Robust spatial approximation of laser scanner point clouds by means of free-form curve and surface approaches

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G05 GNSS++: Emerging Technologies and Applications

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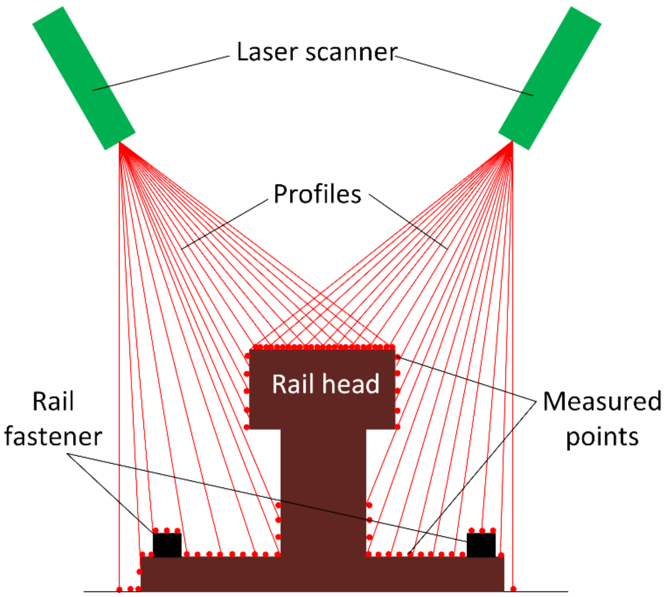
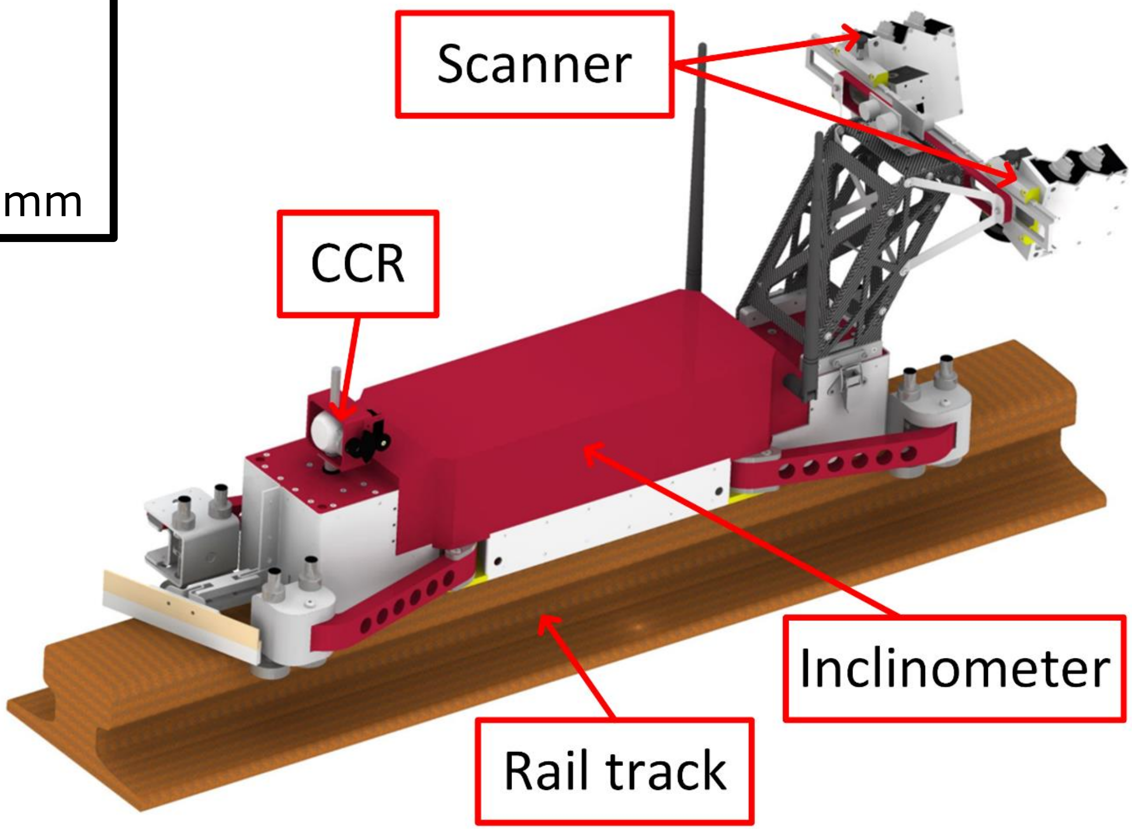
Johannes Bureick, Hamza Alkhatib and Ingo Neumann

Geodetic Institute, Leibniz Universität Hannover, Germany

Advanced Rail Track Inspection System

Key figures
Speed: 1 m/s
Frequency scanner: 200 Hz
Frequency tracker: 1000 Hz
Point distance (along): < 5 mm
Point distance (across): < 0.22 mm

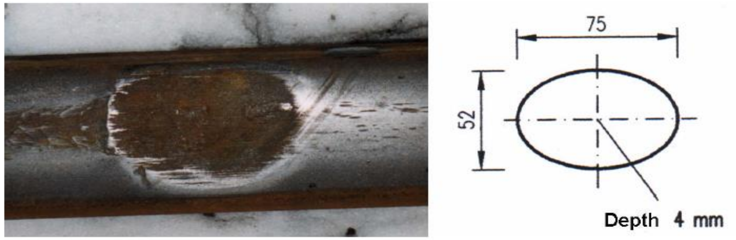




Motivation

- **Uncertainty requirements**
  - Position and height of the rail track < 0.5 mm
  - Surface defects < 0.2 – 0.5 mm
- **Data characteristic**
  - Profile-wise kinematic measurements
  - Data gaps
  - 3D representation
- **Algorithms / Parametrization**
  - Approximate point cloud
  - Identify deformations
  - Cope with uncertainty requirements and data characteristic

