Geodetic Research and Technical Development Projects on BIM 4.0 and Agriculture 4.0 in the HKA Laboratory on GNSS and Navigation

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http://goca.info/Labor.GNSS.und.Navigation/index.php

RaD

www.dfhbf.de, www.goca.info, www.navka.de

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University of
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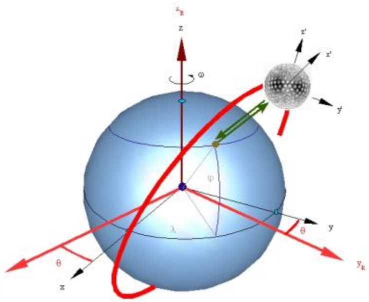
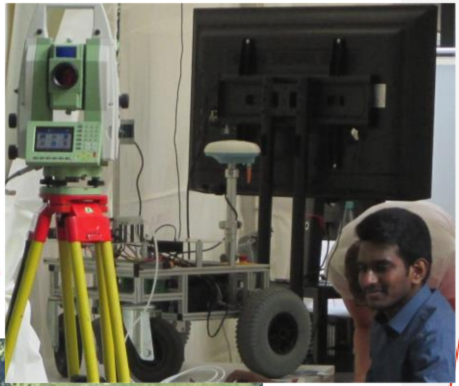
International Master's Degree Programme in Geomatics (MSc)

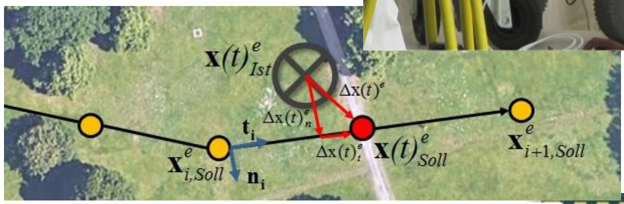
Karlsruhe University of Applied Sciences • https://www2.daad.de/deutschland/studienangebote/international-programmes/en/detail/3757/#tab_detail

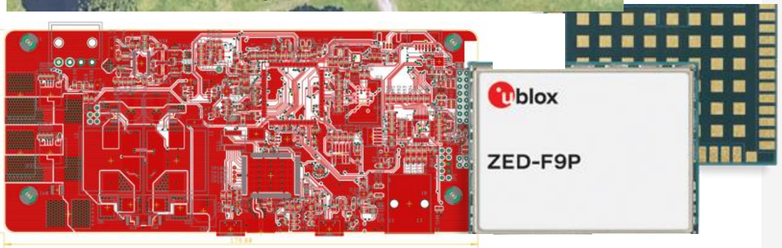
www.h-ka.de/studieren/studienangebot/master/geomatics/profil
www.h-ka.de/studieren/studienangebot/bachelor/geodaesie-und-navigation/profil
https://www.h-ka.de/ugib/profil

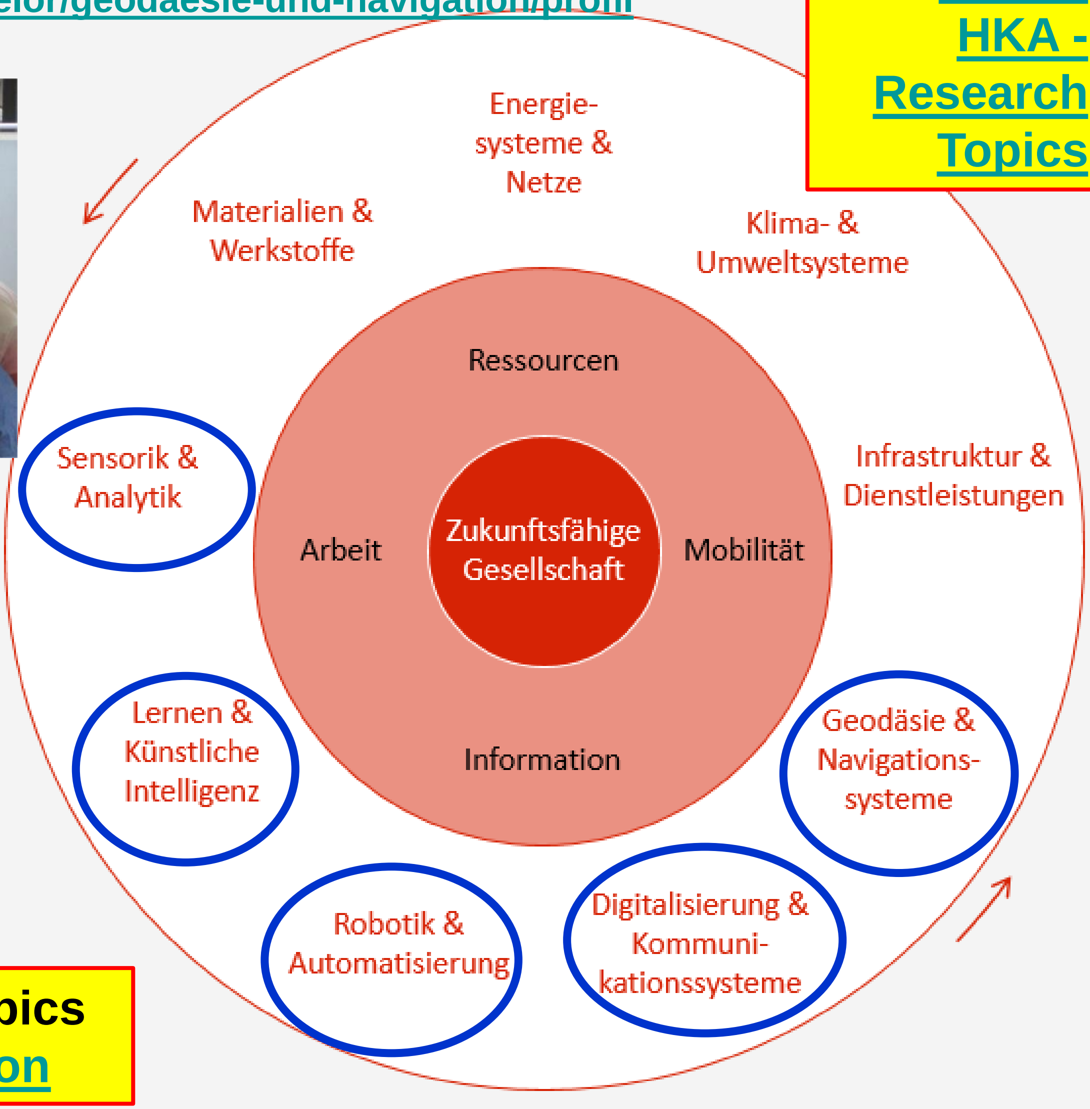
Offical HKA - Research Topics







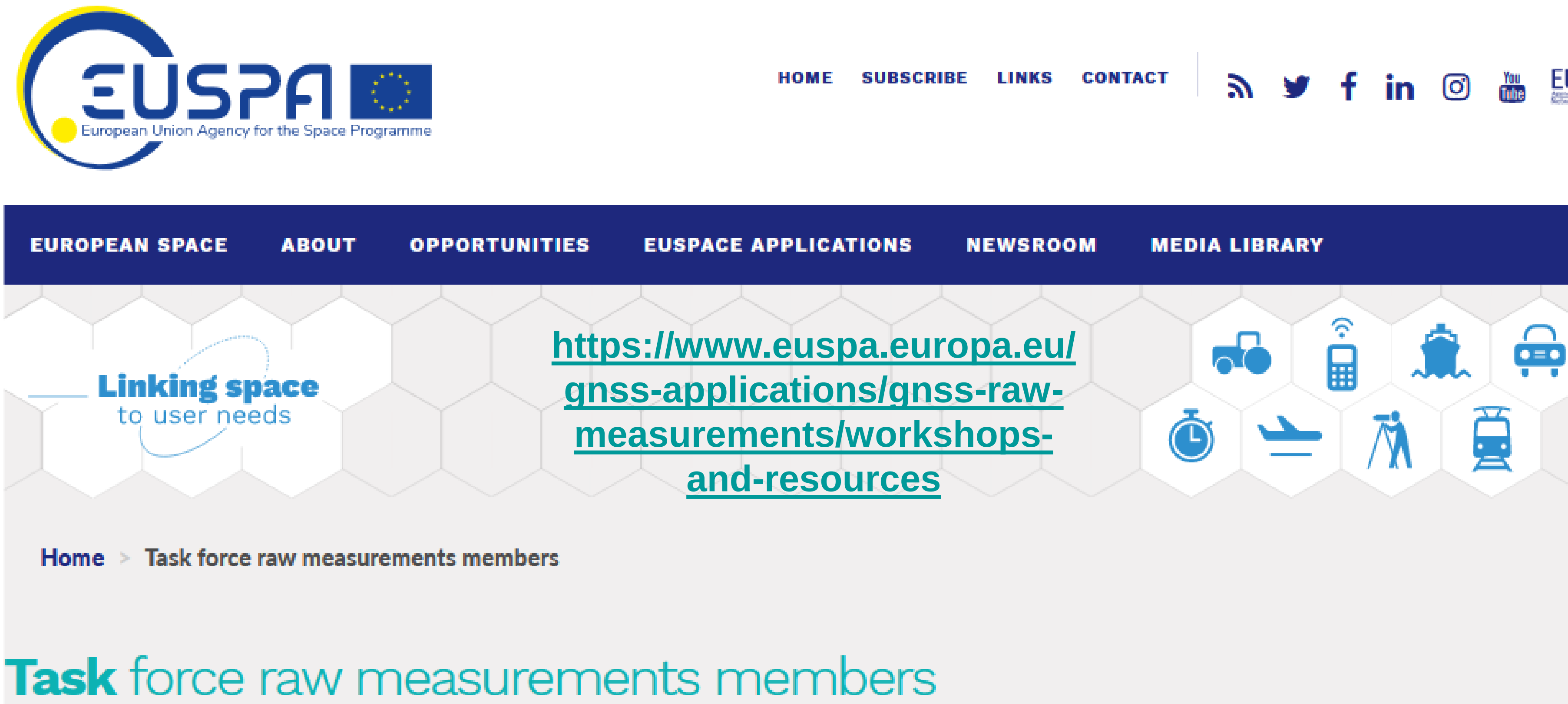




Sensor Systems Technology
https://www.h-ka.de/sstm/profil

Study Programs and Research Topics
Laboratory on GNSS and Navigation

GNSS
PPP & DGNSS
Positioning Algorithms



HKA Redesigned Ambiguity Function Method (RAF)

Phase

Observation Equations

$$\lambda_R^{i,t} = \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t - \left(N^i \cdot \lambda + D^{i,t} \cdot \lambda\right)$$

$$\underbrace{\frac{\lambda_R^{i,t}}{\lambda} - \frac{1}{\lambda} \cdot \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t}_{x^i} = \underbrace{-\left(N^i + D^{i,t}\right)}_{y^i}$$

Euler-Theorem: $e^{iz} = \cos z + i \cdot \sin z$

$$\sum_1^{n \cdot m} \left|e^{i \cdot (2\pi \cdot x^i)}\right| = \sum_1^{n \cdot m} \left|e^{i \cdot 2\pi \cdot \left(\frac{\lambda_R^{i,t}}{\lambda} - \frac{1}{\lambda} \cdot \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t\right)}\right| = n \cdot m$$

