Synchronization aspects of sensor and data fusion in a research multi-sensor-system

MCG 2016, Vichy, France

5th International Conference on Machine Control & Guidance

October 5, 2016

Jens-André Paffenholz, Johannes Bureick, Dmitri Diener, Johannes Link

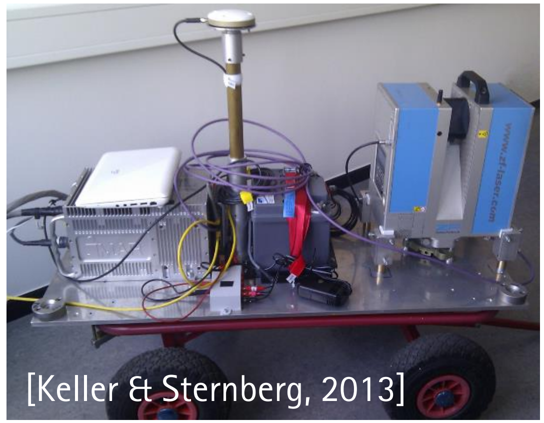
Geodätisches Institut, Leibniz Universität Hannover

- *What is common for multi-sensor-systems (MSS)?*
  - Superior goal: Efficient data capturing of the environment
  - Object capturing sensors: w.l.o.g. laser scanner
  - Referencing sensors: 3D positioning and navigation sensors
  - Use benefits of each enlisted sensor

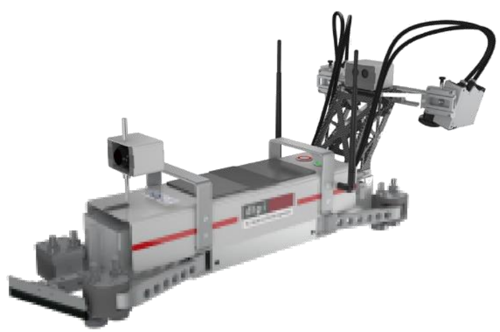
- *What is essential for the MSS?*
  1) Availability of a proper **time reference** for the acquired sensor data
  2) Mutual **spatial relation** of each enlisted sensor

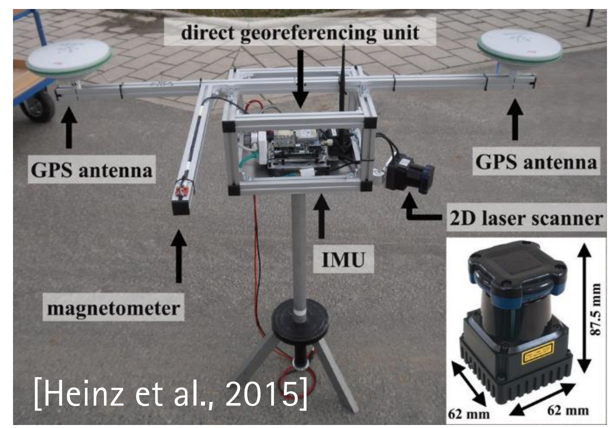
Selected (laser scanner based) multi-sensor-systems in the research community


[Nüchter et al., 2013]


[Keller & Sternberg, 2013]

[Paffenholz and Harmening, 2014]


[ARTIS, research project@GIH, 2016]



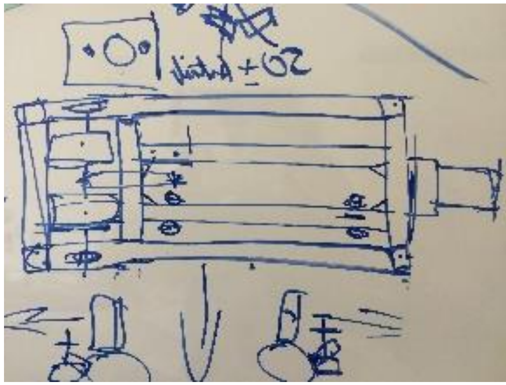
[Heinz et al., 2015]

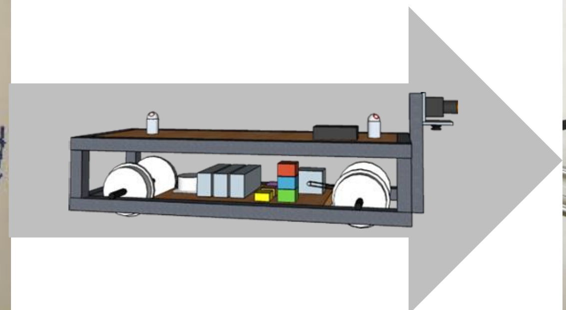
Remark: Commercial MSS are in the portfolio of nearly each manufacturer of geodetic equipment, e.g. Leica, Riegl, Trimble

Outline

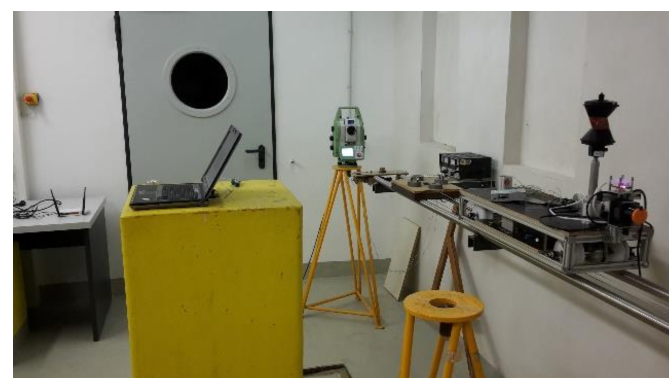
- The research multi-sensor-system
- Synchronization (temporal referencing)
  - Common time reference by means of radio communication and GPS time
- Spatial referencing (registration)
  - 6 dof calibration for a common spatial reference
- Data fusion
  - Kalman Filtering for trajectory estimation
- Conclusion & Outlook

