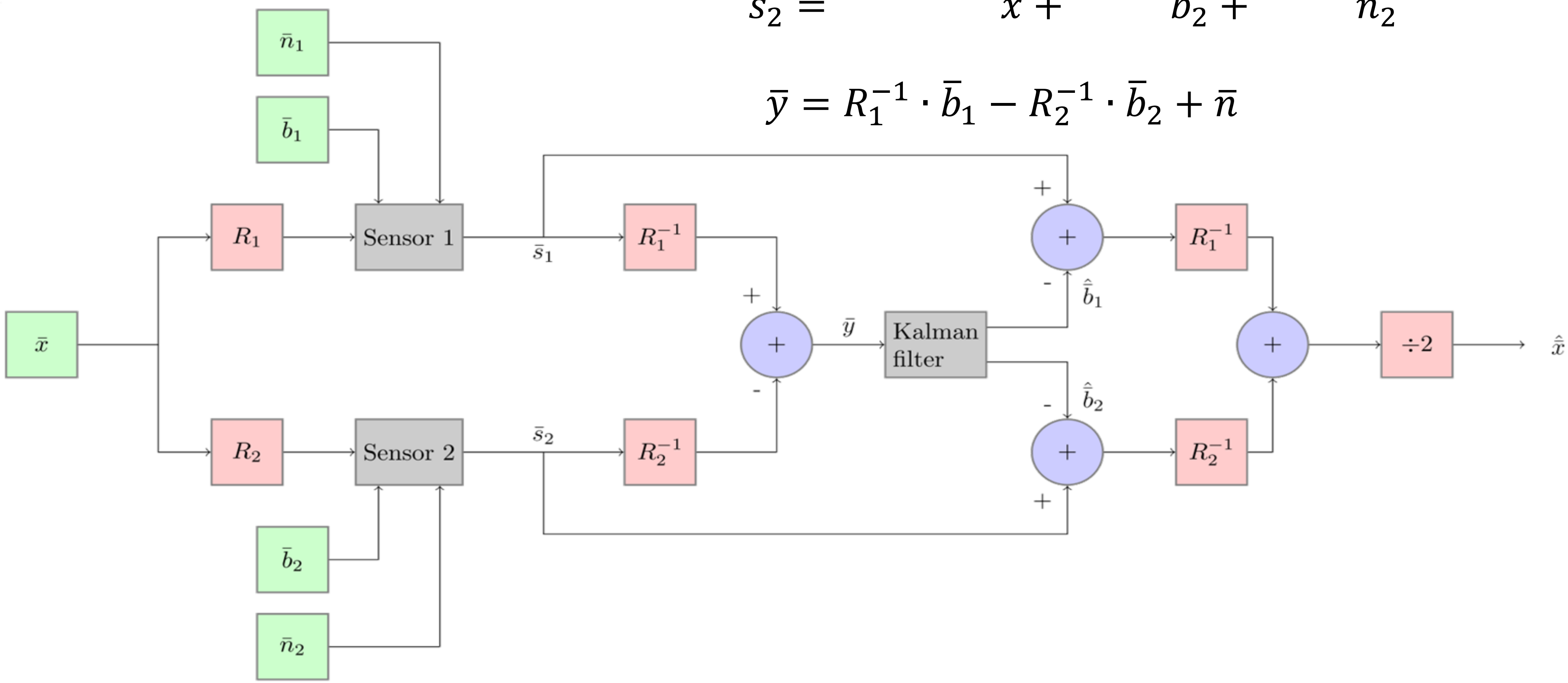
Marcel Ruizenaar, marcel.ruizenaar@tno.nl

DriftLess™, how does it work (3/3)

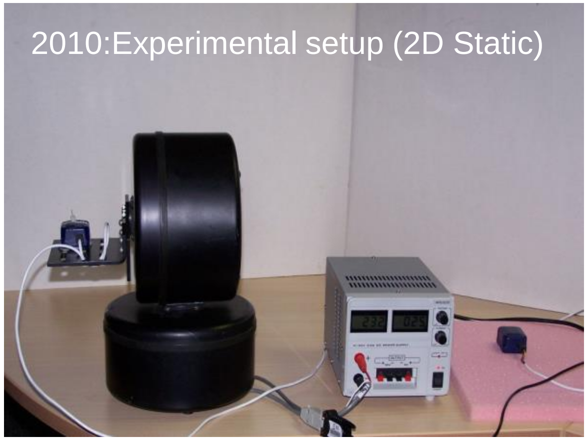
$$\bar{s}_1 = \bar{x} + \bar{b}_1 + \bar{n}_1$$

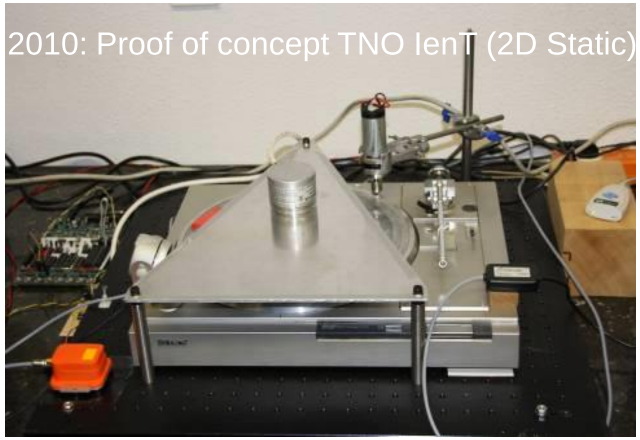
$$\bar{s}_2 = \bar{x} + \bar{b}_2 + \bar{n}_2$$