Classical Ambiguity Function Method

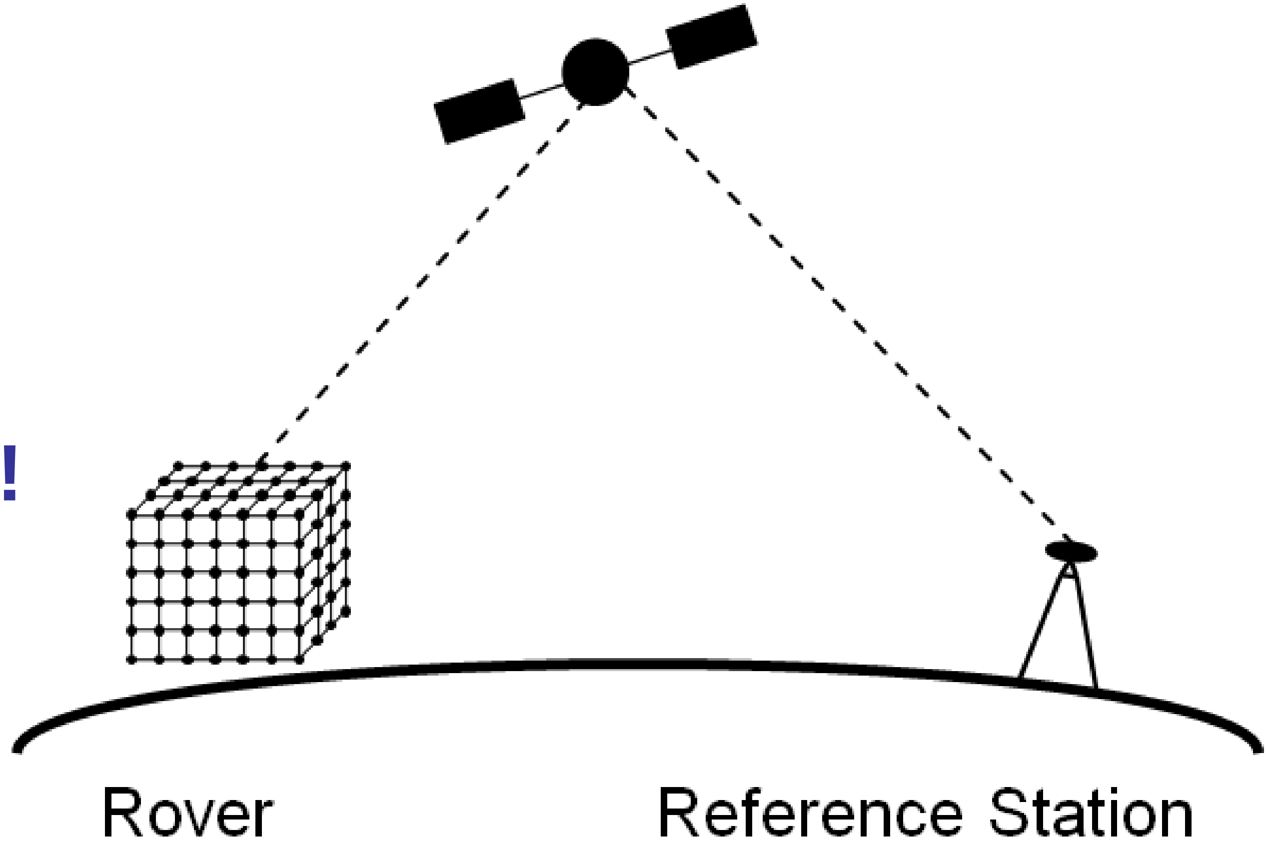
$$\sum_{1}^{n\cdot m}\left|e^{i\cdot 2\pi\cdot\left(\frac{\lambda_R^{i,t}}{\lambda}-\frac{1}{\lambda}\cdot\left(\sqrt{(x_s-x)^2+(y_s-y)^2+(z_s-z)^2}\right)^t\right)}\right|-n\cdot m=0$$

DGNSS

PPP

3D Grid Search

Postprocessing!



HKA Redesigned Ambiguity Function Method (RAF)

Code Observation Equations

$$\rho(t_i)_{Obs} = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j\right) \right| + c \cdot \Delta\bar{t}_{R,i} - c \cdot \Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP}$$

Phase Observation Equations

$$\underbrace{\frac{\lambda_R^{i,t}}{\lambda} - \frac{1}{\lambda} \cdot \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t}_{x^i} = \underbrace{-\left(N^i + D^{i,t}\right)}_{y^i}$$

Euler-Theorem right side

$$z =: 2\pi \cdot y^i \xrightarrow{yields} \begin{cases} \cos z = \cos\left(2\pi \cdot y^i\right) = \cos\left(-2\pi \cdot \left(N^i + D^{i,t}\right)\right) = 1 \\ \sin z = \sin\left(2\pi \cdot y^i\right) = \sin\left(-2\pi \cdot \left(N^i + D^{i,t}\right)\right) = 0 \end{cases}$$

HKA Redesigned Ambiguity Function Method (RAF)

Non-linear Phase Observation Equations

$$f_1(\hat{l}_i^t, \hat{\mathbf{x}}) = \cos\left(2\pi \cdot \left(\underbrace{\frac{\lambda_R^{i,t}}{\lambda} - \frac{1}{\lambda} \cdot \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t}_{x^i}\right)\right) - 1 = 0$$

$$f_2(\hat{l}_i^t, \hat{\mathbf{x}}) = \sin\left(2\pi \cdot \left(\underbrace{\frac{\lambda_R^{i,t}}{\lambda} - \frac{1}{\lambda} \cdot \left(\sqrt{(x_s - x)^2 + (y_s - y)^2 + (z_s - z)^2}\right)^t}_{x^i}\right)\right) = 0$$

Ambiguity-Parameters N are neutralized

Doppler Cycles D and cycle slips ∇D are neutralized

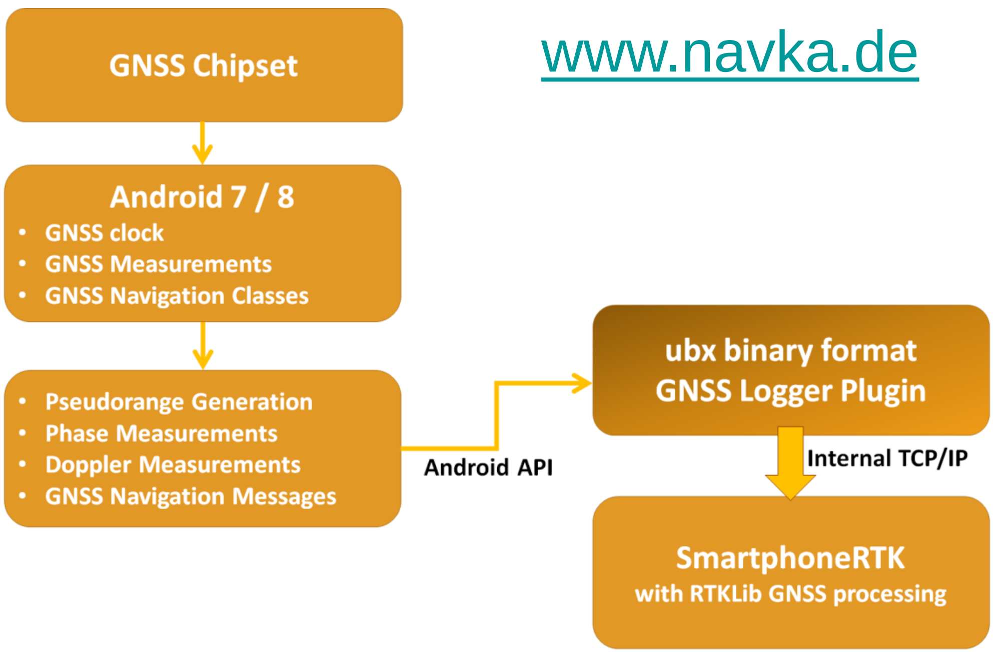
Solution of the overdetermined problem on **x** by SIMPLEX-based minimization of absulut sum of weighted residuals (L1-Norm) – Robust estimation

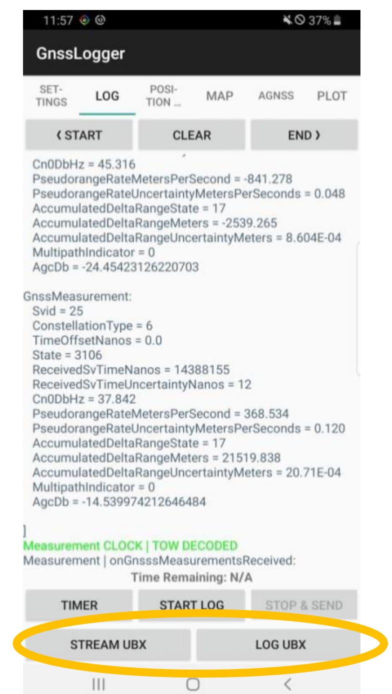
HKA Redesigned Ambiguity Function Method (RAF)

Transition from External GNSS to Internal GNSS

- Same GNSS Algorithms integrated into NAVKA Smartphone RTK developed by NAVKA Team (Karlsruhe University of Appl. Sciences)
- Realtime stream plugin integrated into Google GnssLogger
- Both for prototype and educational purpose

www.navka.de

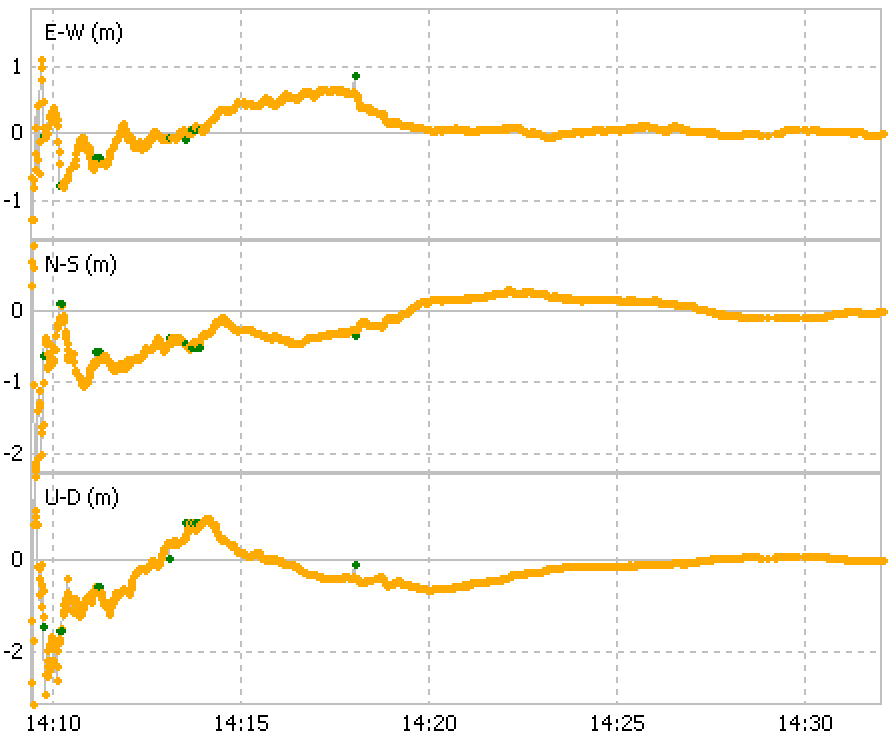




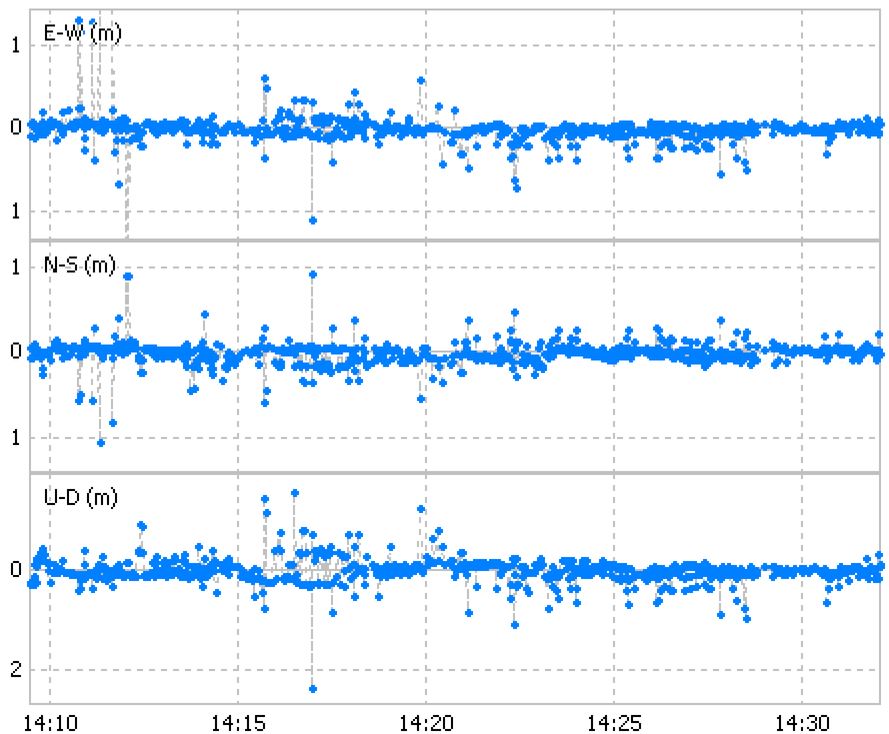
HKA Redesigned Ambiguity Function Method (RAF)

Comparison of Lambda vs. RAF

- RAF by L1-norm stable and „ready for positioning“ from the start. No initial fixing and no ambiguity refixing times in between are wasted.
- RAF noise (right) is non systematic. From the single positions a high precise solution can be computed by a sequential L1-adjustment.