The research multi-sensor-system (RMSS)

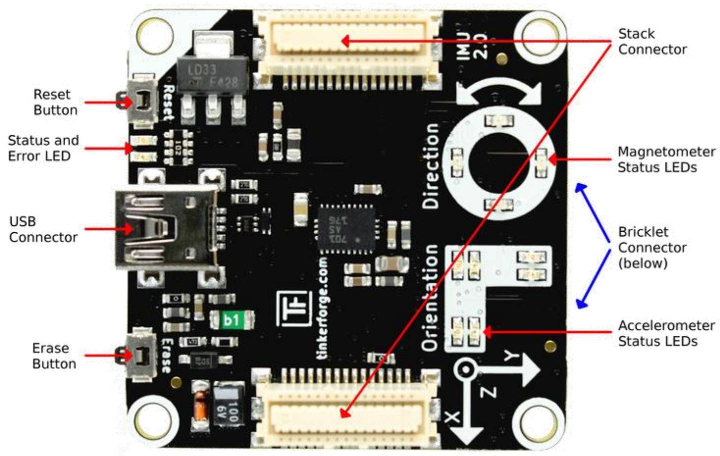




- Small-scale vehicle (LxWxH 74x25x25 cm)
- Accelerated by means of a stepper motor
- Driving autonomously on a rail in an indoor laboratory



RMSS – Referencing sensors

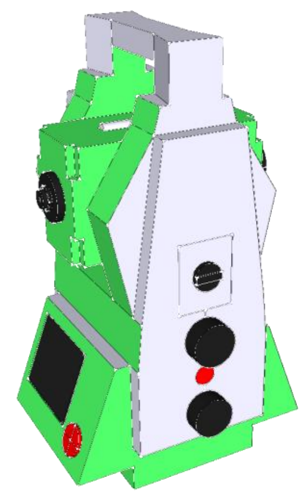


TinkerForge IMU Brick 2.0	
Acceleration, Magnetic, Angular Velocity Resolution	14 bit, 16 bit, 16 bit
Heading, Roll, Pitch Resolution	0.0625° steps
Quaternion Resolution	16 bit
Sampling Rate	100 Hz
Weight	12 g
Current Consumption	415mW (83mA @5V)

[www.tinkerforge.com, 2016]

Absolute position information

- prisms tracked by a robotic total station or a laser tracker



RMSS – Object capturing sensors

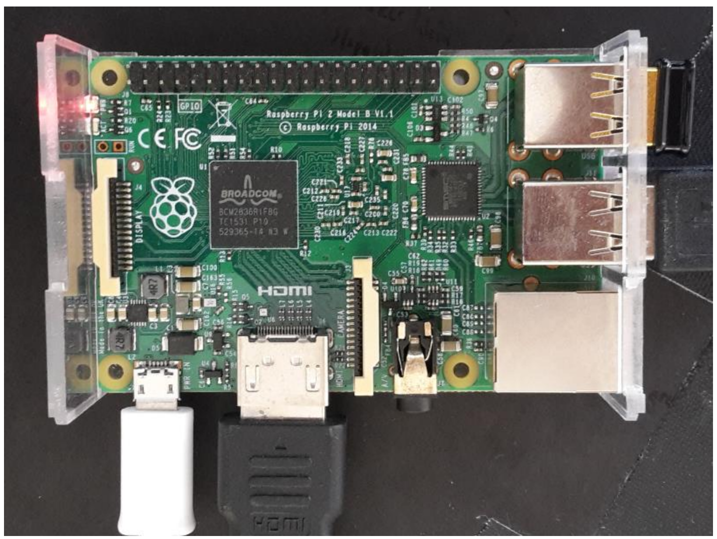
[www.robotshop.com, 2016]

[www.conrad.de, 2016]

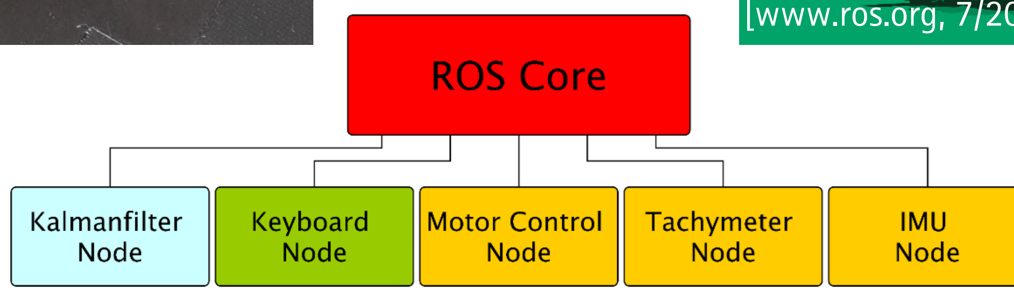
Profile laser scanner Hokuyo UST-10LX	
Range	0.06 – 10 m
Repeatability	30 mm
Absolute uncertainty	40 mm
Scan angle	270°
Angle resolution	0.25°
frequency	40 profiles/s

Raspberry Pi camera module with wide-angle lens	
Resolution	5 MP (2592 x 1944 px.)
Framerate	15 fps
Field of view	122° x 89.5°

