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8.1 Sensors, Measurement and Testing Methods

Application of the inertial navigation system 3D-self-calibration-method for the minimization of the measurement uncertainty

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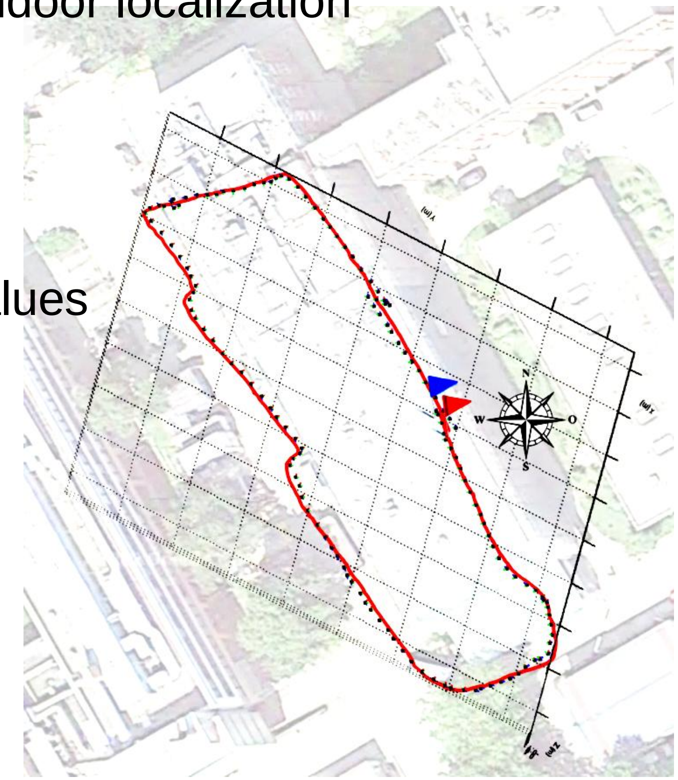
Motivation and Outline

- Hardware for infrastructure-free 3D indoor localization
- 3D self-calibration-method
- GUM - measurement uncertainty
- Contributing parameters and input values
- Uncertainty budget
- Results

What tells us the sensor?



- Test results with active calibration and map projection

3D inertial navigation system

- Infrastructure-free 3D indoor localization
  - 3D accelerometer, 3D magnetic field sensor, 3D gyroscope, air pressure
  - GPS
  - Humidity and temperature
  - Wireless data communication
  - Gas sensor, CO
  - Vital signs, heart rate

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BodyGuard
Version 1.0

BodyGuard
Sensor Version 2.0

BodyGuard
SensorEvalBoard 2.0

The procedure I

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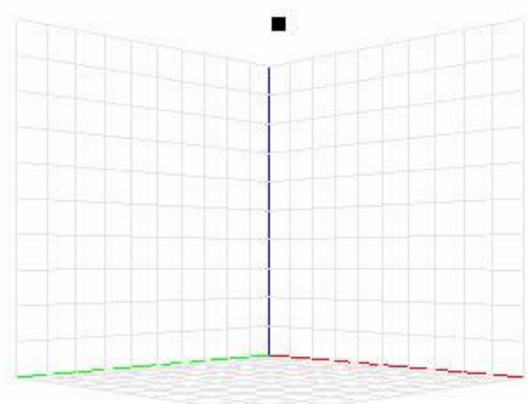
- Model of the measurement data
- Filtering and approximation of the measured values
- Calibration of the sensors
- Motion algorithm
- Position determination