Lambda with KalmanFilter (RTKLIB)



Redesigned Ambiguity Function (RAF)

GNSS/MEMS/Optical Sensors
Navigation, SLAM, Georeferencing,Robotics

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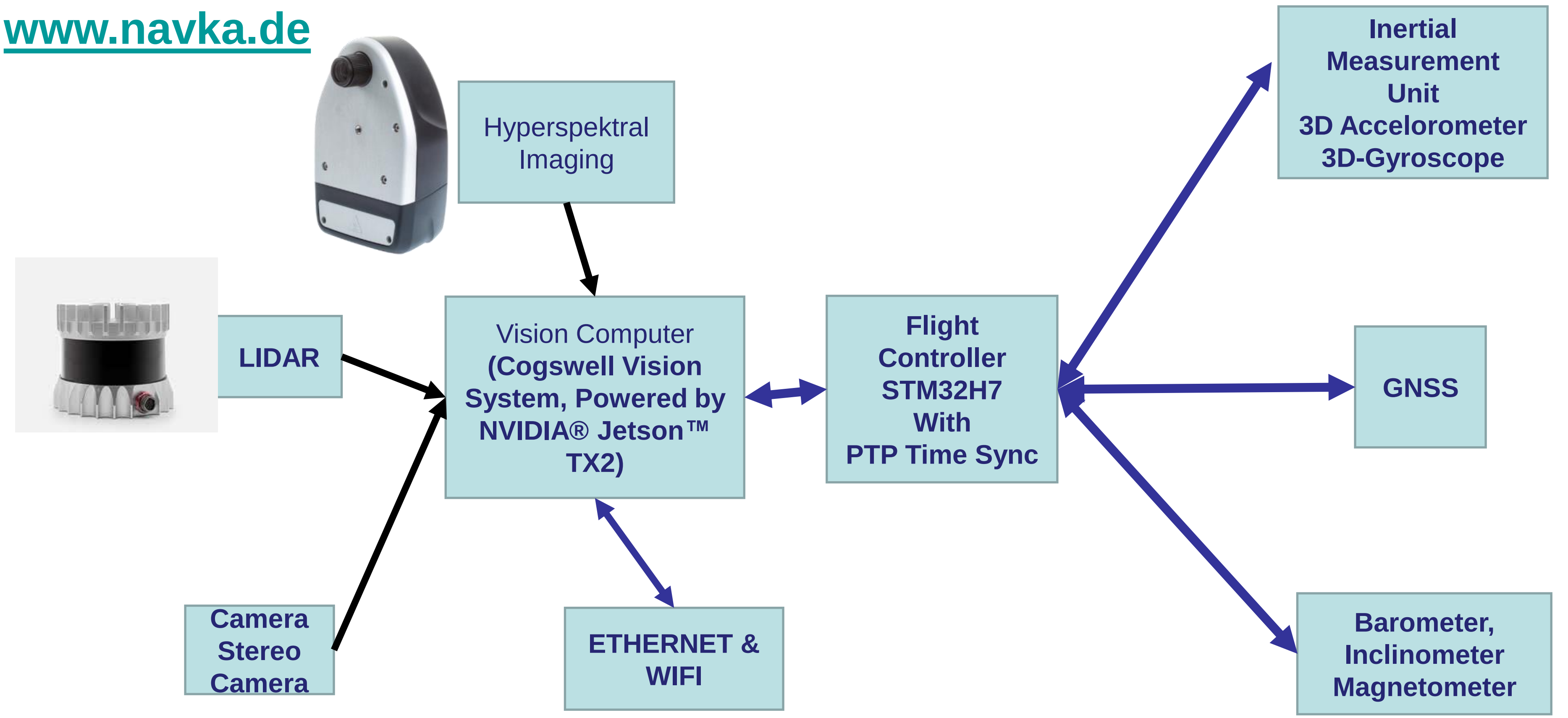
$$
\boldsymbol{y}(\boldsymbol{t})' = [\boldsymbol{y}(\boldsymbol{t}), \boldsymbol{m}(\boldsymbol{t})] = \left[\begin{matrix} \boldsymbol{x}^e\ y^e\ z^e | \dot{x}^e\ \dot{y}^e\ \dot{z}^e\ | \ddot{\boldsymbol{x}}^e \ddot{\boldsymbol{y}}^e \ddot{\boldsymbol{z}}^e | \boldsymbol{r}^e \boldsymbol{p}^e \boldsymbol{y}^e | \\ \boldsymbol{\omega}_{eb,x}^b\ \boldsymbol{\omega}_{eb,y}^b\ \boldsymbol{\omega}_{eb,z}^b | \dot{\boldsymbol{\omega}}_{eb,x}^b\ \dot{\boldsymbol{\omega}}_{eb,y}^b\ \dot{\boldsymbol{\omega}}_{eb,z}^b | \boldsymbol{m}(\boldsymbol{t}) \end{matrix}\right]
$$

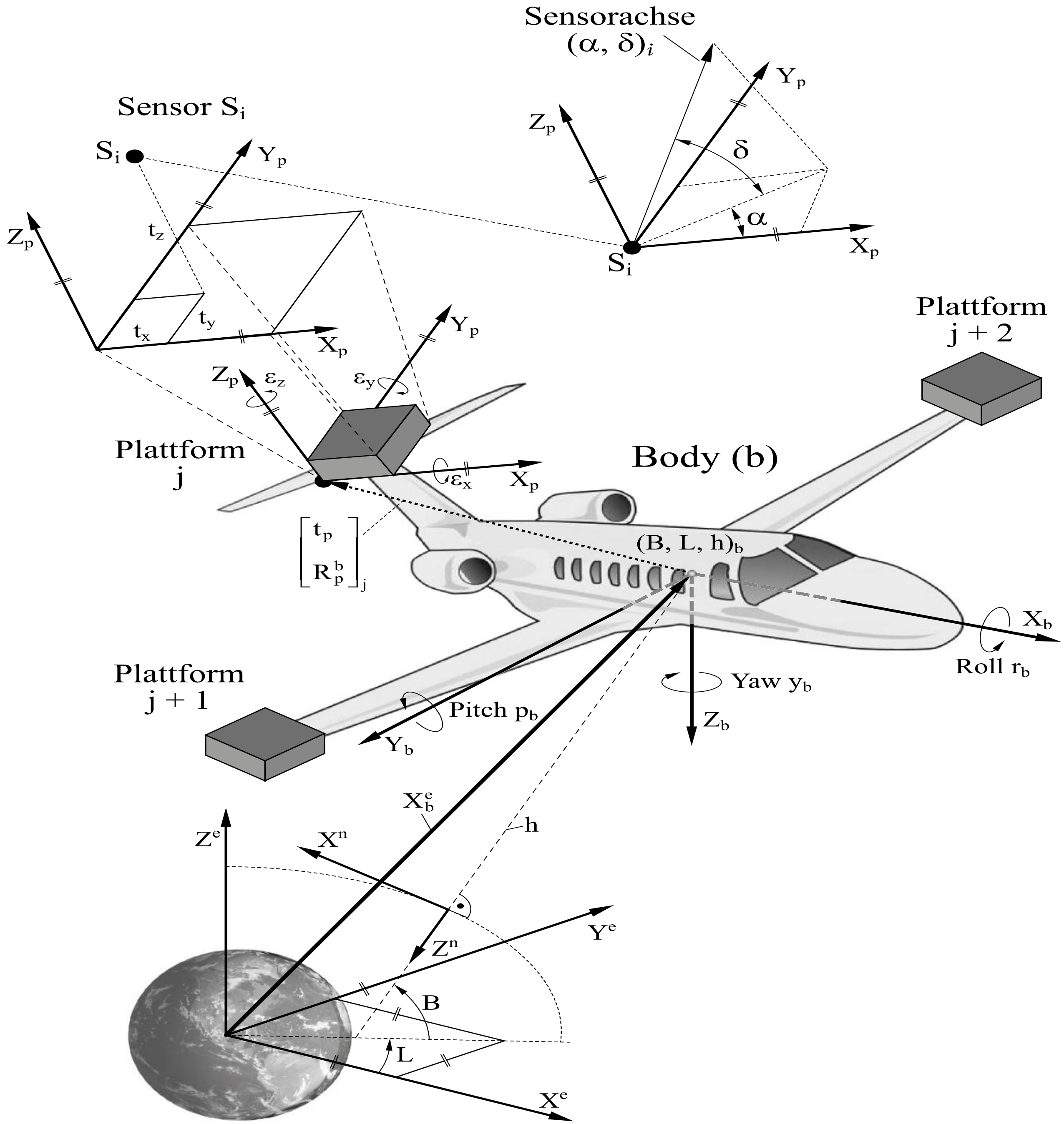


Navigation and SLAM with distributed GNSS/MEMS/Optical Sensors: Sensor leverarm parameter array sl(i,j).
Leverarm Index i for 5 leverarm parameters of sensor i on platform j.
Index j for 6 leverarm parameters platform i on body(b)

$$(\alpha,\delta)_{s_{ij}}$$

$$\mathbf{x}^{e}_{s_{ij}} = \mathbf{x}^{e}_{b} + \mathbf{R}^{e}_{b}(r,p,y)\cdot [\mathbf{t}^{b}_{p_j} + \mathbf{R}^{b}_{p_j}\cdot \mathbf{t}^{p_j}_{s_{ij}}]$$

$$l(i,j)_t = l(\mathbf{y}_t, \mathbf{sl}(i,j))_t$$



Navigation and SLAM with distributed GNSS/MEMS/Optical Sensors
Formal description

Target of Multisensory Navigation & Georeferencing Systems: State Estimation

$$\mathbf{y}_{\mathrm{t}} = (x^e y^e z^e \,|\dot{x}^e \dot{y}^e \dot{z}^e \,|\ddot{x}^e \ddot{y}^e \ddot{z}^e \,|r^e p^e y^e \,|\omega^b_{\mathrm{eb,x}}\ \omega^b_{\mathrm{eb,y}}\ \omega^b_{\mathrm{eb,z}} |\dot{\omega}^b_{\mathrm{eb,x}}\ \dot{\omega}^b_{\mathrm{eb,y}}\ \dot{\omega}^b_{\mathrm{eb,z}})^T$$

Start: Event Chain or Markov Chain

$$\mathbf{e}_{0:\mathrm{t}} = (\mathbf{l}_0, \mathbf{l}_1, .., \mathbf{l}_{\mathrm{t}-1}, \mathbf{l}_{\mathrm{t}}, \mathbf{u}_0, \mathbf{u}_1, .., \mathbf{u}_{\mathrm{t}-1}, \mathbf{u}_{\mathrm{t}}) = (\mathbf{l}_{0:\mathrm{t}}, \mathbf{u}_{0:\mathrm{t}})$$

Hypothesis: Present State as result of Markov Chain and starting state $\mathbf{y}_0$

$$\mathbf{y}_{\mathrm{t}} = \mathbf{y}_{\mathrm{t}}(\mathbf{e}_{0:\mathrm{t}}, \mathbf{y}_0) = \mathbf{y}_{\mathrm{t}}\left(\mathbf{l}_{0:\mathrm{t}}, \mathbf{u}_{0:\mathrm{t}}, \mathbf{y}_0\right) = \mathbf{y}_{\mathrm{t}}\,(\mathbf{l}_0, \mathbf{l}_1, .., \mathbf{l}_{\mathrm{t}-1}, \mathbf{l}_{\mathrm{t}}, \mathbf{u}_0, \mathbf{u}_1, .., \mathbf{u}_{\mathrm{t}-1}, \mathbf{u}_{\mathrm{t}}, \mathbf{y}_0)$$

Now: Turning to Stochastic Process andd Conditioned Probabilty Densities

$$\mathrm{bel}(\mathbf{y}_{\mathrm{t}}) = p\left(\mathbf{y}_{\mathrm{t}} \middle| \mathbf{y}_0, \mathbf{l}_{0:\mathrm{t}}, \mathbf{u}_{0:\mathrm{t}}\right) = p\left(\mathbf{y}_{\mathrm{t}} \middle| \mathbf{y}_0, \mathbf{l}_{0:\mathrm{t}-1}, \mathbf{l}_{\mathrm{t}}, \mathbf{u}_{0:\mathrm{t}}\right)$$