- Single-board computer of type Raspberry Pi (RPI) 2 Model B running Ubuntu 14.04 LTS (Trusty Tahr)



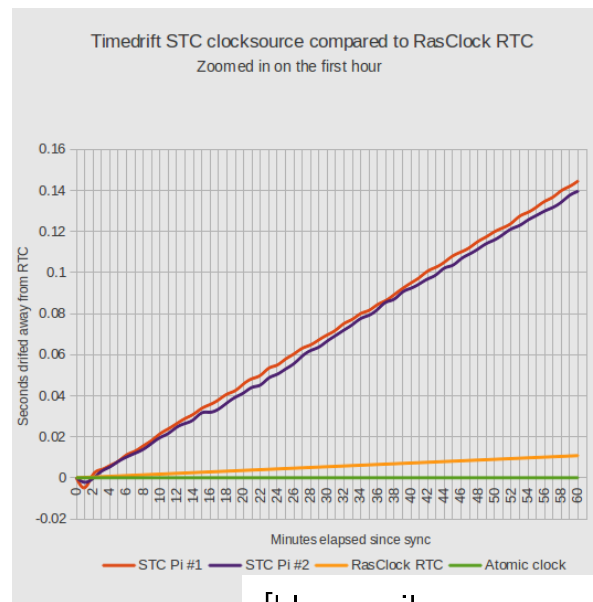
[www.ros.org, 7/2016]



- Synchronization (temporal referencing)
  - Common time scale for different data sources
  - Latency time due to imperfect synchronization

- Problem with RPI
  - Drift of built-in clock

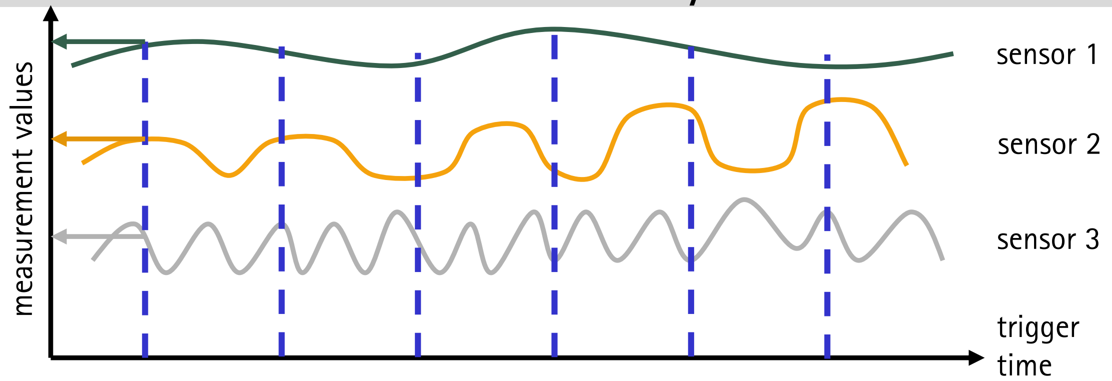
- Solution
  - External clock source
    - Radio communication DCF-77
    - GPS time



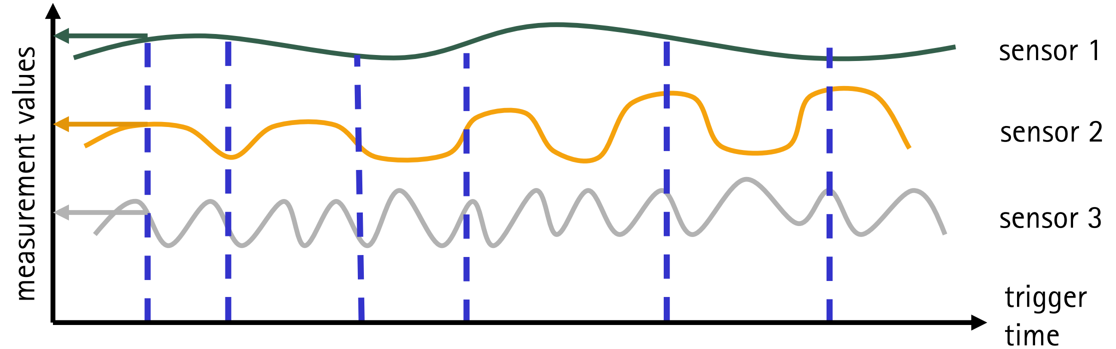
[blog.remibergsma.com]