$$\vec{v} = \int (\vec{a})\, dt$$

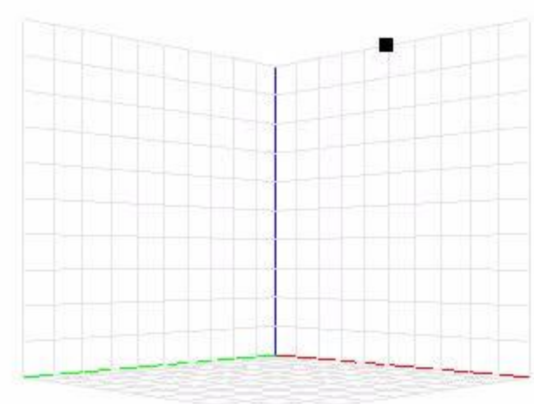
$$\vec{s} = \int (\vec{v})\, dt$$

$$\vec{s} = \int \left[\int (\vec{a})\, dt \right] dt$$

Free 3D motion



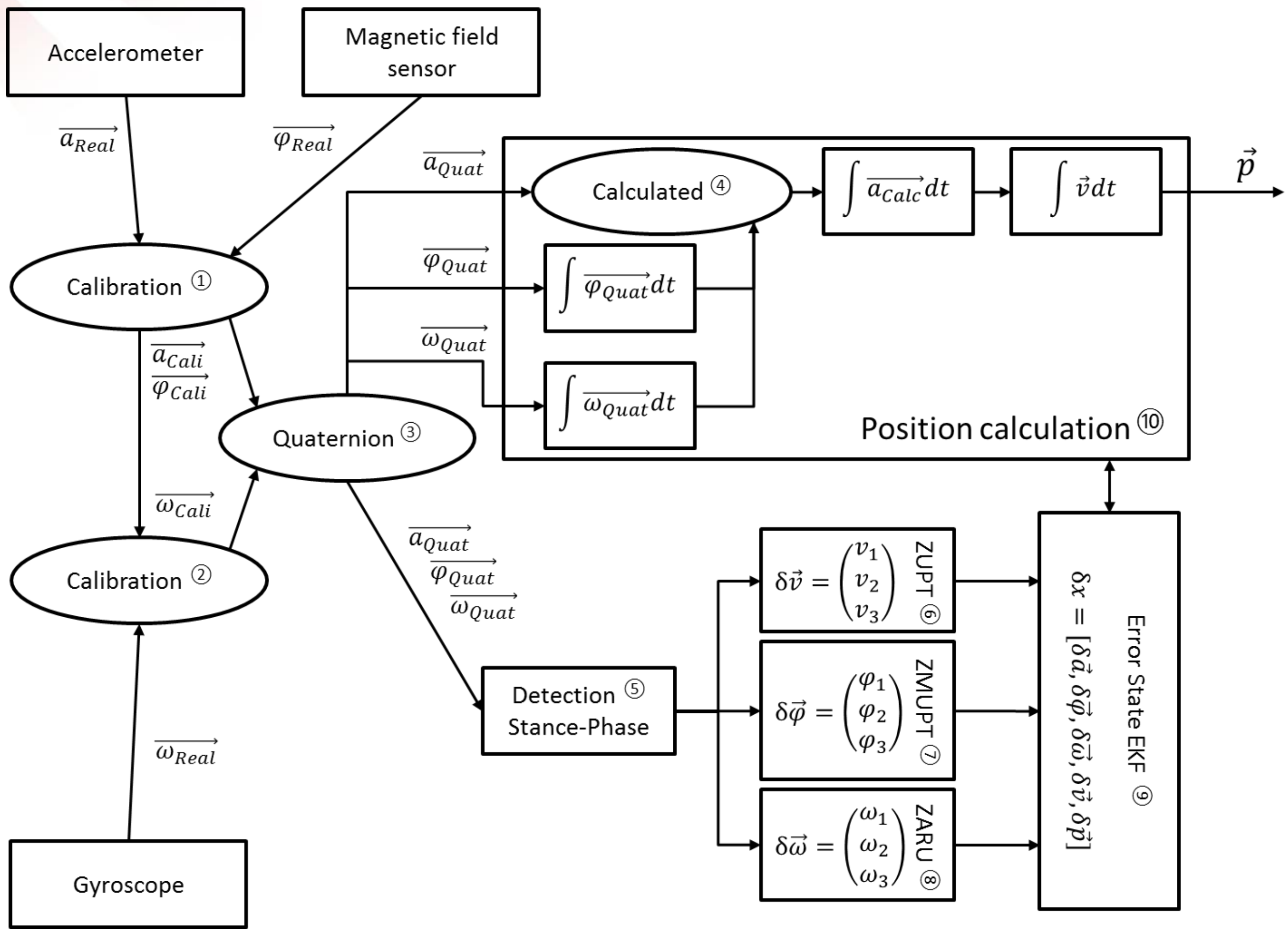
3D accelerometer



3D magnetic field sensor

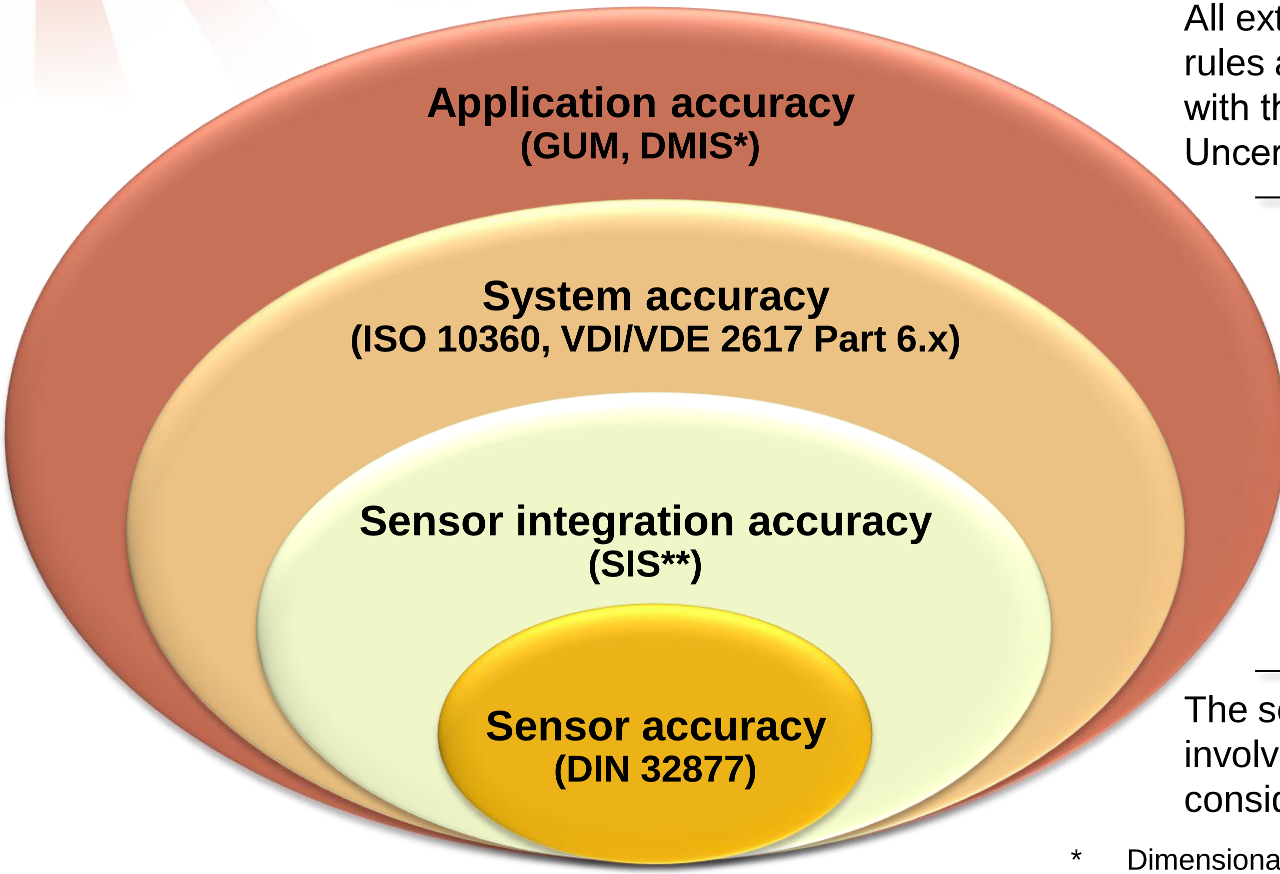
The procedure II

- Inertial navigation system with 3D self-calibration-method



Four layer model

- Structured collection of measurement uncertainty components of hybrid measurement systems



All external influences, rules and regulations are detected with the “Guide to the Expression of Uncertainty in Measurement” (GUM)

Consists of the performance of the system, with mutual support and redundancies.