Now: Inversion of the Problem by Bayes Theorem to exploit information

$$\mathrm{bel}(\mathbf{y}_{\mathrm{t}}) = p\left(\mathbf{l}_{\mathrm{t}} \middle| \mathbf{y}_{\mathrm{t}}, \mathbf{y}_0, \mathbf{l}_{0:\mathrm{t}-1}, \mathbf{u}_{0:\mathrm{t}}\right) \cdot \frac{p\left(\mathbf{y}_{\mathrm{t}} \middle| \mathbf{y}_0, \mathbf{l}_{0:\mathrm{t}-1}, \mathbf{u}_{0:\mathrm{t}}\right)}{p\left(\mathbf{l}_{\mathrm{t}} \middle| \mathbf{y}_0, \mathbf{l}_{0:\mathrm{t}-1}, \mathbf{u}_{0:\mathrm{t}}\right)}$$

Navigation and SLAM with distributed GNSS/MEMS/Optical Sensors
Formal description

Rewriting Bayes Inversion by abreviating constant term

$$p(\mathbf{y}_t|\mathbf{y}_0, \mathbf{l}_{0:t}, \mathbf{u}_{0:t}) = \eta \cdot (\mathbf{l}_t|\mathbf{y}_t, \mathbf{s}\mathrm{l}(\mathrm{i,j})) \cdot p(\mathbf{y}_t|\mathbf{y}_0, \mathbf{l}_{0:t-1}, \mathbf{u}_{0:t})$$

1. Markov-Assumption

Chapman-Kolmogorov-Equation to integrate previous state y_{t-1}

$$p(\mathbf{y}_t|\boldsymbol{y}_0, \mathbf{l}_{0:t-1}, \mathbf{u}_{0:t}) = \int p(\mathbf{y}_t|\boldsymbol{y}_0, \mathbf{l}_{0:t-1}, \mathbf{u}_{0:t}, \mathbf{y}_{t-1}) \cdot p(\mathbf{y}_{t-1}|\boldsymbol{y}_0, \mathbf{l}_{0:t-1}, \mathbf{u}_{0:t}) \cdot d\mathbf{y}_{t-1}$$

Prediction or State Transition Equation

2. Markov-Assumption $\mathbf{p}(\mathbf{y}_t|\boldsymbol{y}_{t-1}, \mathbf{u}_t)$

Preceeding Estimation Prior Information

$$p(\mathbf{y}_{t-1}|\boldsymbol{y}_0, \mathbf{l}_{0:t-1}, \mathbf{u}_{0:t}) = \bar{p}(\mathbf{y}_{t-1}) = \mathrm{bel}\,(\mathbf{y}_{t-1})$$

Final Bayes and Chapman-Kolmogorov-Equation based State Estimation

$$\underbrace{p(\mathbf{y}_t|\mathbf{y}_0, \mathbf{l}_{0:t}, \mathbf{u}_{0:t})}_{\mathrm{bel}\,(\mathbf{y}_t)} = \eta \cdot \underbrace{p(\mathbf{l}_t(\mathbf{sl}(\mathrm{i,j}))|\mathbf{y}_t)}_{\text{Gauß-Markov-Model of Sensorobservations}} \cdot \underbrace{\int_{-\infty}^{+\infty} p(\mathbf{y}_t|\mathbf{y}_{t\text{-}1}, \mathbf{u}_t) \cdot \underbrace{\bar{p}(\mathbf{y}_{t\text{-}1})}_{bel\,(\mathbf{y}_{t\text{-}1})} \cdot d\mathbf{y}_{t\text{-}1}}_{\overline{bel}(\mathbf{y}_t)}$$

Navigation and SLAM with distributed GNSS/MEMS/Optical Sensors
Formal description

Particle Filter

$$bel(\mathbf{y}_{t-1}) = \sum_{i=1}^{N} w_{t-1}^{i} \cdot \delta(\tilde{\mathbf{y}}_{t-1} - \mathbf{y}_{t-1}^{i}) \text{ with } \sum_{i=1}^{N} w_{t-1}^{i} = 1$$

Final Bayes and Chapman-Kolmogorov based State Estimation

Any Distribution

Prediction Equation

$$\underbrace{p(\mathbf{y}_t|\mathbf{y}_0, \mathbf{l}_{0:t}, \mathbf{u}_{0:t})}_{bel\ (\mathbf{y}_t)} = \eta \cdot \underbrace{p(\mathbf{l}_t(\mathbf{sl}(i,j))|\mathbf{y}_t)}_{\text{Gauß-Markov-Model of Sensorobservations}} \cdot \underbrace{\int_{-\infty}^{+\infty} p(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{u}_t) \cdot \underbrace{\bar{p}(\mathbf{y}_{t-1})}_{bel\ (\mathbf{y}_{t-1})} \cdot d\mathbf{y}_{t-1}}_{\overline{bel}(\mathbf{y}_t)}$$

Exponential Distributions, e.g. Gauß, Laplace

Exponential Distributions Gauß, Laplace

M-Estimation Type

- LS Kalman Filter
- Robust L1 KF
- L1 SIMPLEX

$$\overline{bel}(\mathbf{y}_{t}) = \exp\left(\mathbf{y}(t)_{t-1}, \mathbf{C}_{\mathbf{y}(t)_{t-1}}\right)$$

$$\hat{\mathbf{y}}_{t_M} = \underbrace{\operatorname{argmax}\{p(\mathbf{l}_t(\mathbf{sl}(i,j))|\mathbf{y}_t) \cdot \overline{bel}\ (\mathbf{y}_t)\}}_{bel\ (\mathbf{y}_t)}$$

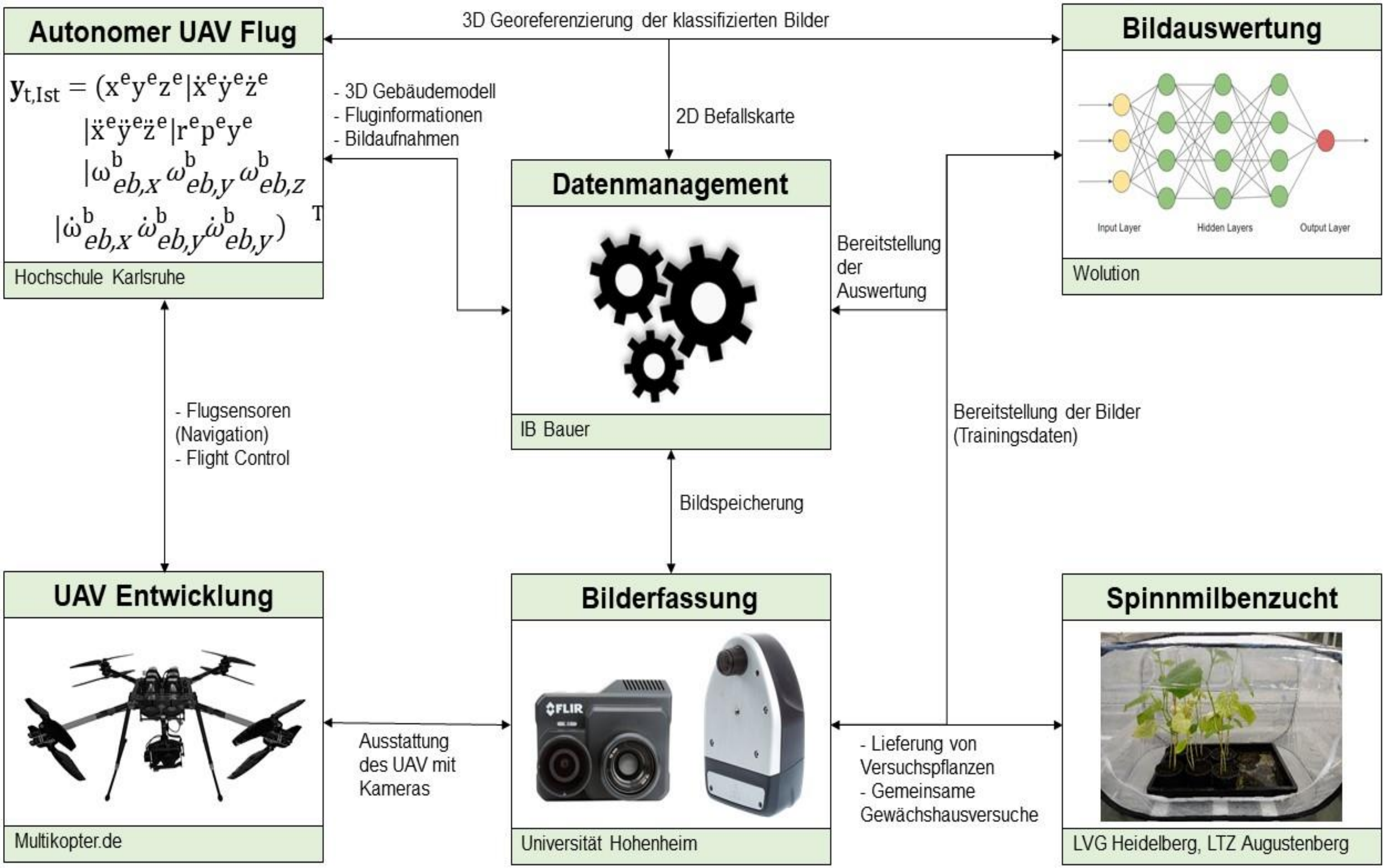
Product again exponentially distributed

Project 1

MITESENS

Agriculture 4.0 / Horticulture 4.0
UAS for Mites-Detection, Navigation, Flight Control
Autonomous UAS-Flight in Buildings, BIM Model

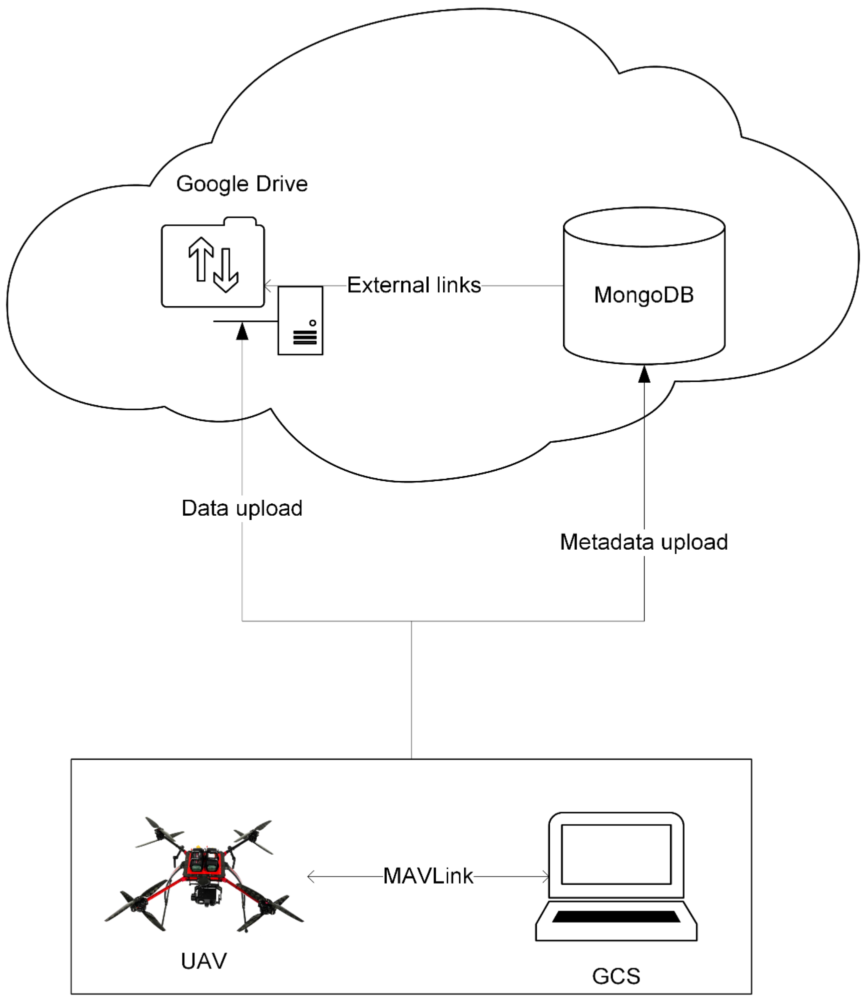
MITESENS - RaD Concept & Components - Consortium