Establishment of temporal reference
Methods of synchronization

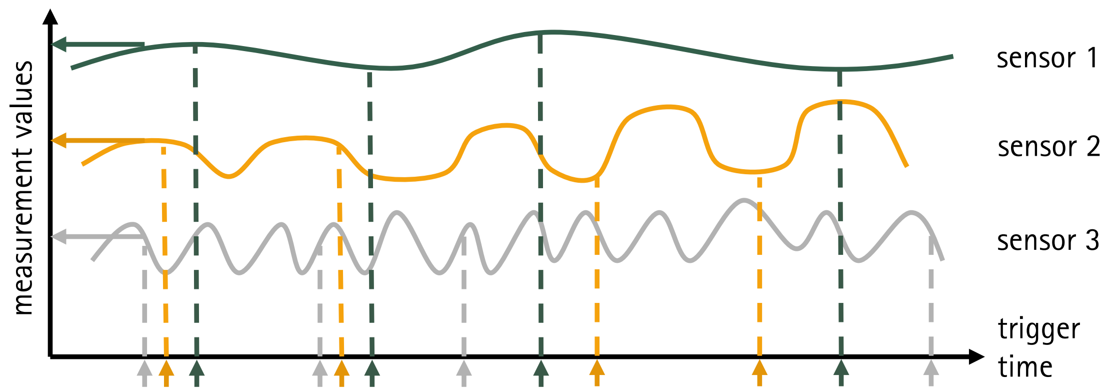
a) Clock-controlled registration



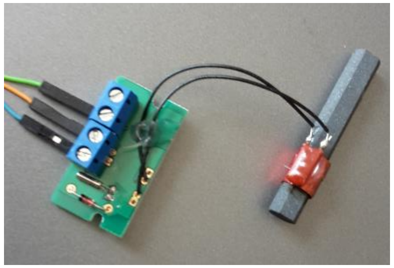
b) Event-driven registration

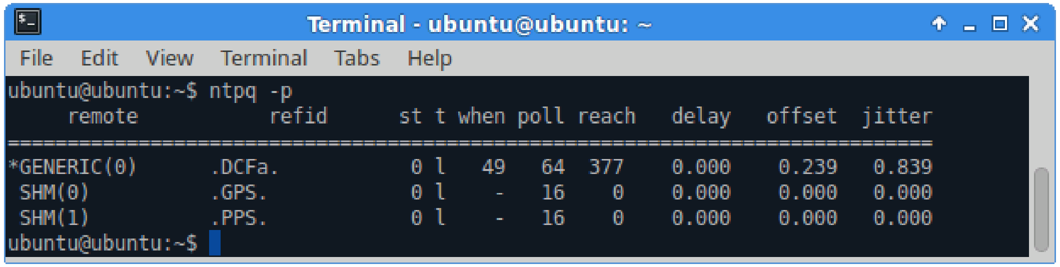


c) Event-based registration

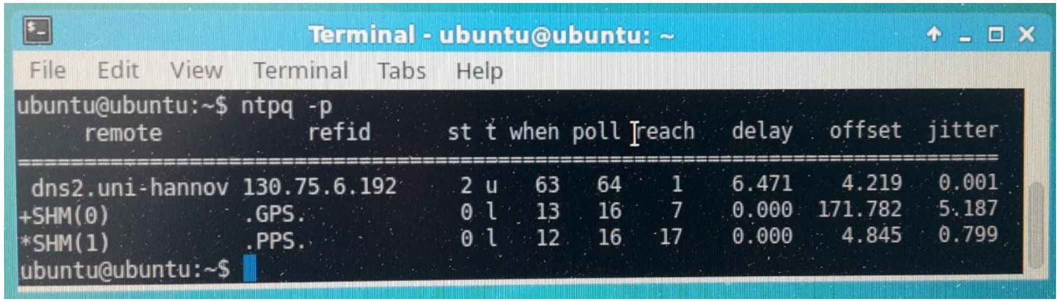


- Radio communication; DCF-77





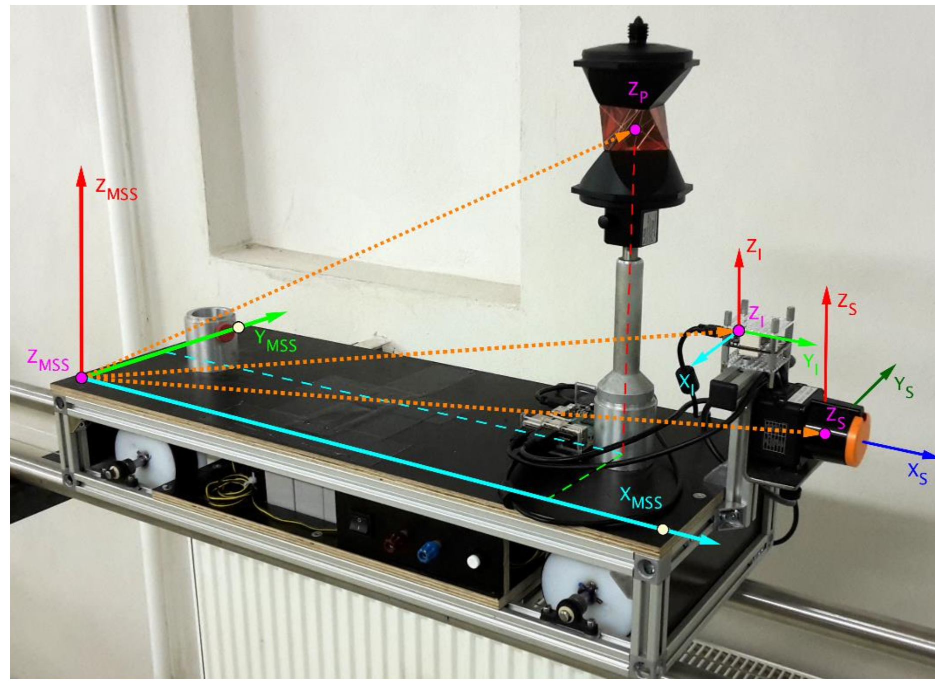
- GPS time introduced via GPIO pins of RPI



Spatial referencing (registration)

- Definition of RMSS coordinate system (body frame, BF)

- Sensor coordinate systems
  - External tracking (prism)
  - IMU
  - Laser scanner