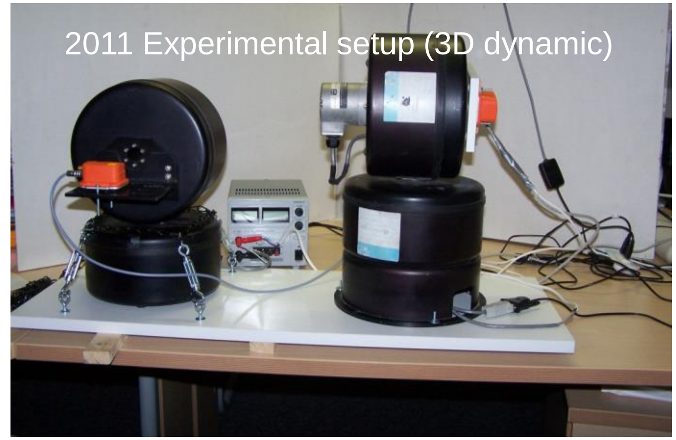
$$\bar{y} = R_1^{-1} \cdot \bar{b}_1 - R_2^{-1} \cdot \bar{b}_2 + \bar{n}$$



Historic development of DriftLess™





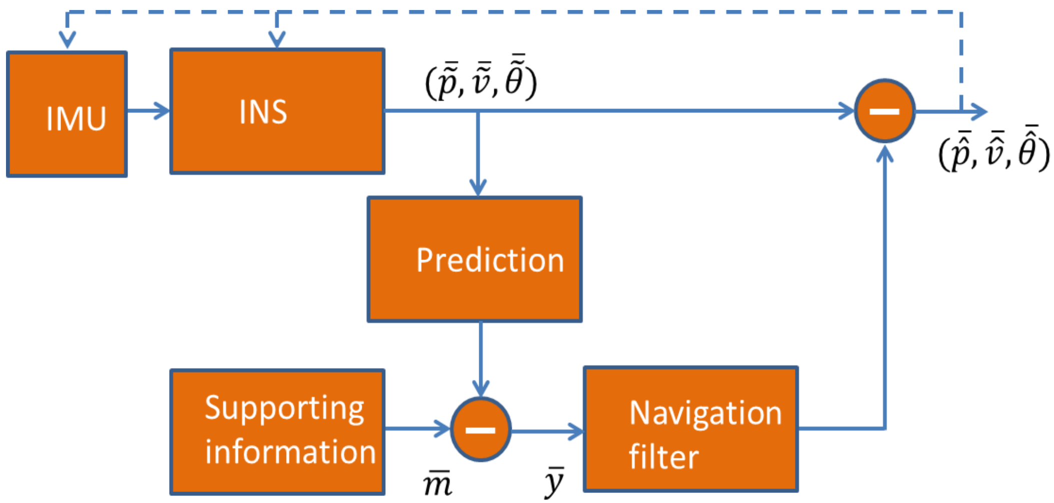


Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Integrated navigation systems

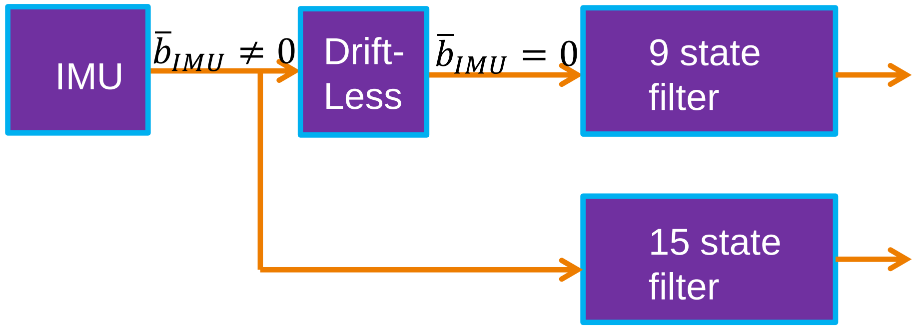
Gyro biases only indirectly observable

- Attitude errors equivalent with accelerometer biases
- Accuracy bias estimation depends on
  - IMU noise
  - Bias stability
  - Measurement noise
- MEMS gyros: long estimation time