MITESENS - RaD Concept & Components HKA

$$\boldsymbol{y}(t)' = [\boldsymbol{y}(t), \boldsymbol{m}(t)] = \begin{bmatrix} x^e\ y^e\ z^e | \dot{x}^e\ \dot{y}^e\ \dot{z}^e\ | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \\ \omega_{eb,x}^b\ \omega_{eb,y}^b\ \omega_{eb,z}^b | \dot{\omega}_{eb,x}^b\ \dot{\omega}_{eb,y}^b\ \dot{\omega}_{eb,z}^b | \boldsymbol{m}(t) \end{bmatrix}$$

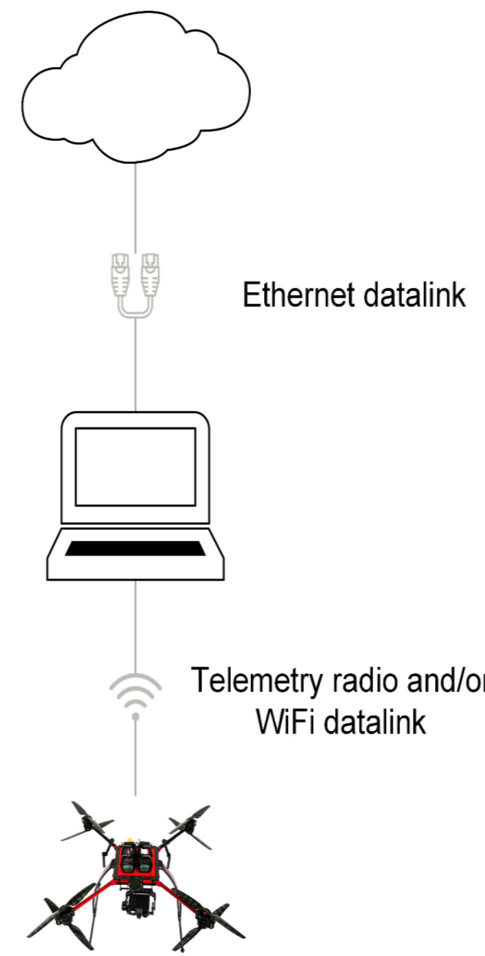
Basicdata: Navigation-Statevector y(t) of UAS and unique Time Stamp t



Cloud level processes:
Storage, machine learning (training), photogrammetry (CloudODM)

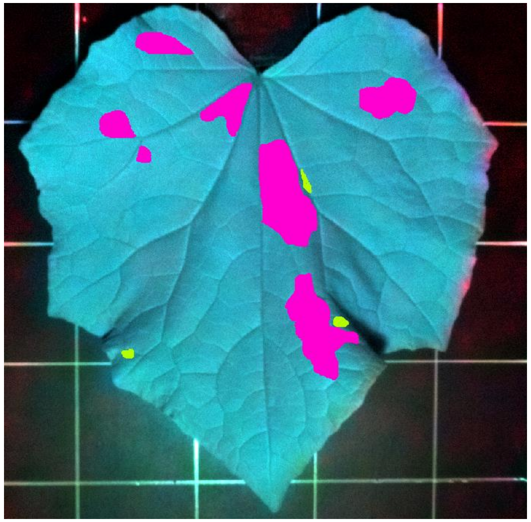
Desktop level processes:
Photogrammetry, navigation/ SLAM post-processing, visualization, flight planning

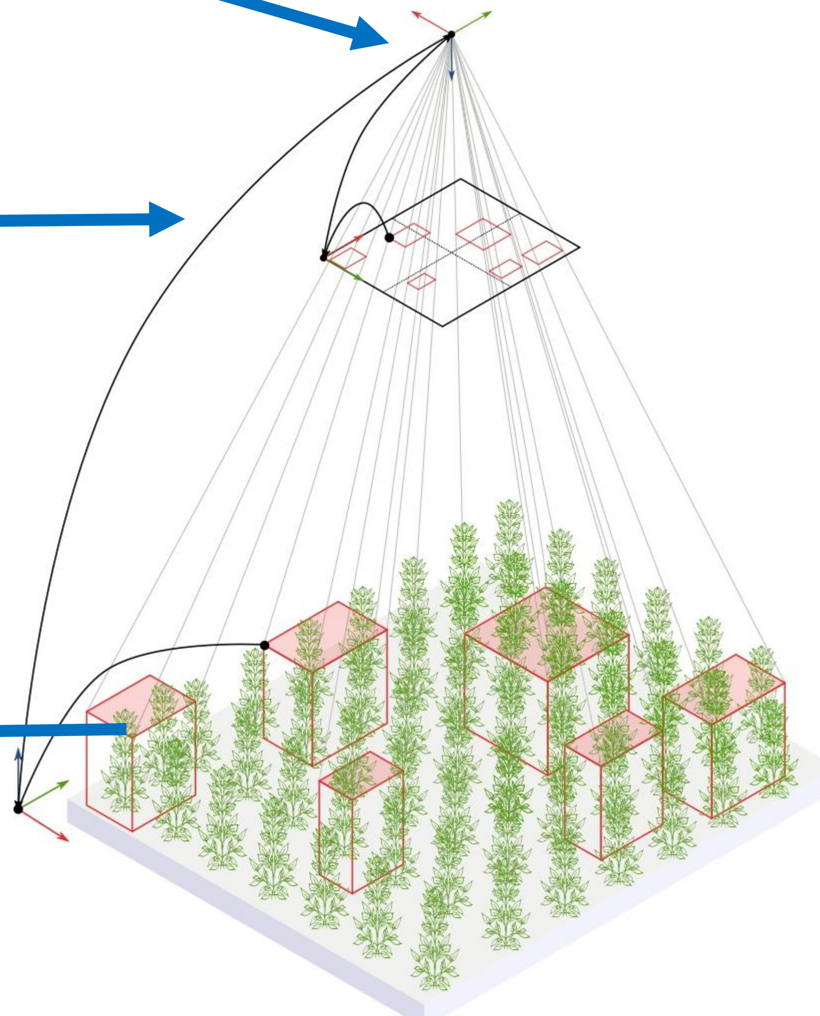
Embedded level processes:
Flight control, state estimation, obstacle avoidance, SLAM and synchronized data capture



Photogrammetry KA University of Applied Sciences (HKA)

$$\boldsymbol{y}(t)' = [\boldsymbol{y}(t), \boldsymbol{m}(t)] = \begin{bmatrix} x^e\ y^e\ z^e | \dot{x}^e\ \dot{y}^e\ \dot{z}^e\ | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \\ \omega^b_{eb,x}\ \omega^b_{eb,y}\ \omega^b_{eb,z} | \dot{\omega}^b_{eb,x}\ \dot{\omega}^b_{eb,y}\ \dot{\omega}^b_{eb,z} | \boldsymbol{m}(t) \end{bmatrix}$$





ETRF89/ITRF 3D Voxel-Model

Georeferencing of Point Clouds

Algorithm for direct georeferencing of Pointclouds Navigation State Vector

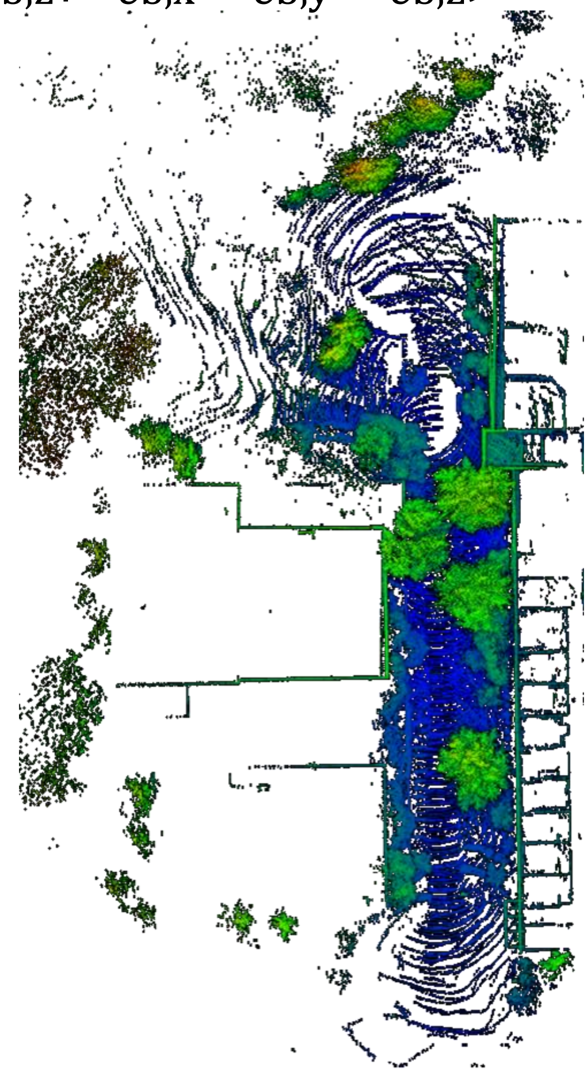
$$\mathbf{y}(t) = (x^e y^e z^e | \dot{x}^e \dot{y}^e \dot{z}^e | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \omega^b_{eb,x}\ \omega^b_{eb,y}\ \omega^b_{eb,z} | \dot{\omega}^b_{eb,x}\ \dot{\omega}^b_{eb,y}\ \dot{\omega}^b_{eb,z})^T$$

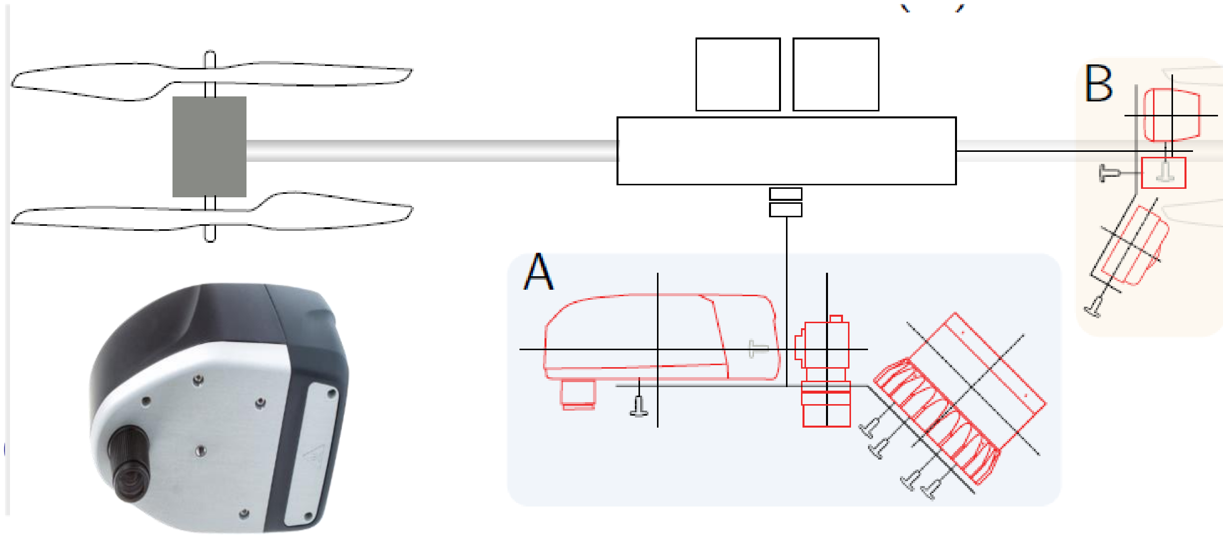
Algorithm 1: Non-rigid direct-georeferencing

input : $\mathbf{r}^s, \mathbf{R}_s^b, \mathbf{l}^b$,
$\mathcal{T}(\mathbf{t}_i, \mathbf{P}^l_{gps}, \mathbf{R}^l_b)$

output: $\mathbf{P}^l_G$

```
forall r_i^s ∈ r^s do
    /* Boresignt and lever-arm correction
    r_i^b = R_s^b r_i^s + l^b;
    /* Interpolate pose at t_i from INS trajectory
    ξ_{b_i}^l = Interpolate(T, t_i);
    {R_b^l, P_gps^l} ← ξ_{b_i}^l
    /* Apply transformation
    P_{G_i}^l = R_b^l r_i^b + P_gps^l;
end
return P_G^l
```





$$\mathbf{x}^{p}_{m,Pi} = s_{ij} \cdot \begin{pmatrix} \sin z_{ij} \cdot \cos \alpha_{ij} \\ \sin z_{ij} \cdot \sin \alpha_{ij} \\ \cos z_{ij} \end{pmatrix}^{p}$$

