

# A hybrid CAI/IMU navigation solution for higher performance

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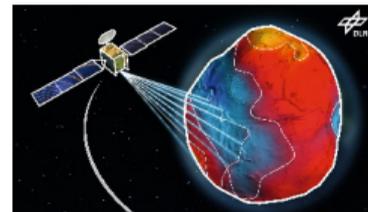
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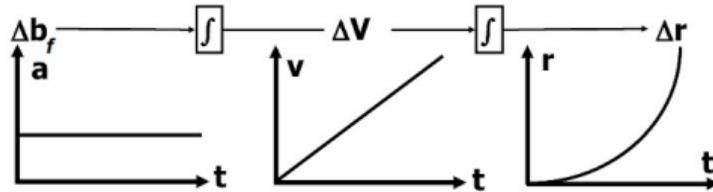
*Positioning and Navigation Group (Prof. Dr.-Ing. Steffen Schön)*

on the basis of a decision  
by the German Bundestag



## Inertial navigation

### Conventional IMU



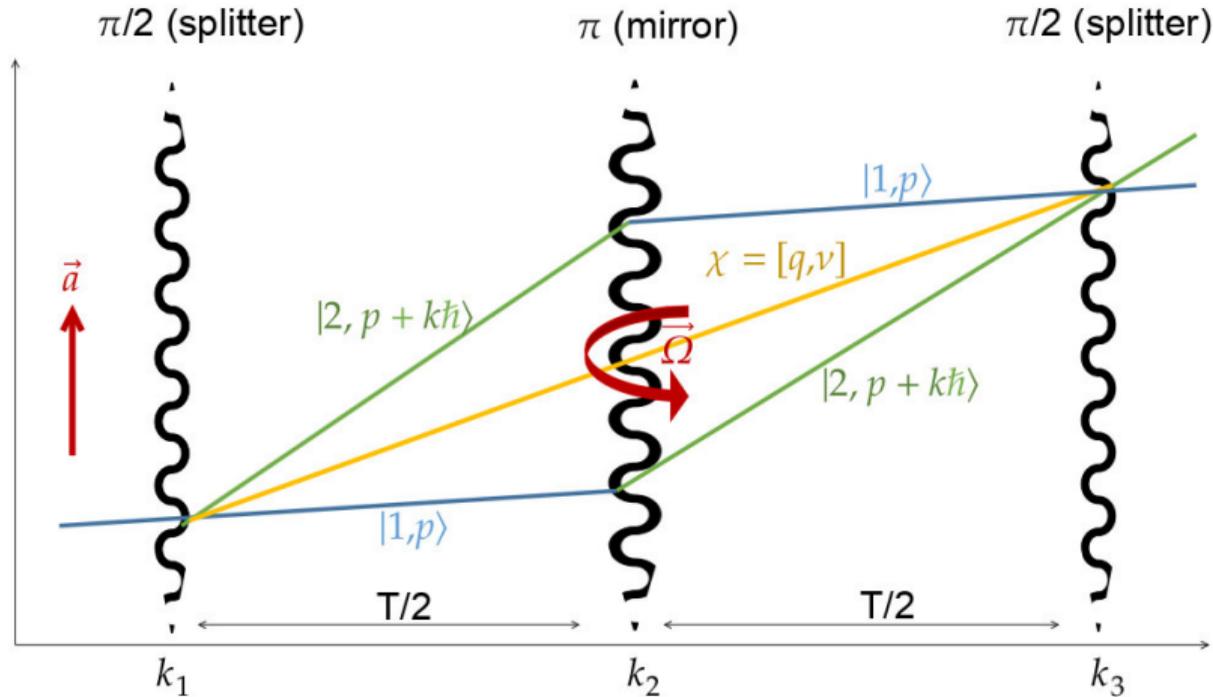
- ▶ systematic errors and noise is integrated
- ▶ drift and random walk

### Atom Interferometers

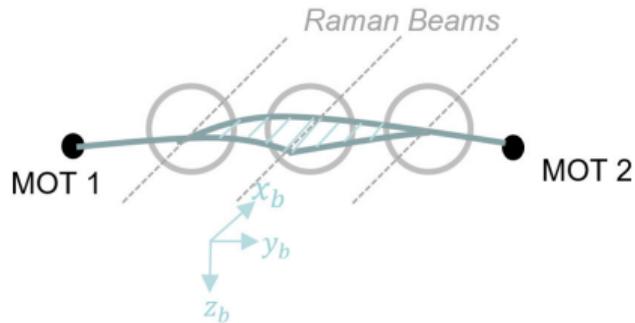
Sensor specification	RLG-IMU	CAI-IMU
Gyro Scale error [ppm]	< 15	$2 \cdot 10^{-3}$
Acc Scale error [ppm]	< 100	$3 \cdot 10^{-4}$
Gyro Noise Density [ $nrad/s/\sqrt{Hz}$ ]	19.4	120
Gyro Bias Instability [ $nrad/s$ ]	4.8	26
Acc Noise Density [ $nm/s^2/\sqrt{Hz}$ ]	49 050	96
Acc Bias Instability [ $nm/s^2$ ]	11 772	39