Combine with DriftLess

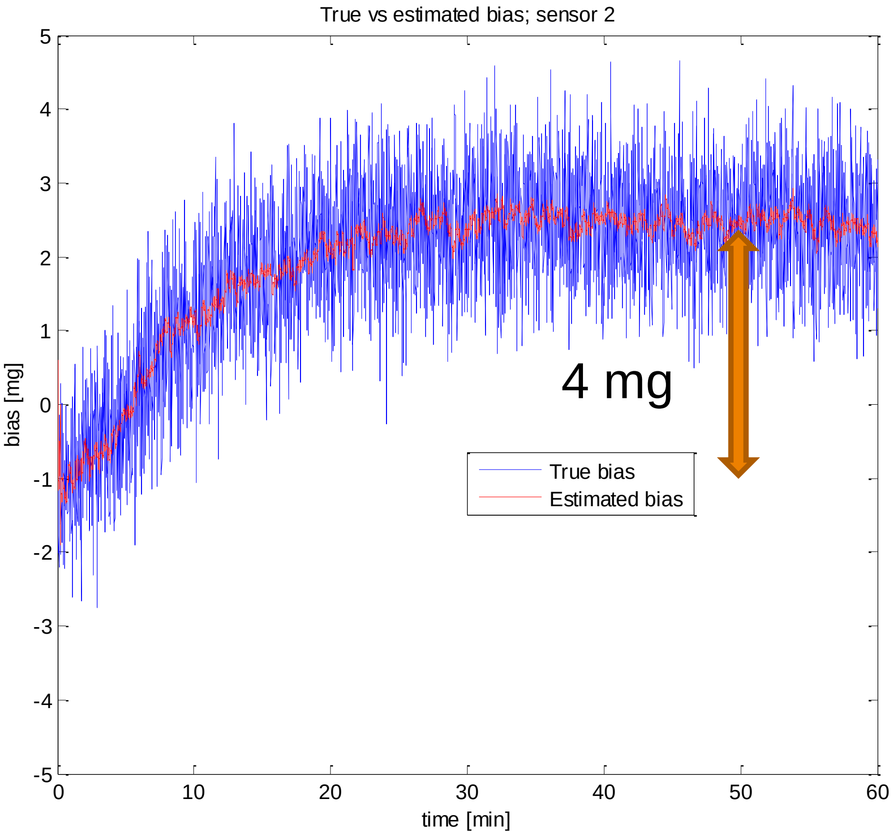
- Biases already estimated
- Less filter states (computationally more attractive)
- Allows for longer unaided periods

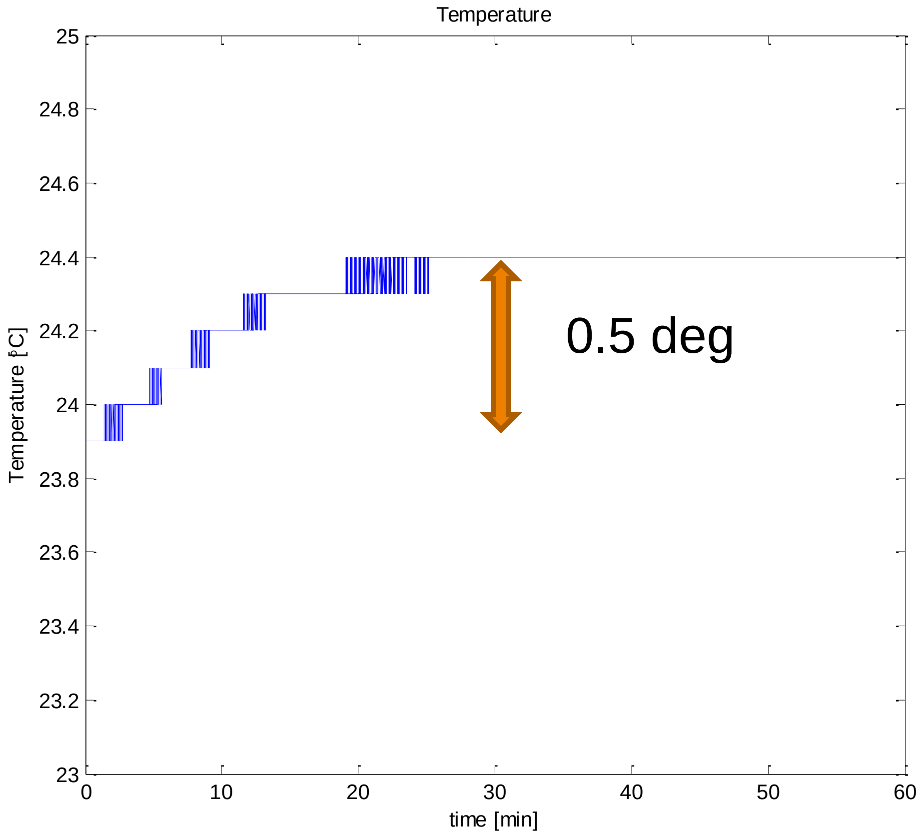


Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Example 1: accelerometer bias estimation

- Output of 1 accelerometer
- 1 hour, corrected with DriftLess™ technology
- 4 mg bias change due to temperature rise of 0.5 degree
- With DriftLess™, residual bias < 0.1 mg