Georeferencing Equation

$$\boldsymbol{y}(t) = \begin{bmatrix} x^e \; y^e \; z^e | \dot{x}^e \; \dot{y}^e \; \dot{z}^e \; | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \\ \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} | \dot{\omega}^b_{eb,x} \; \dot{\omega}^b_{eb,y} \; \dot{\omega}^b_{eb,z} \end{bmatrix}$$

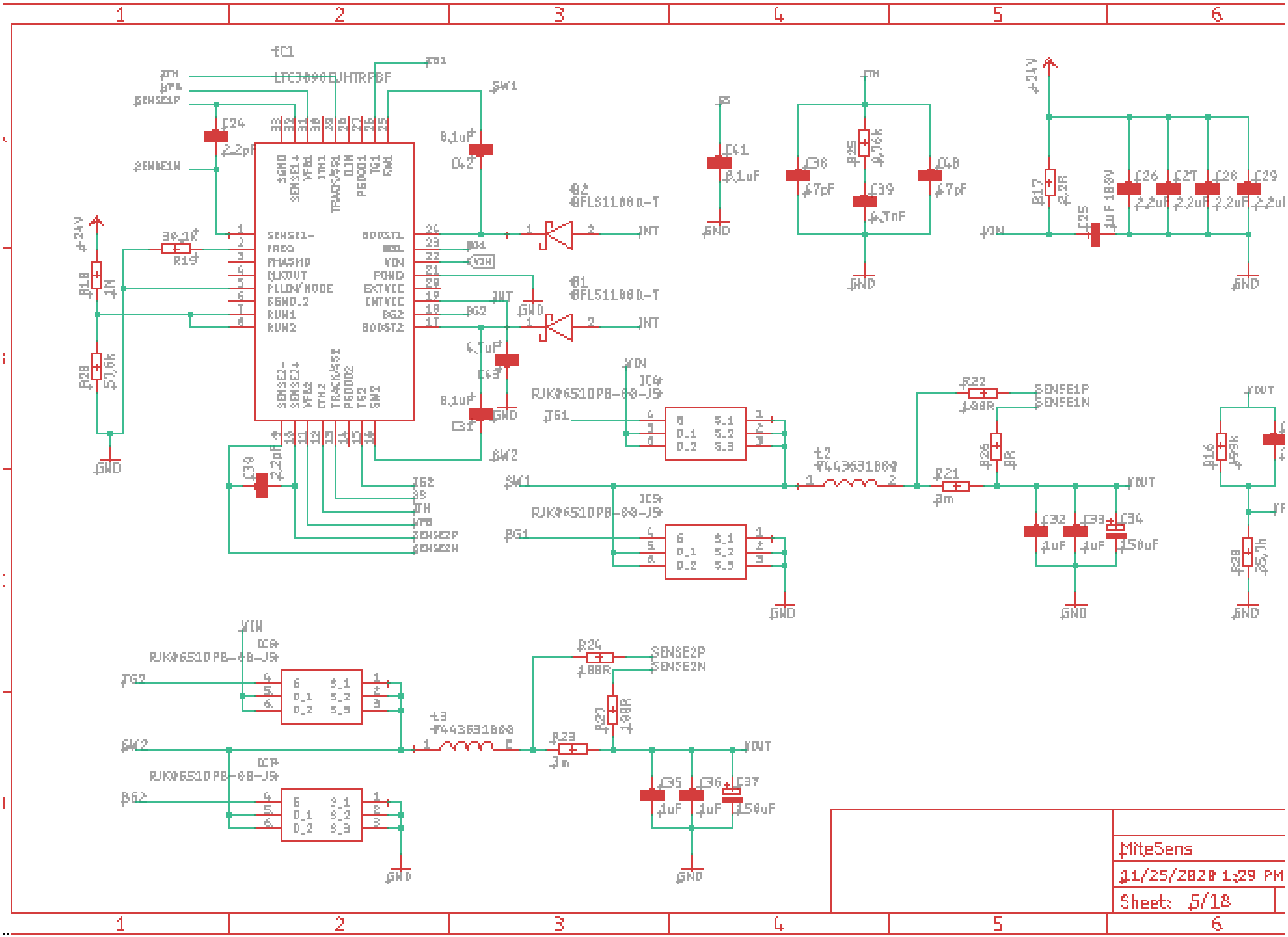
$$\mathbf{x}^{e}_{m,Pi} = \mathbf{x}^{e}_{b} + \mathbf{R}^{e}_{b}(r,p,y) \cdot (\mathbf{t}^{b}_{p} + \mathbf{R}^{b}_{p} \cdot \mathbf{x}^{p}_{m,Pi})$$

SLAM Observation Equation

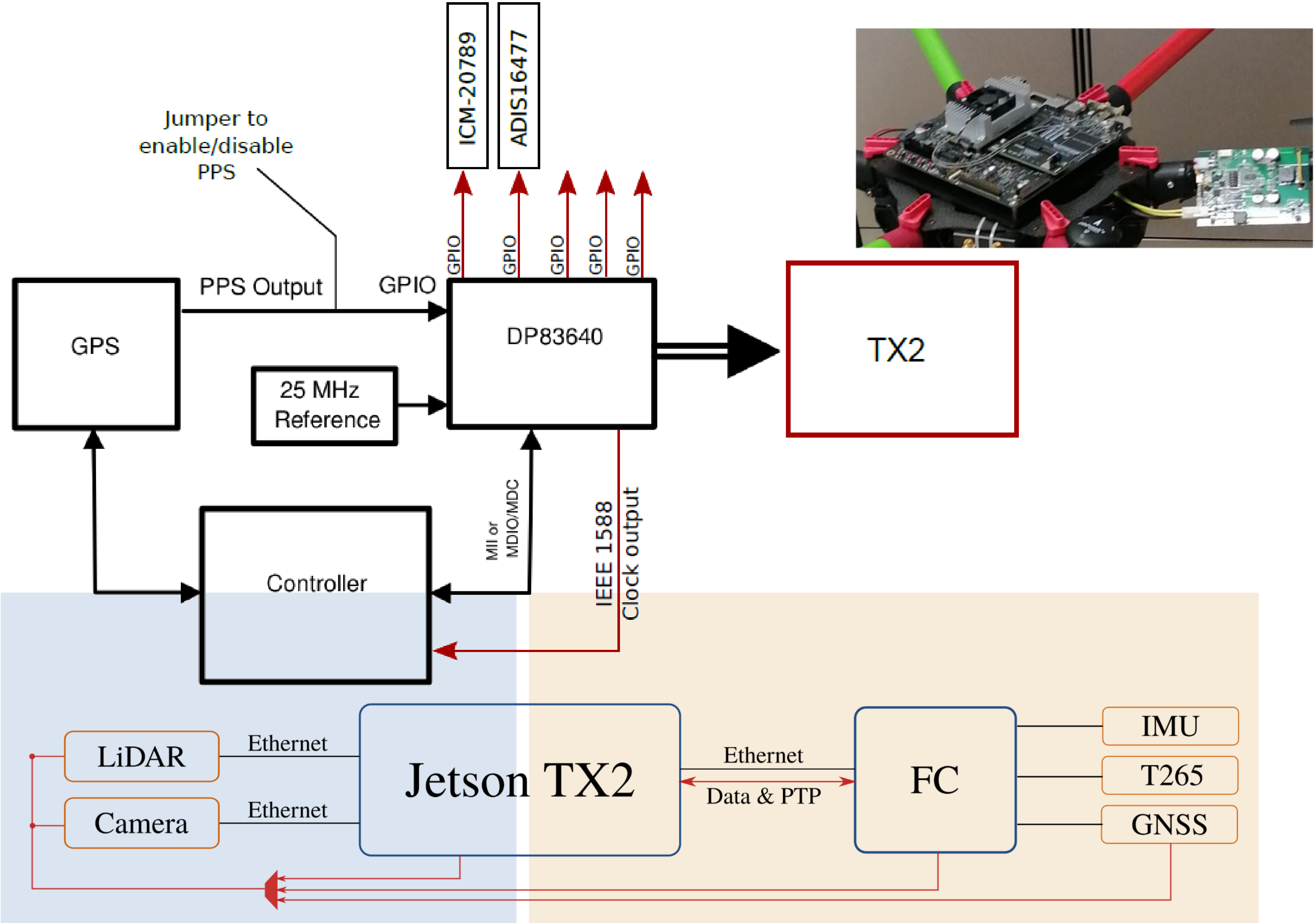
$$\mathbf{x}^{p}_{m,Pi} = {\mathbf{R}^{b}_{p}}^{T} \cdot [\mathbf{R}^{e}_{b}(r,p,y)^{T} \cdot (\mathbf{x}^{e}_{m,Pi} - \mathbf{x}^{e}_{b}) - \mathbf{t}^{b}_{p}]$$

$$\boldsymbol{y}(t)' = [\boldsymbol{y}(t), \boldsymbol{m}(t)] = \begin{bmatrix} x^e \; y^e \; z^e | \dot{x}^e \; \dot{y}^e \; \dot{z}^e \; | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \\ \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} | \dot{\omega}^b_{eb,x} \; \dot{\omega}^b_{eb,y} \; \dot{\omega}^b_{eb,z} | \boldsymbol{m}(t) \end{bmatrix}$$

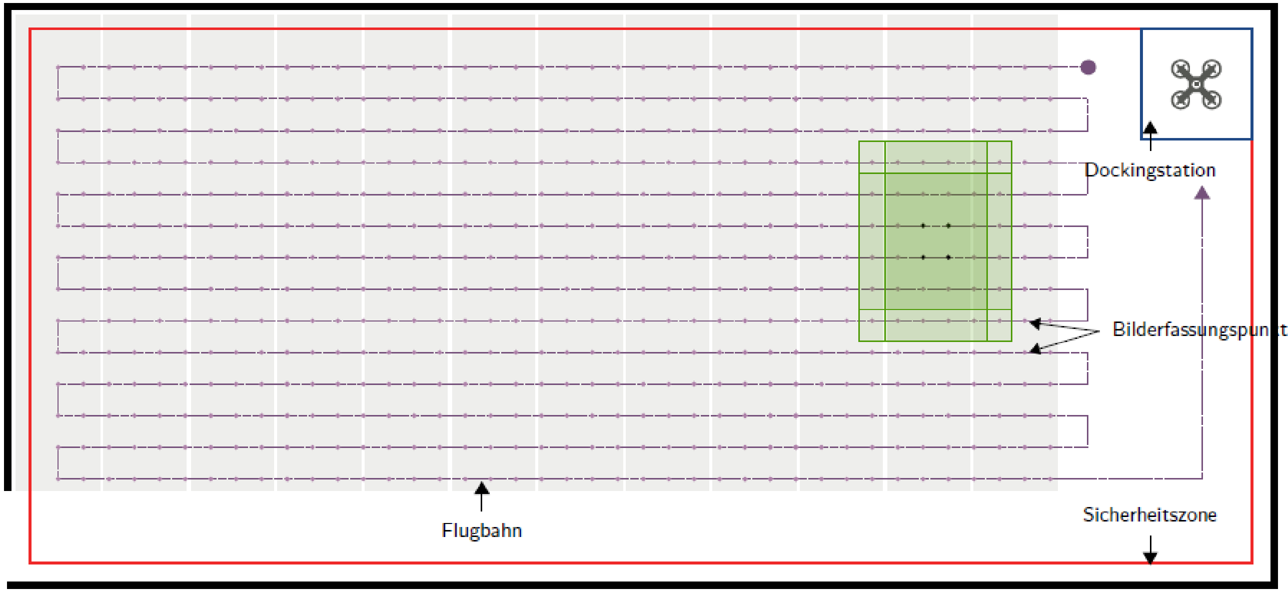
MITESENS – Flight Control Hardware Development