- ▶ low datarate (1 Hz)
- ▶ extremely low dynamic range (mg-realm for  $T=0.005s$ )

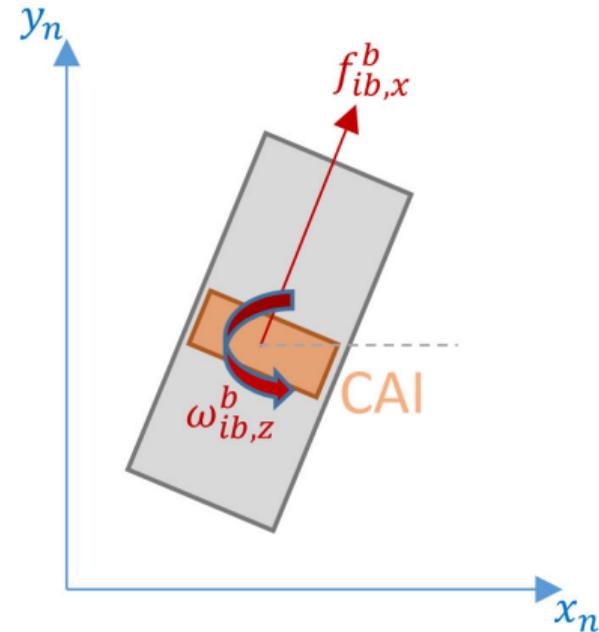
# Measurement Principle



## 6DOF inertial sensor



“Sagnac-Unit“, differentiates between acceleration and rotation



## 6DOF inertial sensor

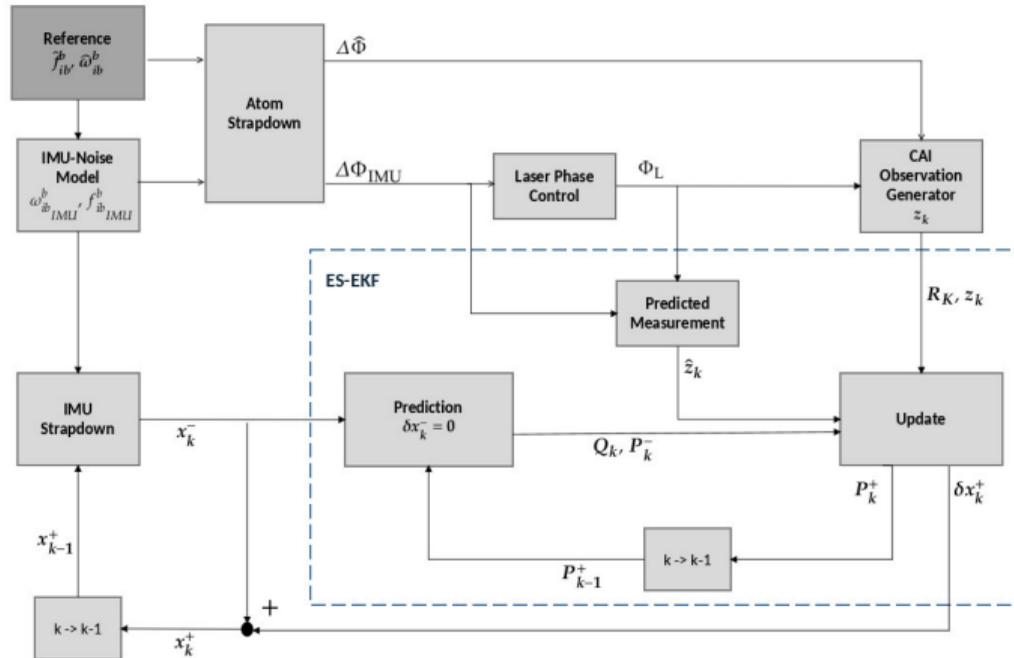
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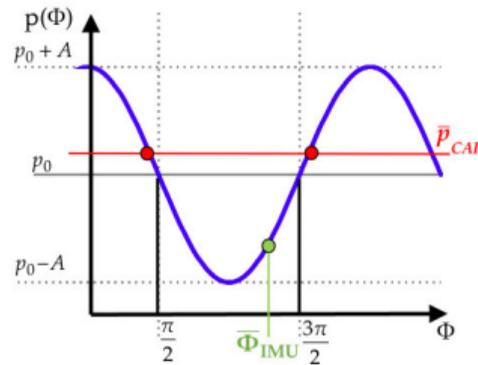
Kernel of a conventional FOG IMU [hydro-international.com]