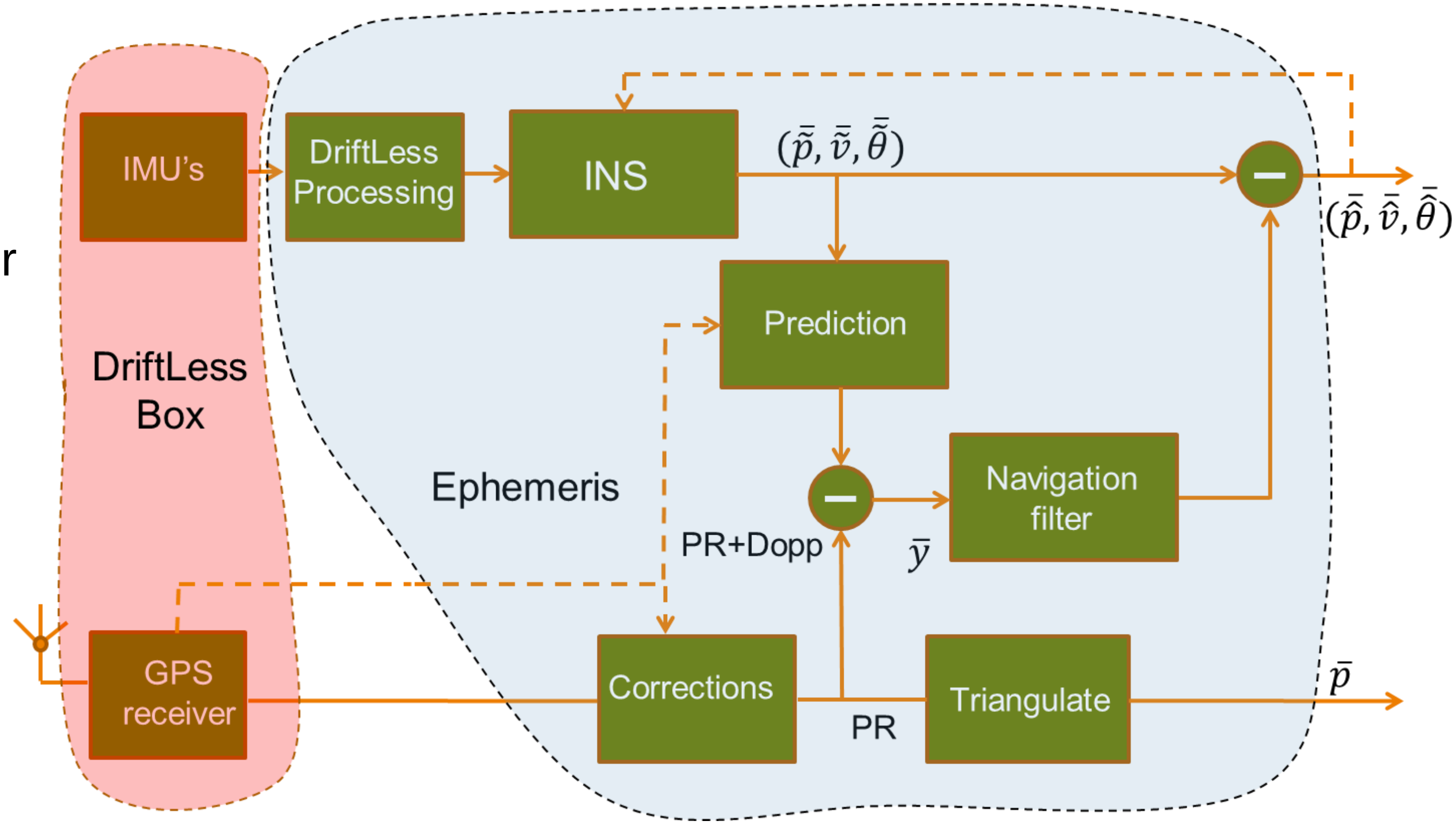


Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Example 2: Field test with DriftLess (1/3) INS/GNSS/DriftLess processing

- IMU's & GPS receiver inside box
- Processing afterwards in the lab

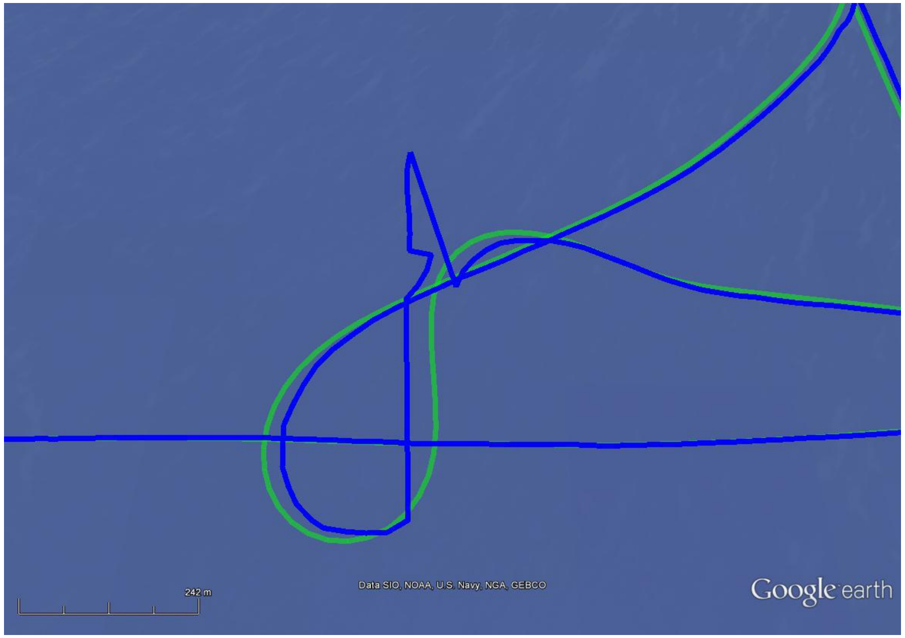
- Triangulate PR to get position
- Process PR + Doppler to get blended INS/GPS solution