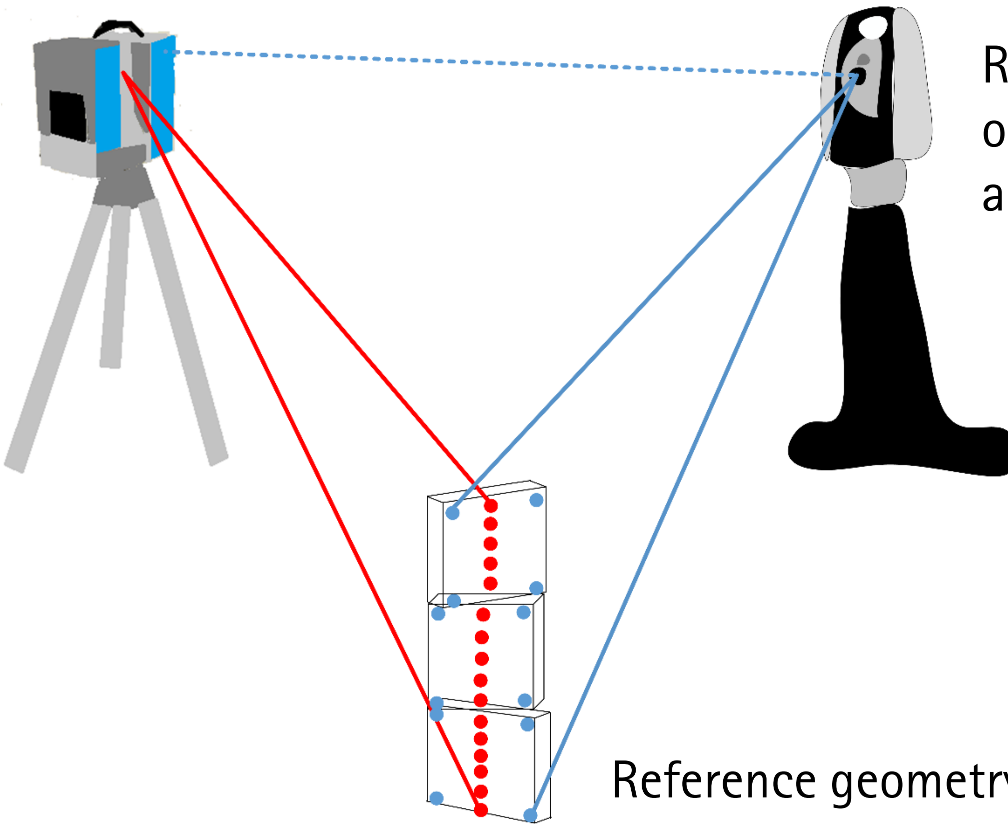


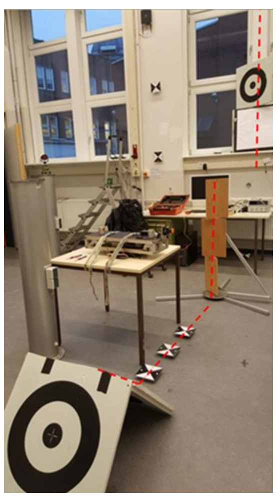
- System calibration to obtain the spatial reference
  - Pose: position and orientation estimation of individual sensors in BF

Spatial referencing (registration)
Approach for pose estimation of laser scanner in BF

Laser scanner (LS)

Reference sensor of superior accuracy (LT)





Reference geometry (RG)

- Approach according to Strübing & Neumann (2013)

Functional relation (Gauß-Helmert model)

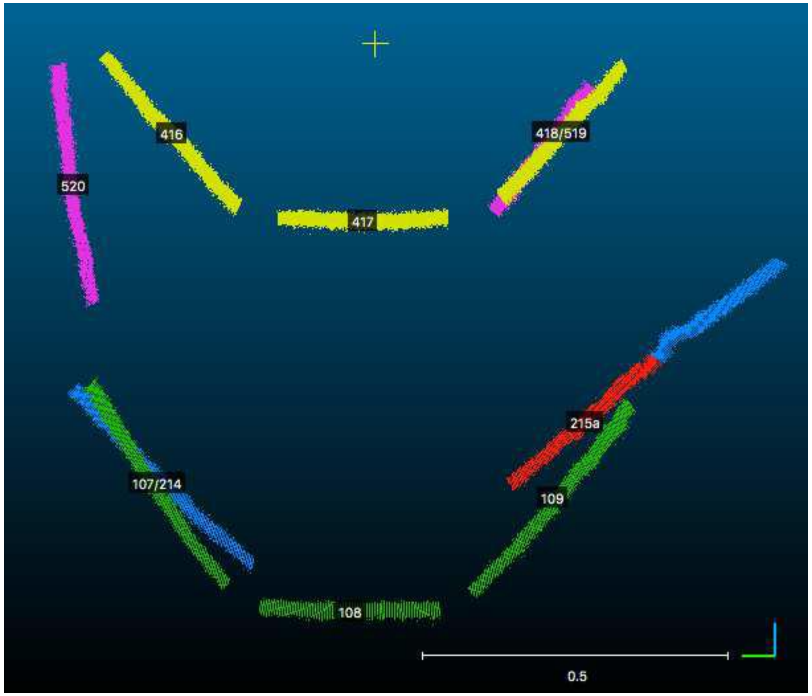
$$\begin{bmatrix} \mathbf{x}_{BF} \\ \boldsymbol{y}_{BF} \\ \boldsymbol{z}_{BF} \end{bmatrix} = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} + R_x(\omega)R_y(\varphi)R_z(\kappa) \begin{bmatrix} \mathbf{x}_{LS} \\ \boldsymbol{y}_{LS} \\ \boldsymbol{z}_{LS} \end{bmatrix}$$

$$\mathbf{w} = n_x \mathbf{x}_{BF} + n_y \boldsymbol{y}_{BF} + n_z \boldsymbol{z}_{BF} - \mathrm{d}$$