- ▶ Do the same with 3 Sagnac Units
- ▶ Conventional calibration techniques possible
- ▶ Bias, scale errors and misalignment no problem

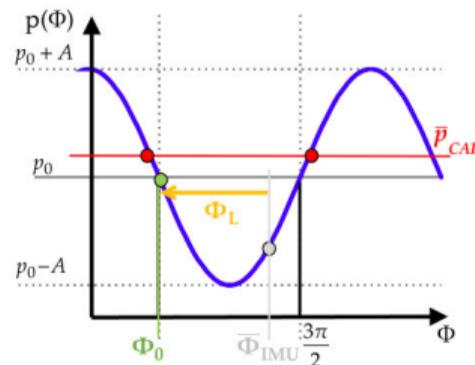
# Filter Framework



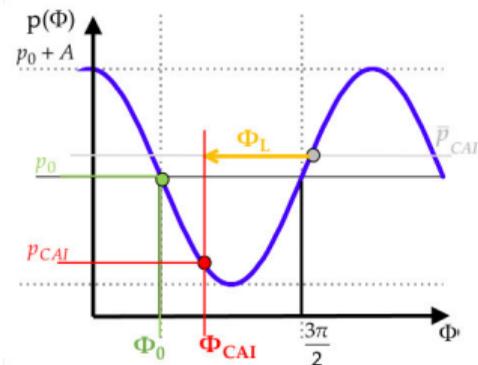
## Phase Prediction



(a)



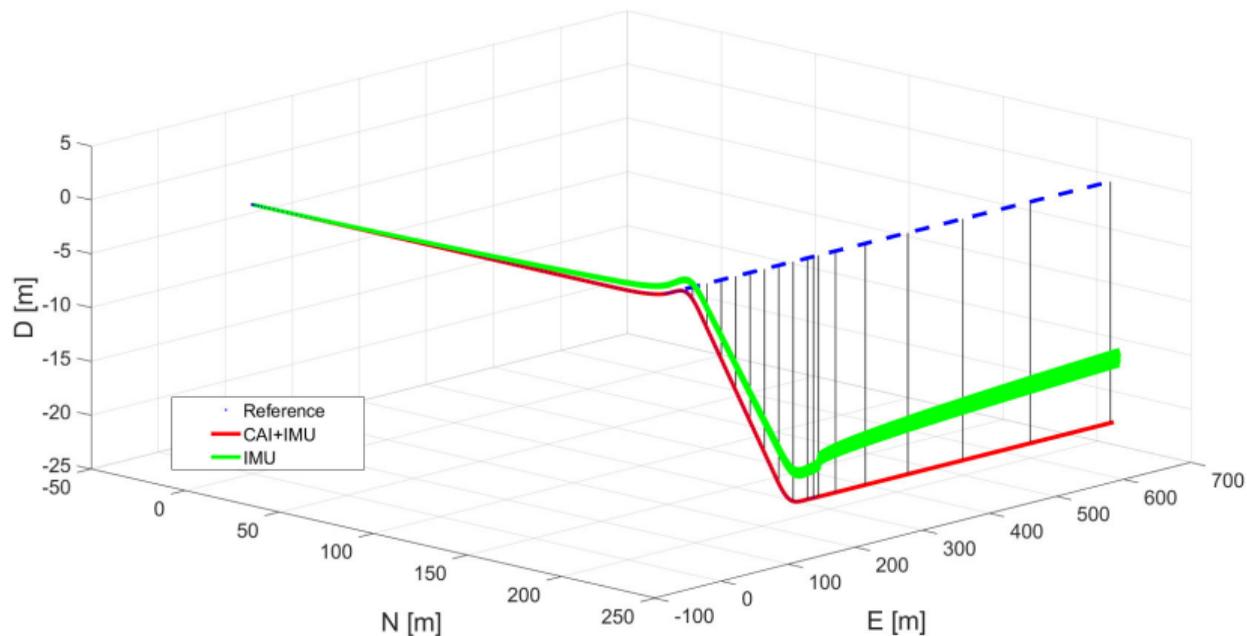
(b)