All additional effects that may occur through the integration of multiple sensors or measurement systems are considered.

The sensor or an individual involved measuring system is considered.

* Dimensional Measuring Interface Standard
** Sensor Interface Standard

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Guideline of measurement uncertainty

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“**G**uide to the Expression of **U**ncertainty in **M**easurement" (GUM)

- **Type A evaluation of measurement uncertainty**

  Evaluation of a component of **measurement uncertainty** by a statistical analysis of **measured quantity** values obtained under defined measurement conditions.

- **Type B evaluation of measurement uncertainty**

  Evaluation of a component of **measurement uncertainty** determined by means other than a **Type A evaluation of measurement uncertainty.**

GUM principle

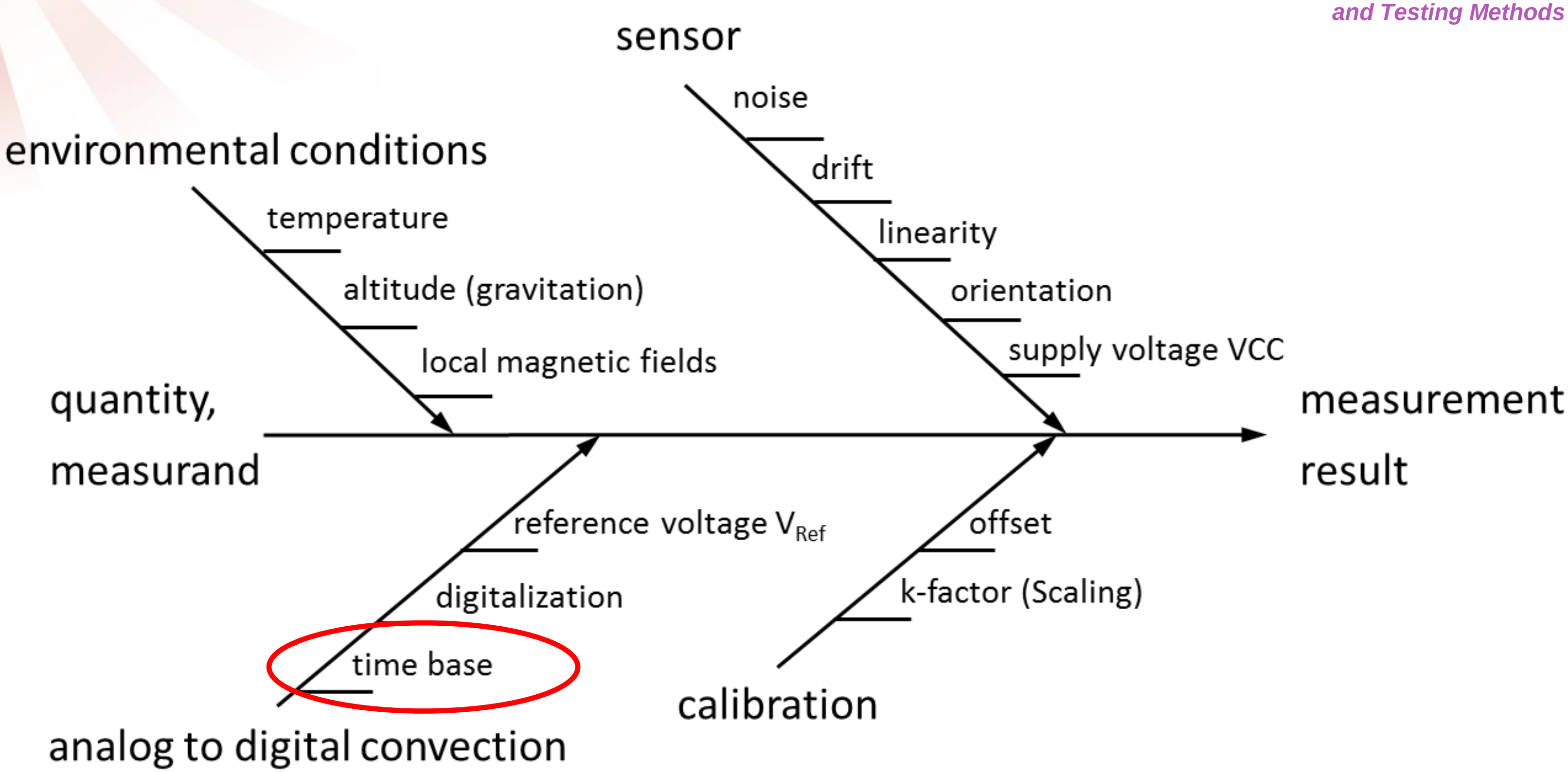
Measurement data of all sensor X_i, (input quantity)