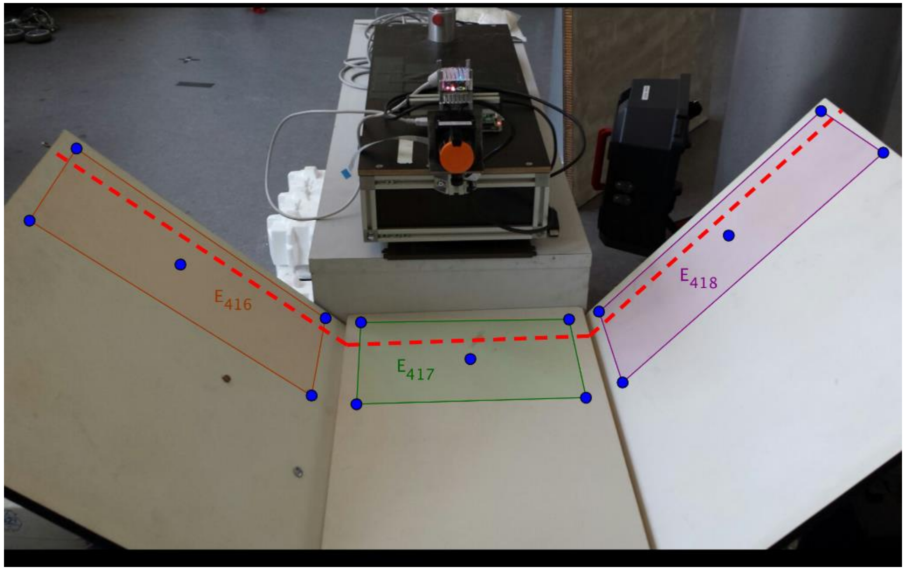
- Input:
  - Laser scanner measurements $[\mathbf{x}_{LS}, \boldsymbol{y}_{LS}, \boldsymbol{z}_{LS}]$ to the RG-planes as observations
  - Estimated plane parameters $\left[n_x, n_y, n_z, d\right]$ of the RG-planes measured with the reference sensor (here laser tracker)
- Output:
  - 6 dof: translations t_x, t_y, t_z and rotations ω, φ, κ of the laser scanner

- All parameter sensitive for light changes in the measured data
- Tricky for translation across scanning plane (parameter x)

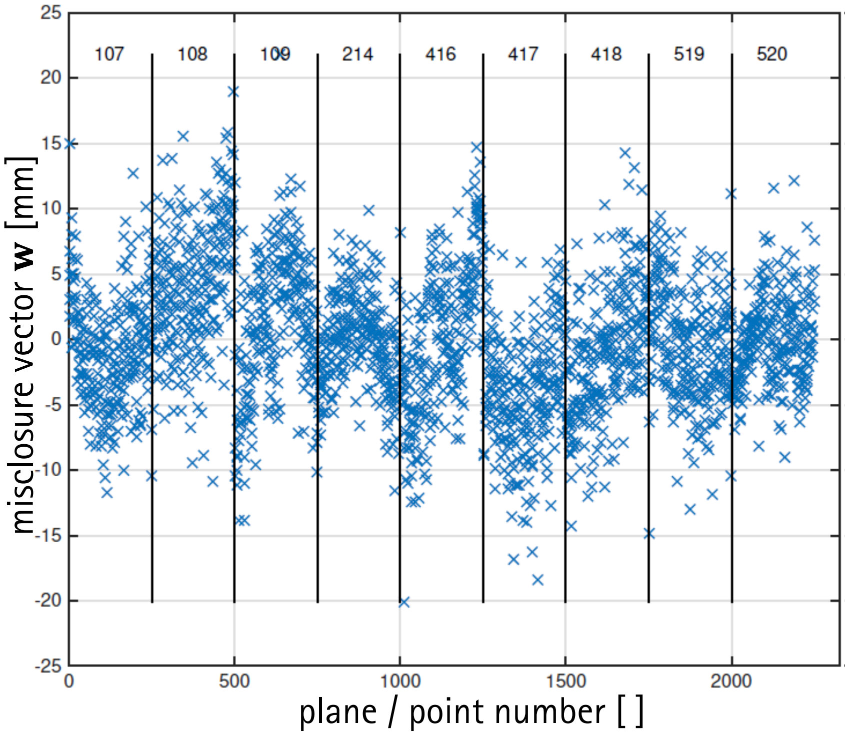
Spatial distribution of the planes



Selected view of plane configuration



Misclosure vector of the adjustment ($\mathbf{w}$)