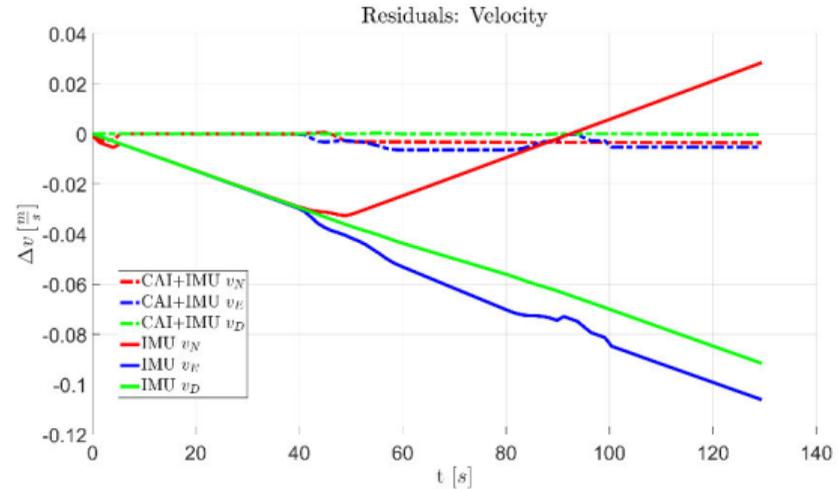
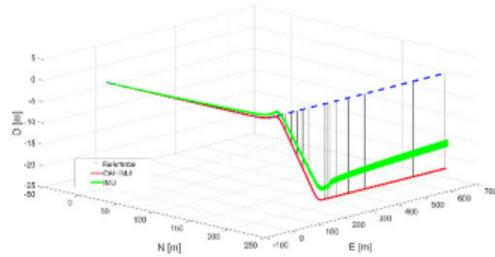
(c)

- ▶ Fringe ambiguity solved
- ▶ Tracking of different IMU errors possible (misalignment, bias, leverarms,...)

## Simulation Results

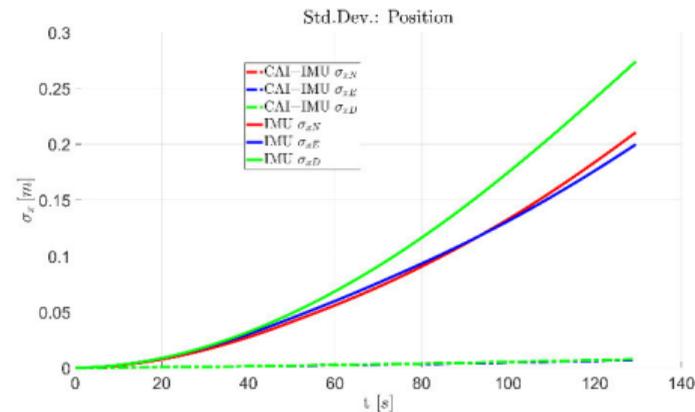
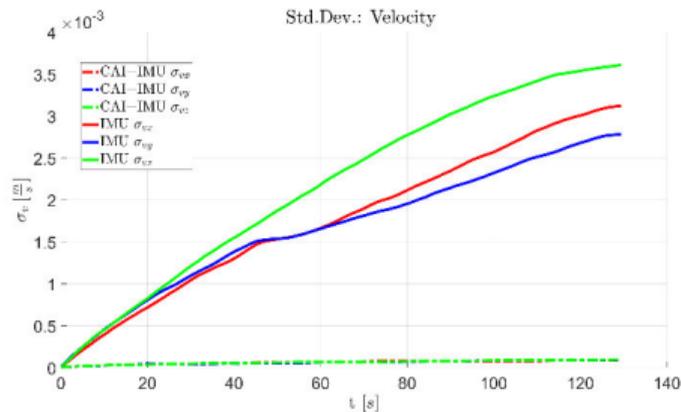


## Residuals: Velocity



- ▶ Drift is greatly reduced
- ▶ Change of dynamics leads to small systematic effects

## Standard Deviation: Velocity and Position



- ▶ Improvement of factor 30
- ▶ Even better when little or no change of dynamics

## See also

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- [1] B. Tennstedt and S. Schön, "Dedicated Calculation Strategy for Atom Interferometry Sensors in Inertial Navigation," 2020 IEEE/ION Position, Location and Navigation Symposium (PLANS), 2020, pp. 755-764, doi: 10.1109/PLANS46316.2020.9110142.
- [2] B. Tennstedt and S. Schön, "Integration of Atom Interferometers and Inertial Measurement Units to Improve Navigation Performance." 28th ICINS 2021, St. Petersburg, Russia, accepted.