Estimates of input quantities of sensor X_i

Analysis of standard uncertainties of input estimates x_i

Determination of expanded uncertainty according to GUM (combination of standard uncertainties incl. correlations)

Contributing parameters and input values (quantity, measurand)



- Measurement result of one sensor x_i and the input quantity X_{i_j} including all corrections leading to the final measurement result $Y = f(x_i)$, with i=1..n (sensors)

Contributions to uncertainties and the influencing variables

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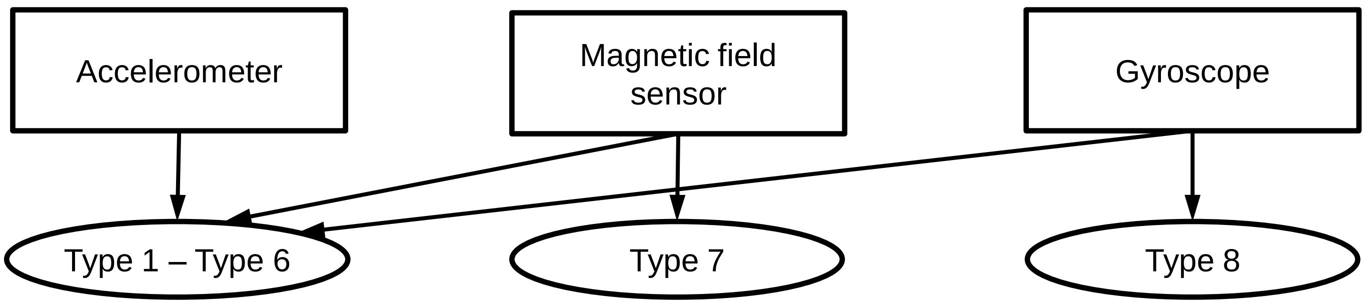
Sensor:

Uncertainty contributions :



Measured variable:	U [mV] → a [m/s²]	U [mV]→ B [µT]	U [mV] → ω [°/s]
Calibrated variable:	[earth gravity field, 1g]	Direction of the earth's magnetic field vector	Angle velocity of the calibrated accelerometer and magnetic field sensor
Sensitivity factor:	g/mV	µT/mV	°/s/mV