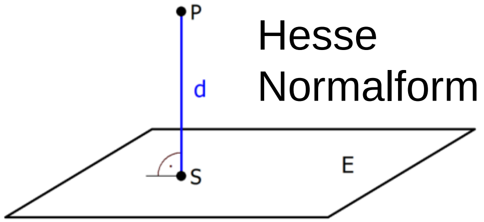


MITESENS – Flight Control Hardware Development

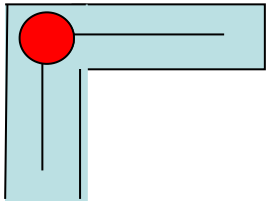


MITESENS – Flight Control for Autonomous Indoor UAS Flights

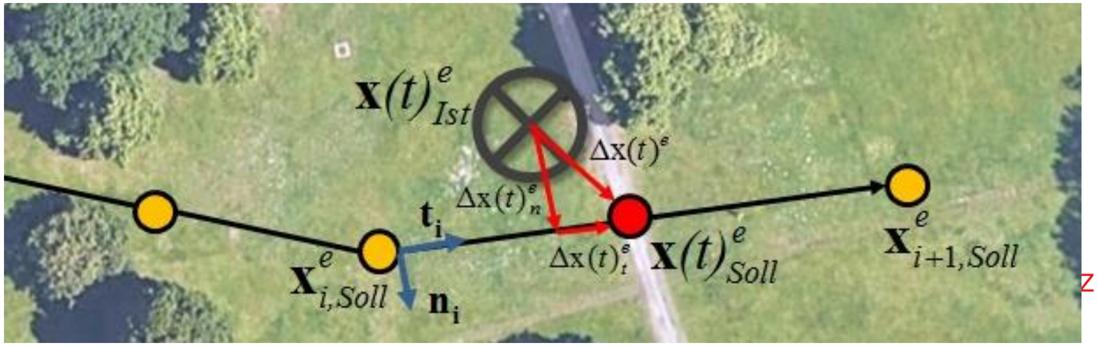




Inequations on position

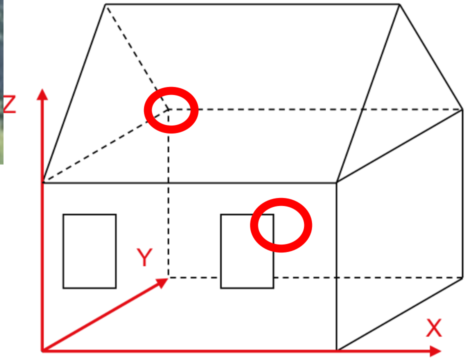


Out-/and indoor UAS flights



Robust L1-Norm Kalman-filter based on SIMLEX-Algorithm with space-related inequations, e.g. on distances to walls. Using ETRF89/ITRF BIM model

Waypoints completed to fully trajecory $y(t)_{desired}$
Control-deviation **d** = $y(t)_{desired}$ - y(t)
as flight-control input



BIM model as coordinate marker by camera-based feature detection

MITESENS – Flight Control for Automous Indoor UAS Flights

2021

- Multisensor-fusion of distributed GNSS/MEMS / Optical sensors
- Robust navigation state estimation y(t) and SLAM y(t)'=(y(t),m(t)) via L1-norm SIMPLEX
- Algorithms for modeling different time stamps t in sensor observations l(t)

May 2021

- Robust motorcontroller via SIMPLEX with inequations on propeller rotation rates
- Control of the fully actuated and the under-actuated (VTOL) multicopter type
- Set-up of a prototype UAS for industry partner

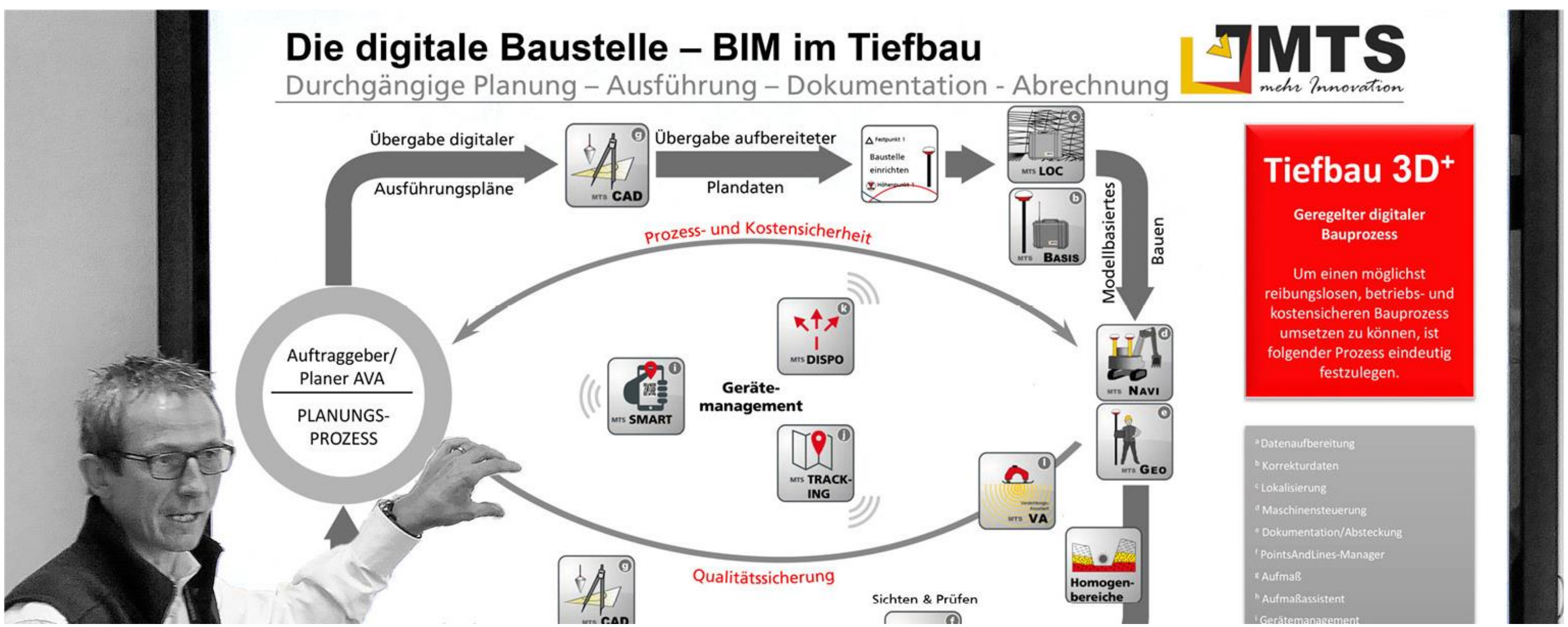
3. Quart 2021

- Dynamic trajectory generation in collision avoidance process
- Collision avoidance
- Safe landing at docking-station

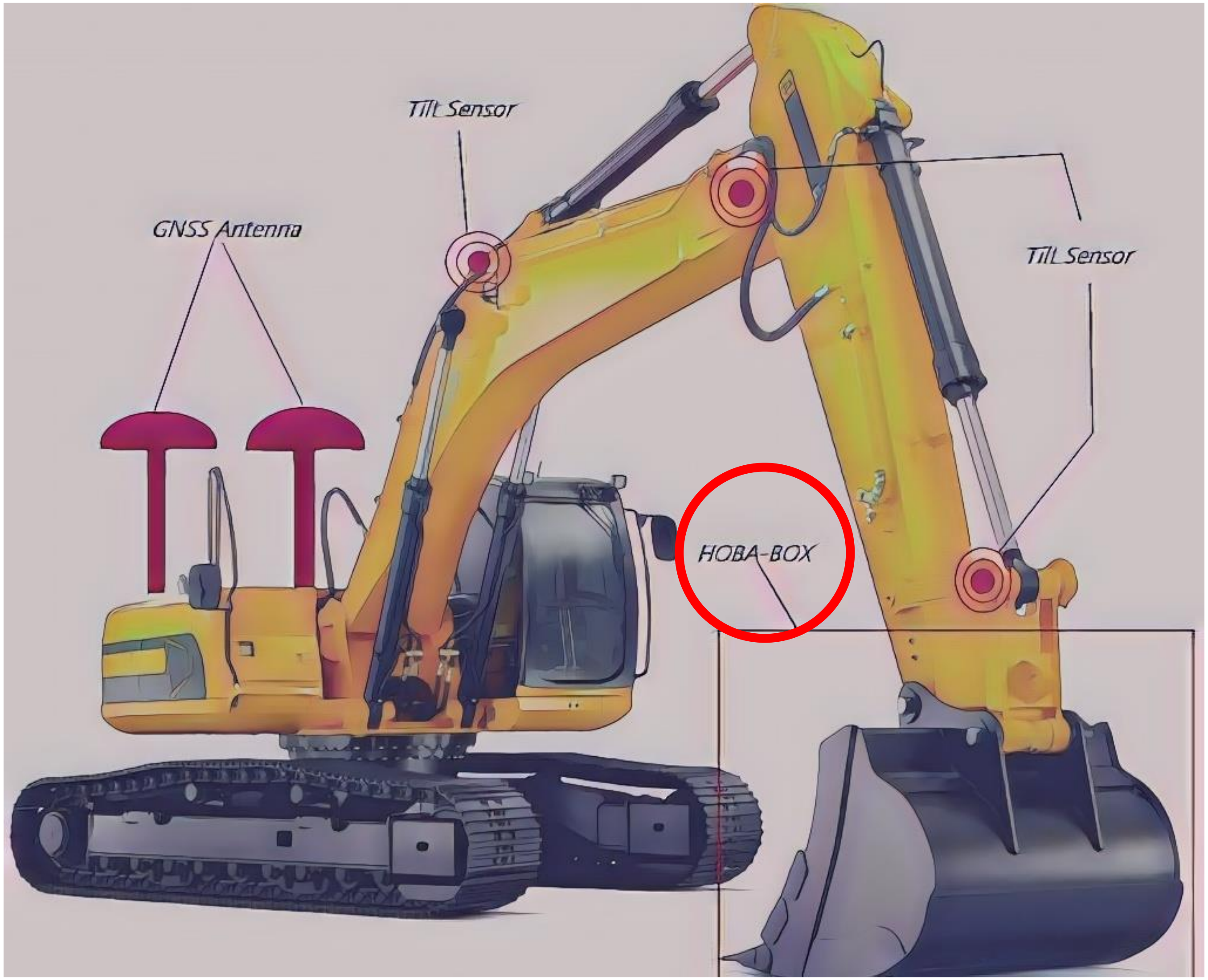
- Indoornavigation via optical markers (step 1)
- Indoornavigation via feature detection in the building using BIM model (step 2)

Project 2 HOBA

The R&D project "Homogeneous soils assistant for the automatic, construction site-specific recording of soil classes according to the new VOB 2016, shortly HOBA.HOBA deals with the development of a system for an automatic classification, detection & segmentation and a georeferenced voxel-based 3D-volume model generation for excavation site specific soil types according to the new BIM regulation called “VOB 2016”.
Cooperation Partner www.mts-online.de

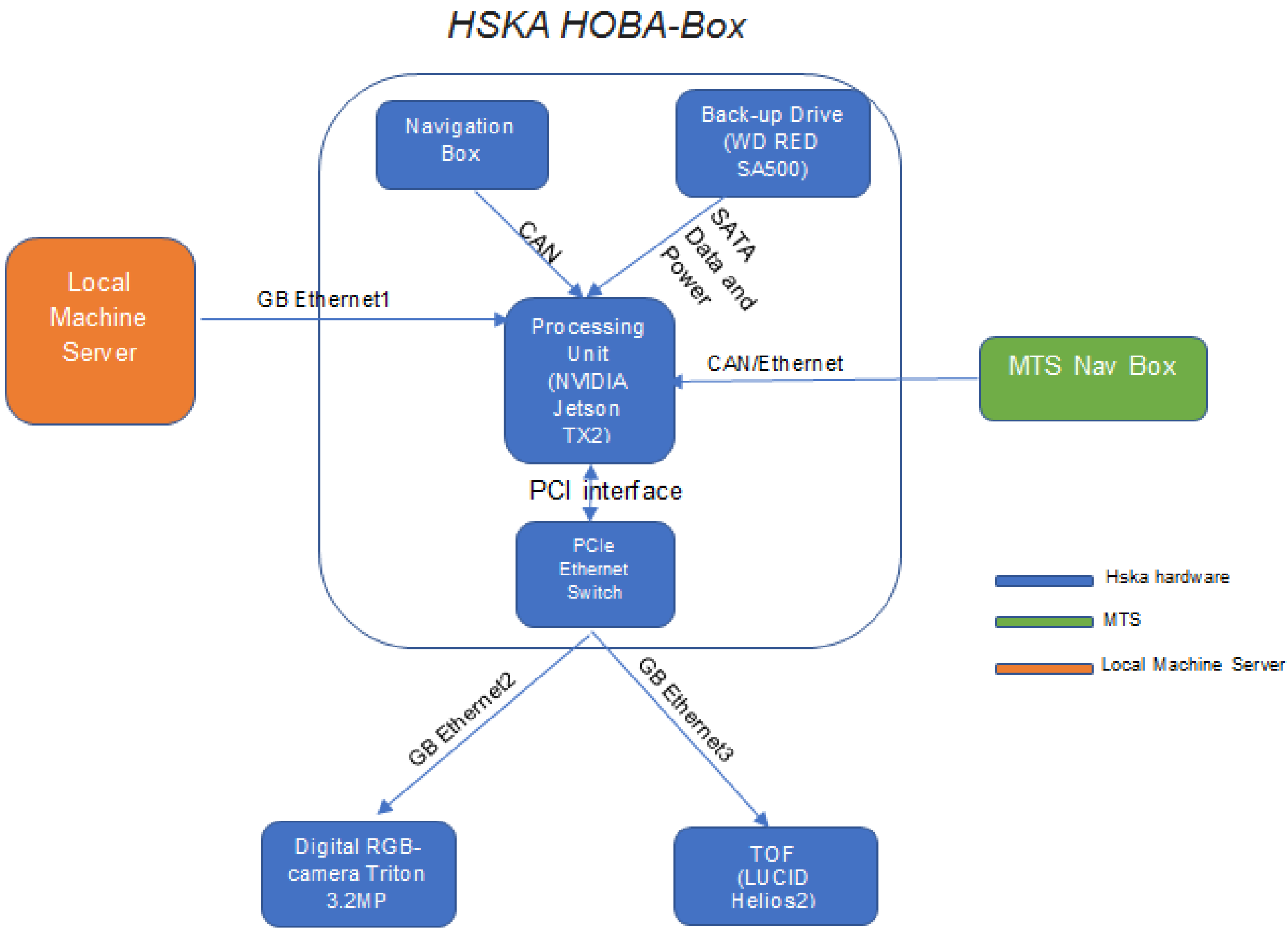


HOBA – Box



Excavator with distributed MTS sensors and HKA HOBA-Box located in the area of the excavator bucket