Example 2: Field tests with DriftLess (2/3)

- Main goal to improve SAR imaging
- Tightly coupled INS/GNSS configuration
- 9+2 states (pos, vel, att + clock bias/drift)
- No ground truth available

- Simulated GPS outages
- Calculated equivalent gyro bias
  - Stationary
  - During flight

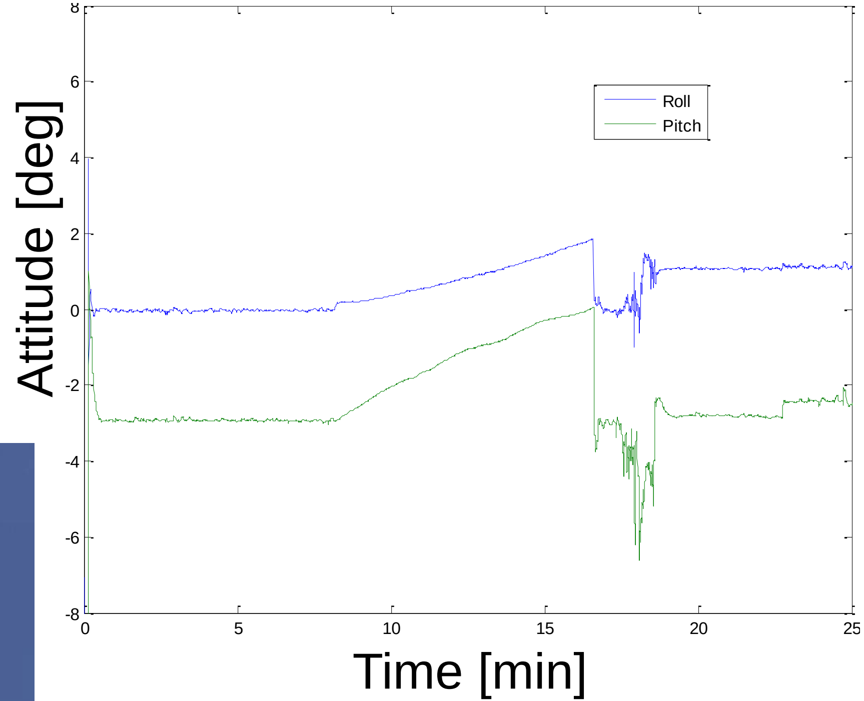


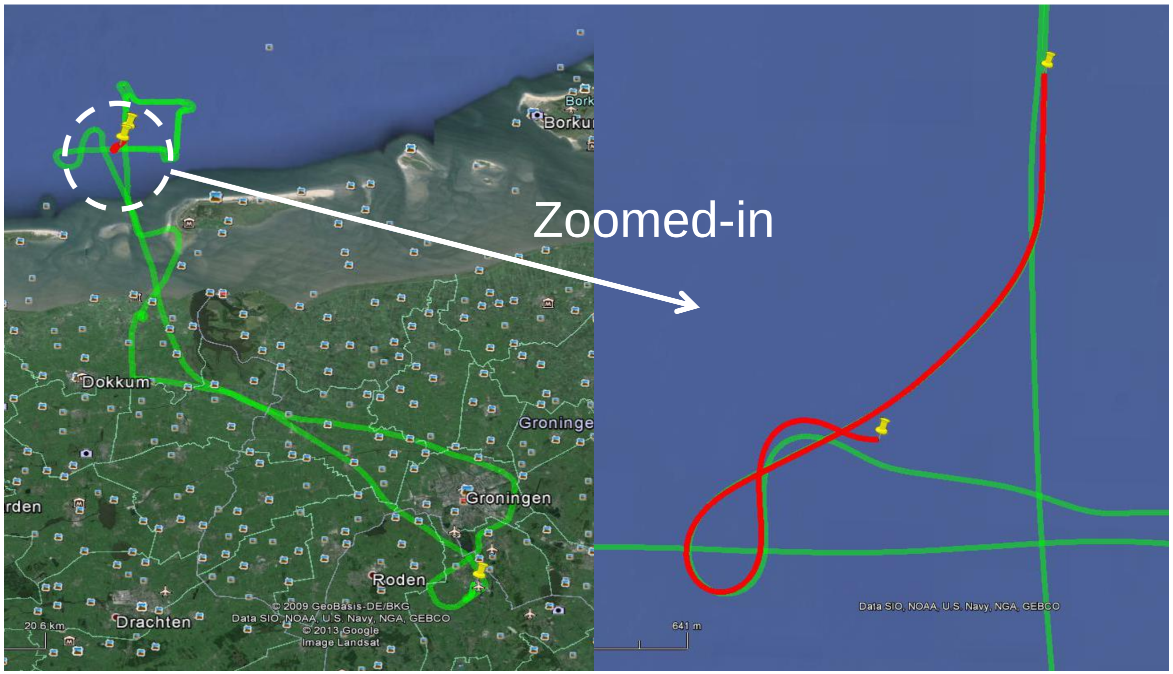
$$P_{drift} = \frac{1}{6} b_g g_0 t^3$$

$$P_{drift} = \frac{1}{2} b_a t^2$$

Example 2: Field tests with DriftLess (3/3)