Types of the uncertainty contribution

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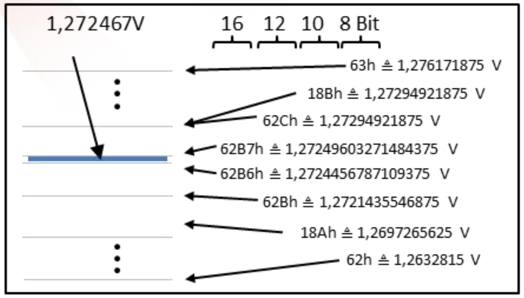
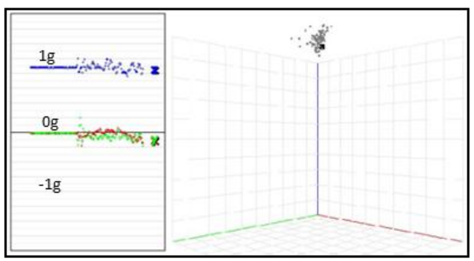
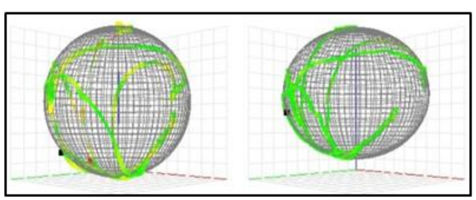
Type 1: Resolution of the digitalization
e.g. at 3,3 V_{Ref} and 12 Bit ADU
1 Digit = 0,8056640625 mV



Type 2: Sensor noise



Type 3: Scaling error

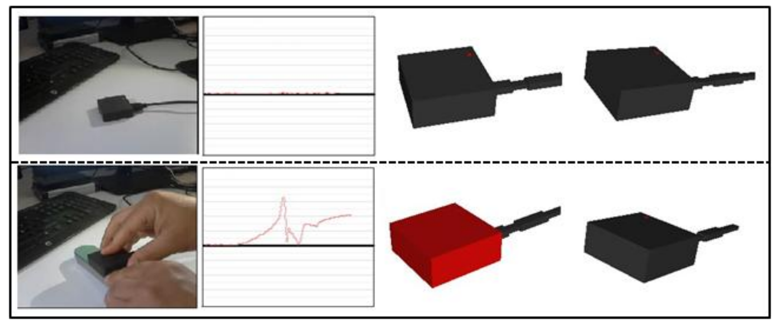


Type 4: Temperature drift

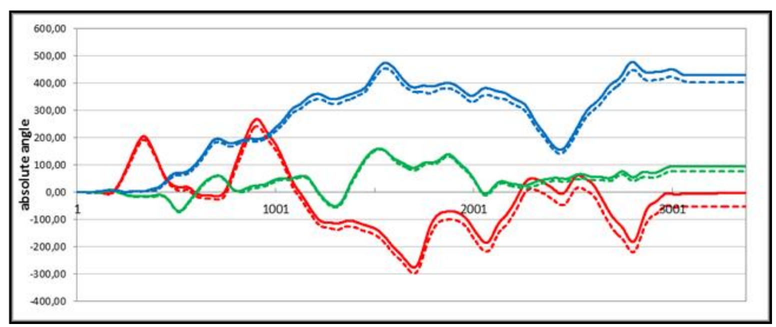
Type 5: voltage fluctuation
- supply voltage

Type 6: voltage fluctuation
- reference voltage

Type 7: fluctuations
- Local magnetic fields



Typ 8: Sensor drift



Uncertainty Budget

- Uncertainty estimation $u\left(s\left(t_{\text{int}}\right)\right)$ including (systematic) time basis error Δt_{err}

$$u^2\left(s\left(t_{\text{int}}\right)\right) \approx u^2\left(v(t)\right)\left(\delta t + \Delta t_{err}\right)^2 + 2u^2\left(a(t)\right)\left(\frac{\left(\delta t + \Delta t_{err}\right)^2}{2}\right)^4$$