HOBA Box – Hardware, Software and Algorithms Design

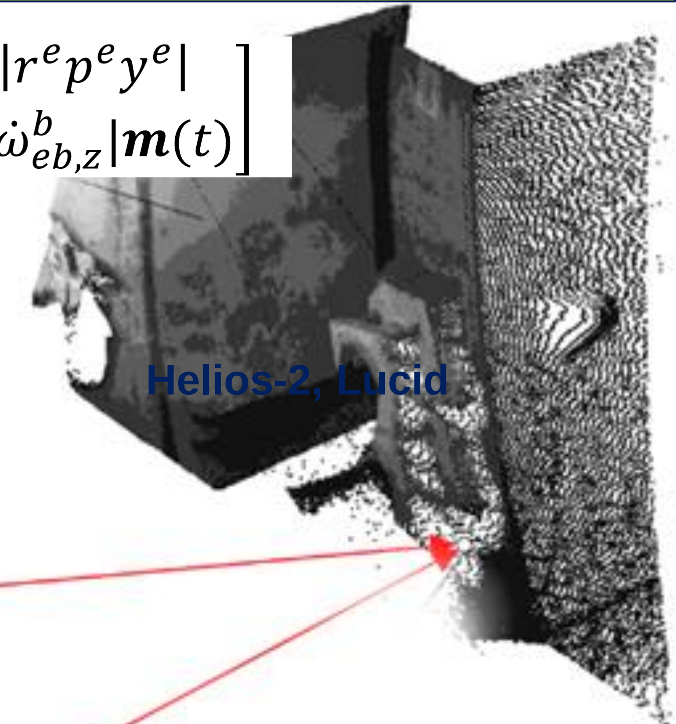


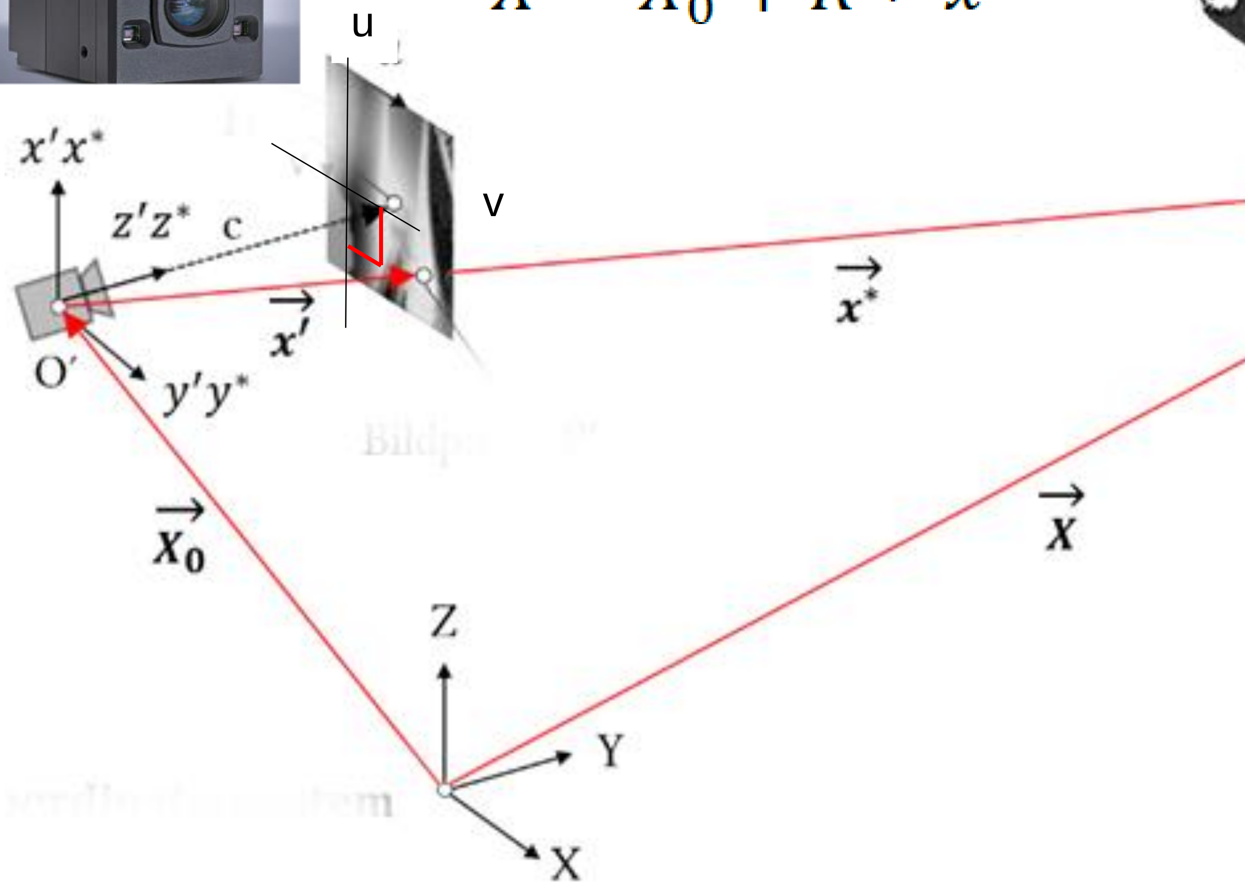
HOBA Box – Hardware, Software and Algorithms Design

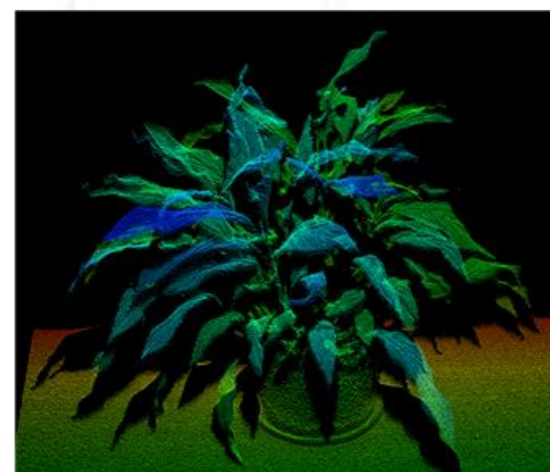
$$\boldsymbol{y}(t)' = [\boldsymbol{y}(t), \boldsymbol{m}(t) = \begin{bmatrix} x^e\ y^e\ z^e | \dot{x}^e\ \dot{y}^e\ \dot{z}^e\ | \ddot{x}^e \ddot{y}^e \ddot{z}^e | r^e p^e y^e | \\ \omega^b_{eb,x}\ \omega^b_{eb,y}\ \omega^b_{eb,z} | \dot{\omega}^b_{eb,x}\ \dot{\omega}^b_{eb,y}\ \dot{\omega}^b_{eb,z} | \boldsymbol{m}(t) \end{bmatrix}$$

Time of Flight Camera

$$\vec{X} = \overrightarrow{X_0} + R * \overrightarrow{x^*}$$

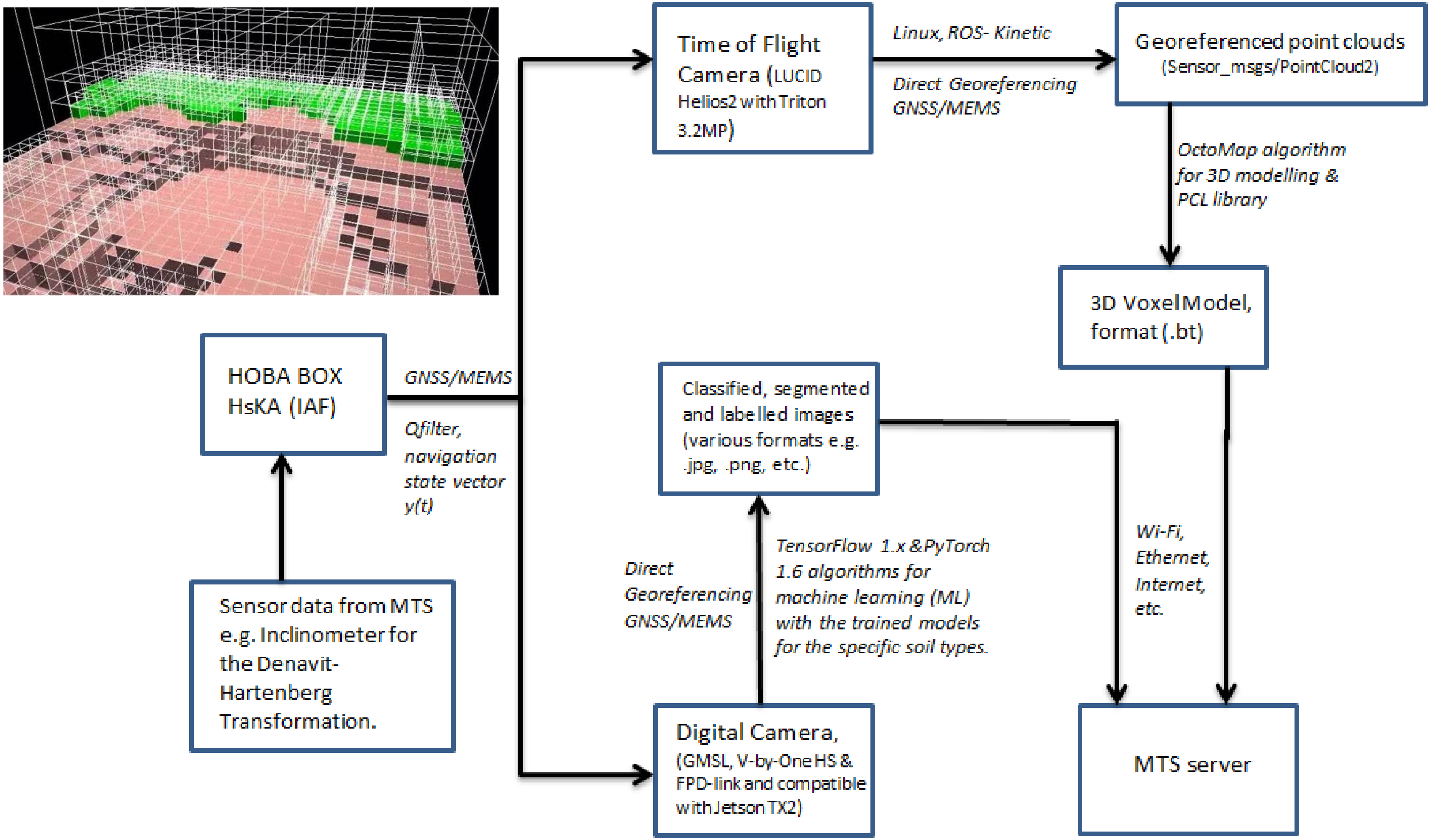






HOBA Box – Hardware, Software and Algorithms Design

Target: Realtime ITRF/ETRF89 georeferenced voxel-model with classified soils of excavation



Further Information on projects: www.navka.de