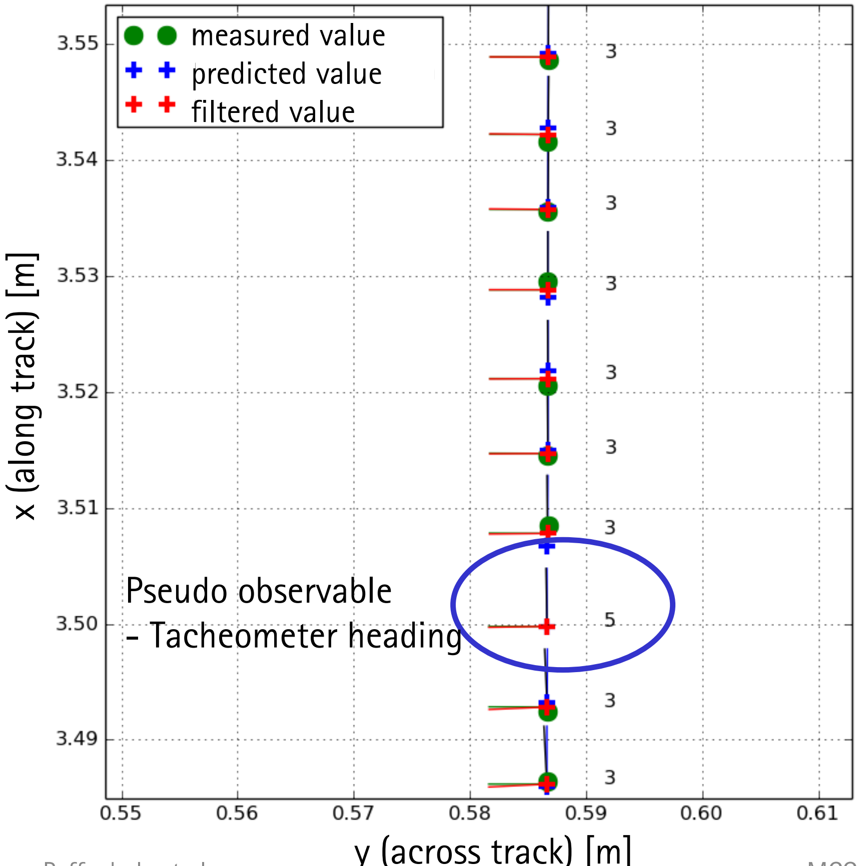


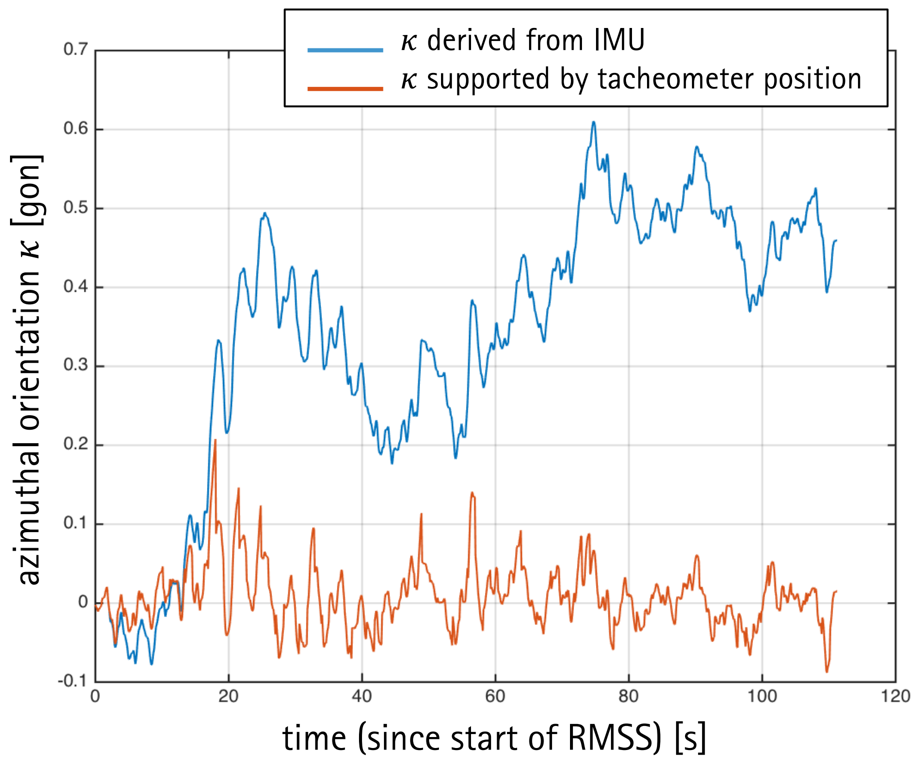
Numerical results for parameter

Parameter	$\hat{x}$	$\sigma_{\hat{x}}$
x [mm]	710.52	0.85
y [mm]	96.79	0.23
z [mm]	63.73	0.16
ω [gon]	-0.198	0.037
φ [gon]	-1.798	0.086
κ [gon]	+0.660	0.104