- By numerical integration approximation (one space coordinate) for displacement calculation interval $t_{\text{int}} \equiv n \cdot \left(\delta t + \Delta t_{err}\right)$

$$s\left(t_{\text{int}}\right) \approx \left(\sum_{i=1}^{n} v\left(t_{i-1}\right)\right) \cdot \left(\delta t + \Delta t_{err}\right) + \sum_{i=1}^{n}\left(a\left(t_i\right) + a\left(t_{i-1}\right)\right) \cdot \left(\frac{\left(\delta t + \Delta t_{err}\right)^2}{2}\right)^2$$

$$t_{\text{int}} \equiv n \cdot \left(\delta t + \Delta t_{err}\right)$$

where

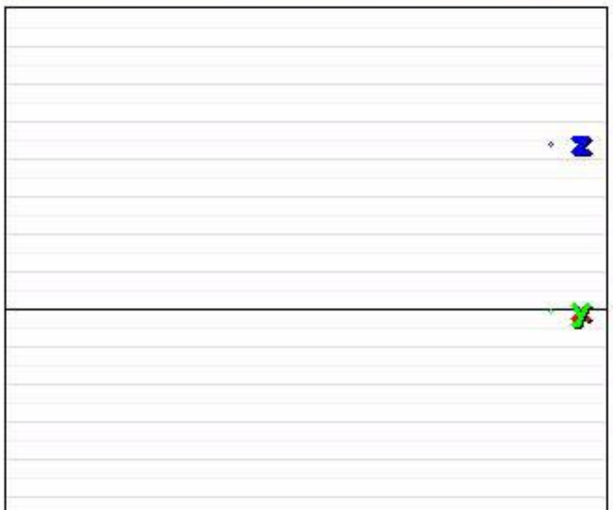
$u\left(v(t)\right)$: uncertainty contribution concerning determination of actual velocity

$u\left(a(t)\right)$: uncertainty contribution concerning determination of actual acceleration

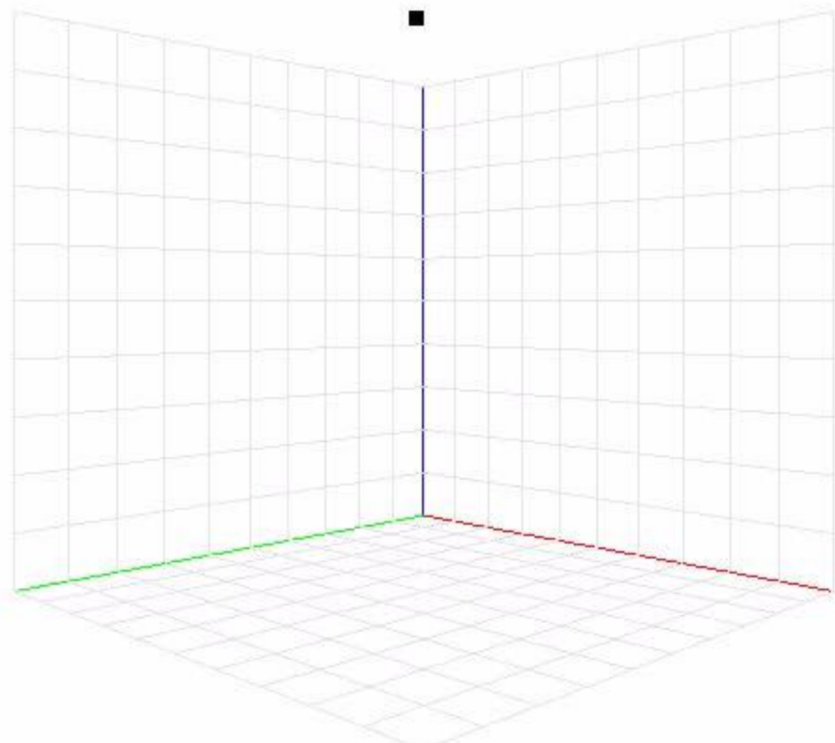
Δt_{err} : highly correlated interval deviation

Estimation of are input quantity $X_{Acc.}$

Illustration of space vectors, the free 3D motion



Input quantities → measurand



Summary and Outlook

- Reduction of the uncertainty estimation with the 3D self-calibration-method
- Acquisition of contributing parameters and input values (quantity, measurand)
- Application of type A for uncertainty determination

- Building of all uncertainty budgets for all sensors of the hybrid sensor systems according to GUM
- Improvement of the long-term stability and determination of the "working time" of 3D inertial navigation system without infrastructure, BodyGuard-System

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Thank you for your attention!

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