- Drift observed during:
  - Airplane stationary (~8 min outage)
  - Airplane in flight (~90 sec outage)
- Equivalent gyro bias ~ 20 deg/hr
- INS/GNSS 15state: >100 deg/hr



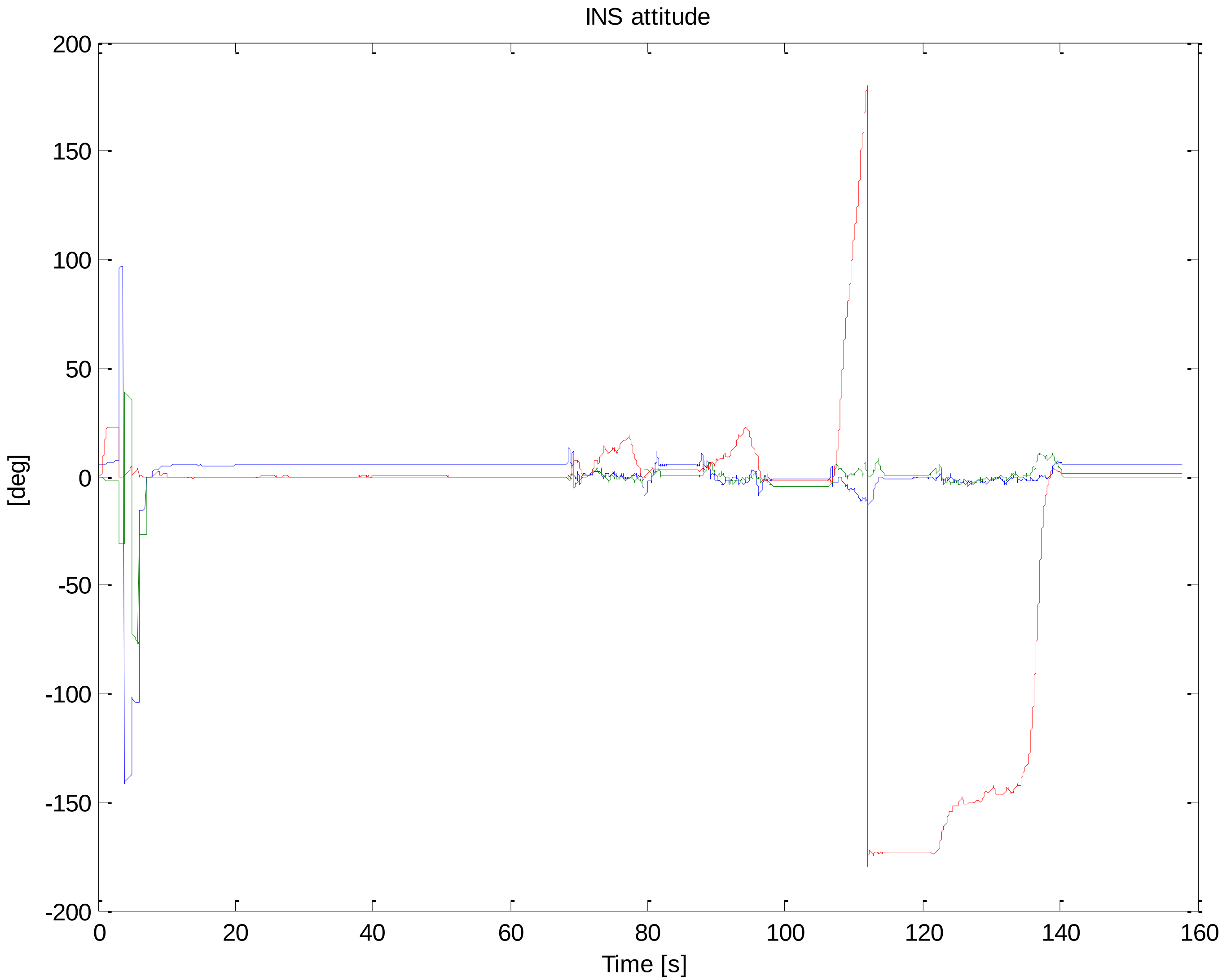


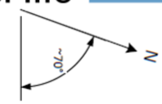
$$P_{drift} = \frac{1}{6} b_g g_0 t^3$$

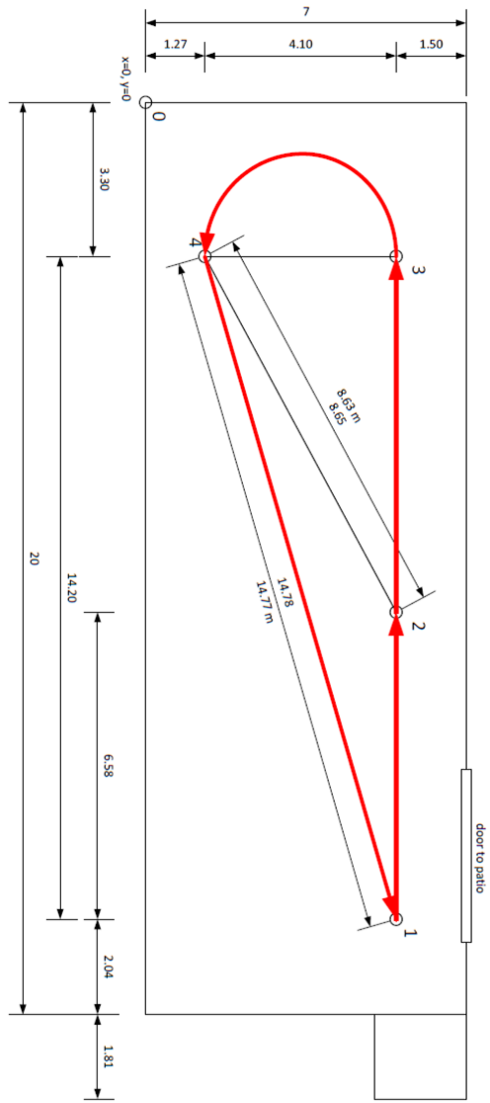
$$P_{drift} = \frac{1}{2} b_a t^2$$

innovation for life

Example 3: DINS indoor (1/3) INS attitude reconstruction

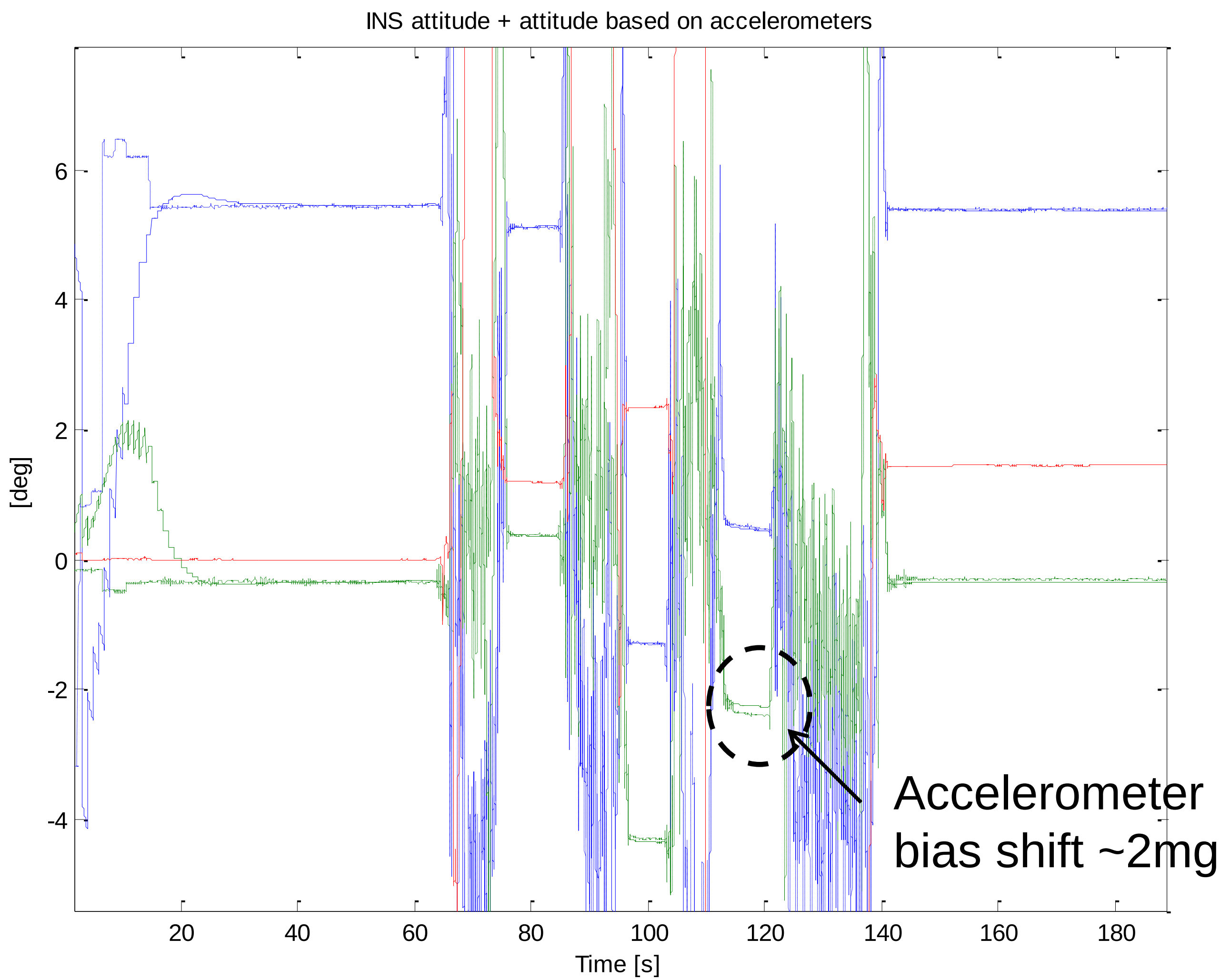






Marcel Ruizenaar, marcel.ruizenaar@tno.nl

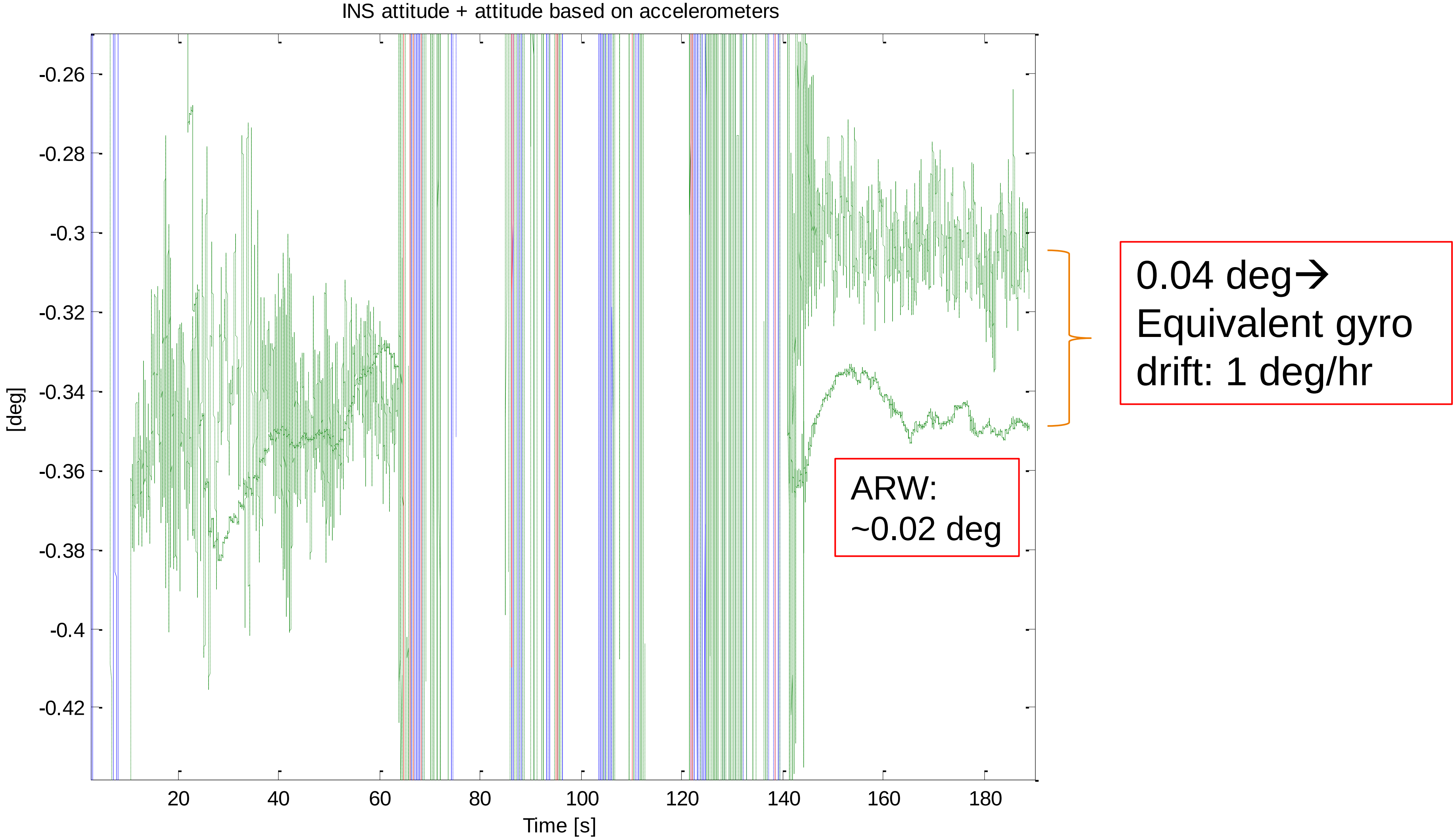
Example 3: INS-only indoor (2/3) Tracking attitude



- Accelerometer biases accurate to 0.1 mg with DriftLess if stationary
- Accelerometer attitude measurement accurate to 0.01 deg
- Use as baseline during stationary conditions
- Observed gyro bias ~ 1 deg/hr

Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Example 3: DINS indoor (3/3) INS attitude reconstruction



Conclusions

- DriftLess capable of correcting nearly all fixed and varying bias in dynamic situations.
- Residual gyro bias ~1 deg/hr demonstrated
- Residual accelerometer bias <0.1 mg
- Integrated systems more accurate when combined with DriftLess

Further work

- Miniaturization of the set-up, current size: 10x10x10 cm
- Upcoming: first miniaturization step: 4x4x4 cm
  - Application in UAV’s, ROV’s or other small automated platforms
- Future miniaturization: 1x1x1 cm
  - Application in “Smart Phone” applications (military or civil) or navigation equipment (TomTom, Garmin)
- Far future: rotation mechanism implemented on chip
  - Civil Smart phone applications

Marcel Ruizenaar, marcel.ruizenaar@tno.nl

Drawbacks, limitations and unknowns

- Due to imperfect calibration, residual bias depends on input signal
- Currently no experience with mechanical limitations
- Mechanical: how about life time expectancy
- Mechanical: shock resistance?