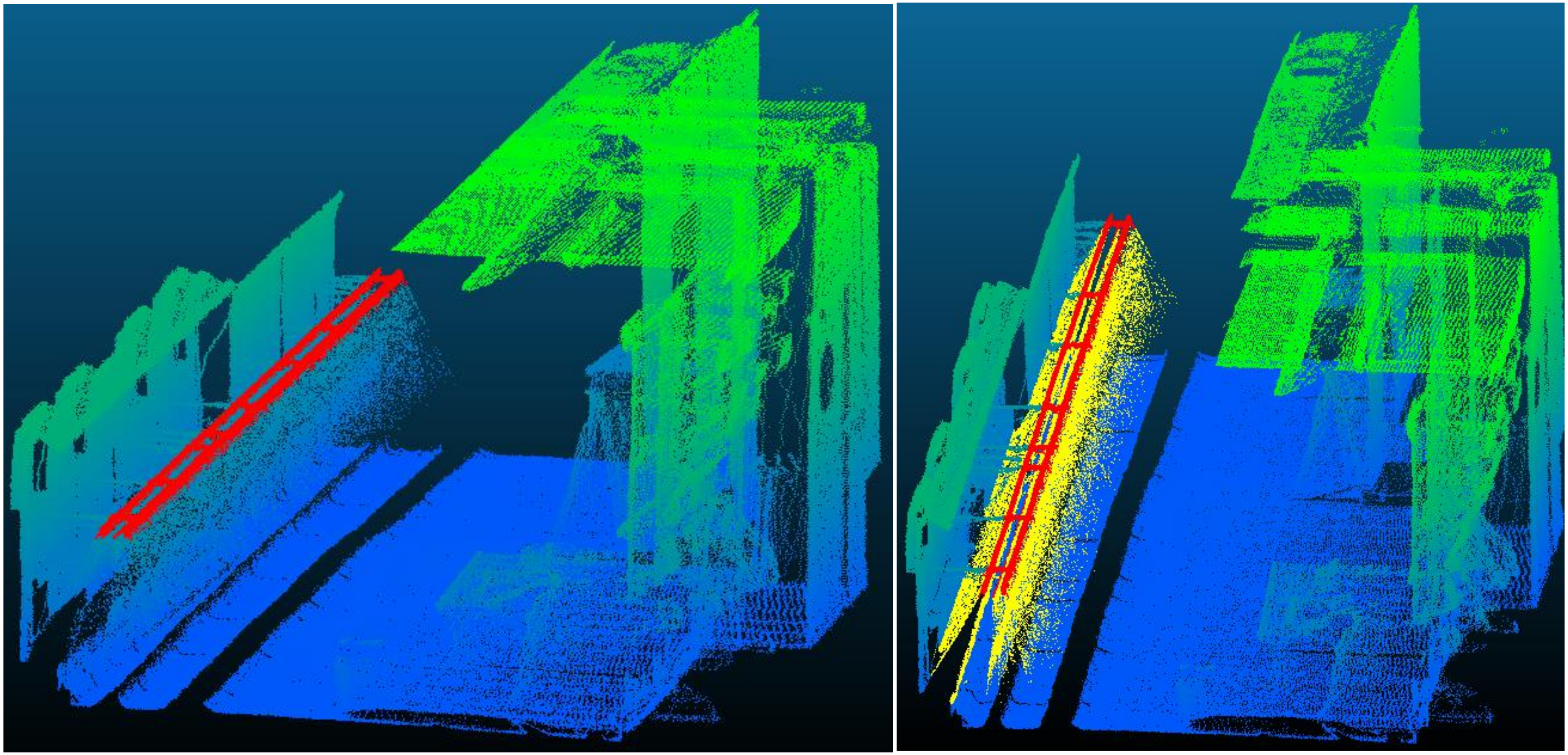
State vector: Position, Orientation and Velocity of the RMSS

Observation vector: IMU, tacheometer and Pseudo observations





Resulting 3d point cloud of RMSS of indoor laboratory situation



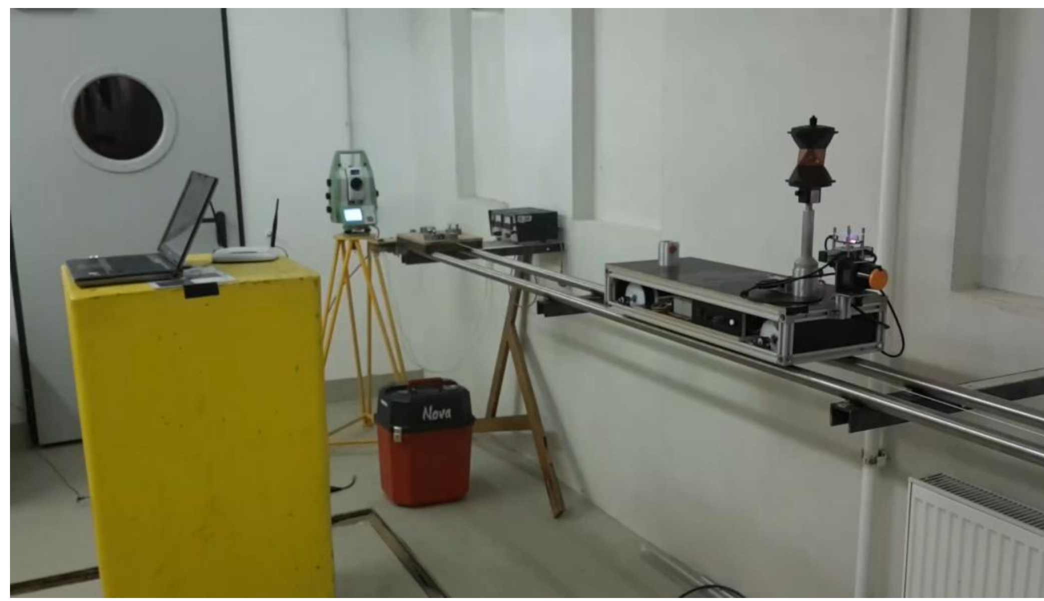
Colour scheme

- Z-value from blue to green
- Rail highlighted in red
- Deflected pixel area close to the rails in yellow

Conclusion & Outlook

- Conclusion
  - Synchronization of different sensor data
  - Spatial referencing: pose estimation of laser scanner
  - Data fusion within Kalman filter

- Outlook
  - Improvement of ROS-node implementation
  - In-depth analysis of stratum-0 time server implementation on RPI



Thank you for your attention.

Synchronization aspects of sensor and data fusion in a research multi-sensor-system




Dr.-Ing. Jens-André Paffenholz, Johannes Bureick, M.Sc., Dmitri Diener, B.Sc., Johannes Link, B.Eng.

Geodätisches Institut, Leibniz Universität Hannover

paffenholz@gih.uni-hannover.de | www.gih.uni-hannover.de