Head Checks (Source: Dey et al., 2009)



Wheel-Slip (Source: Tagungsbericht Internationales Symposium „Schienenfehler“, 2000)

B-Splines

Agenda

- Motivation
- Mathematical basics – approximation
- Modification parameters / Related work
- Methodology
- Results
- Summary / Outlook

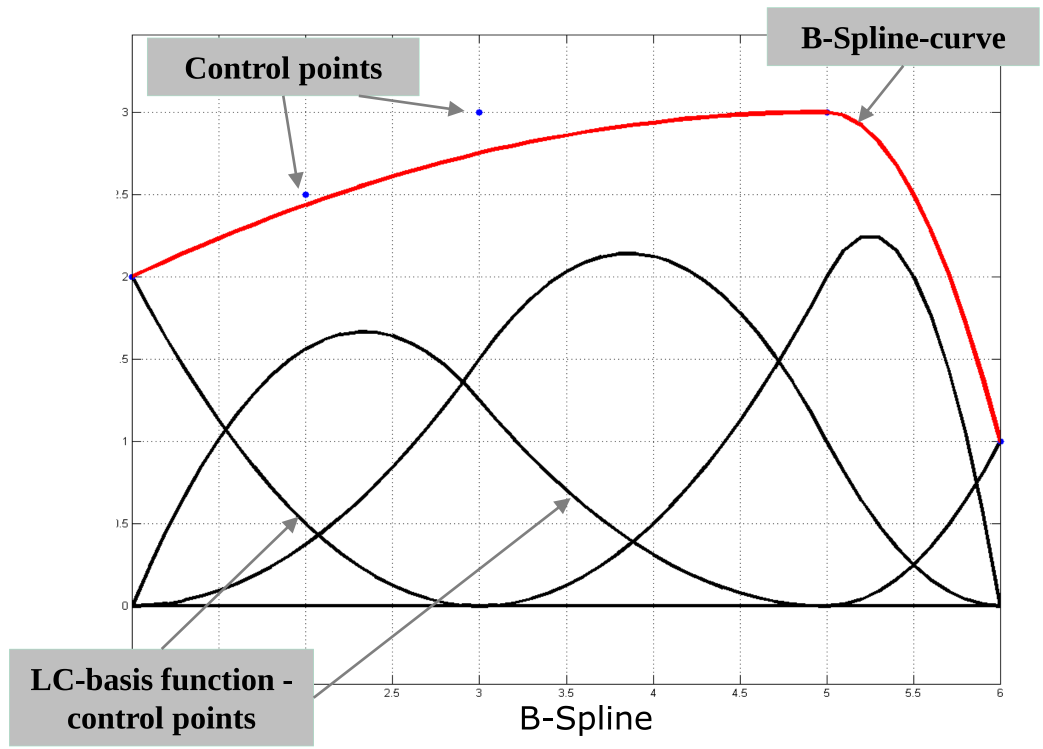
Mathematical basics - approximation

Parametric curve approximation: B-Spline

- Functional relation: piecewise polynomial function

$$\mathbf{x}(u) = \begin{bmatrix} x(u) \\ y(u) \end{bmatrix} = \sum_{i=0}^{n} N_{i,p}(u)\mathbf{p}_i, \quad u_{\min} \le u < u_{\max}$$

- Curve-point $\mathbf{x}(u)$
- Basis function $N_{i,p}(u)$
- Control point $\mathbf{p}_i$
- Location parameter u



Mathematical basics - approximation

- $N_{i,p}(u)$: basis function of degree p; recursive function:

$$N_{i,0}(u) = \begin{cases} 1, & u_i \leq u < u_{i+1} \\ 0, & else \end{cases}$$

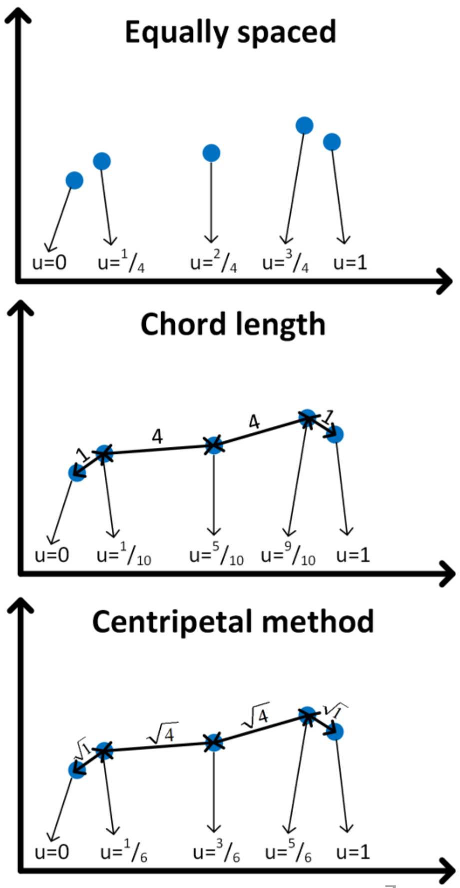
$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u)$$

- Location parameter u → $u_i \leq u < u_{i+1}$
- Knotvector $U = [u_{min},\dots,u_{min},\dots,u_i,u_{i+1},\dots,u_{max},\dots,u_{max}]$

- Gauss-Markov-Model (cf. Piegl and Tiller 1997 and Koch 2009):
  - Parameter: Control points $\mathbf{p}_i$
  - Observations: Measured laserscanner points $\mathbf{x}(u)$
  - Design matrix: Consists of basis functions $N_{i,p}(u)$

Modification parameters / Related work

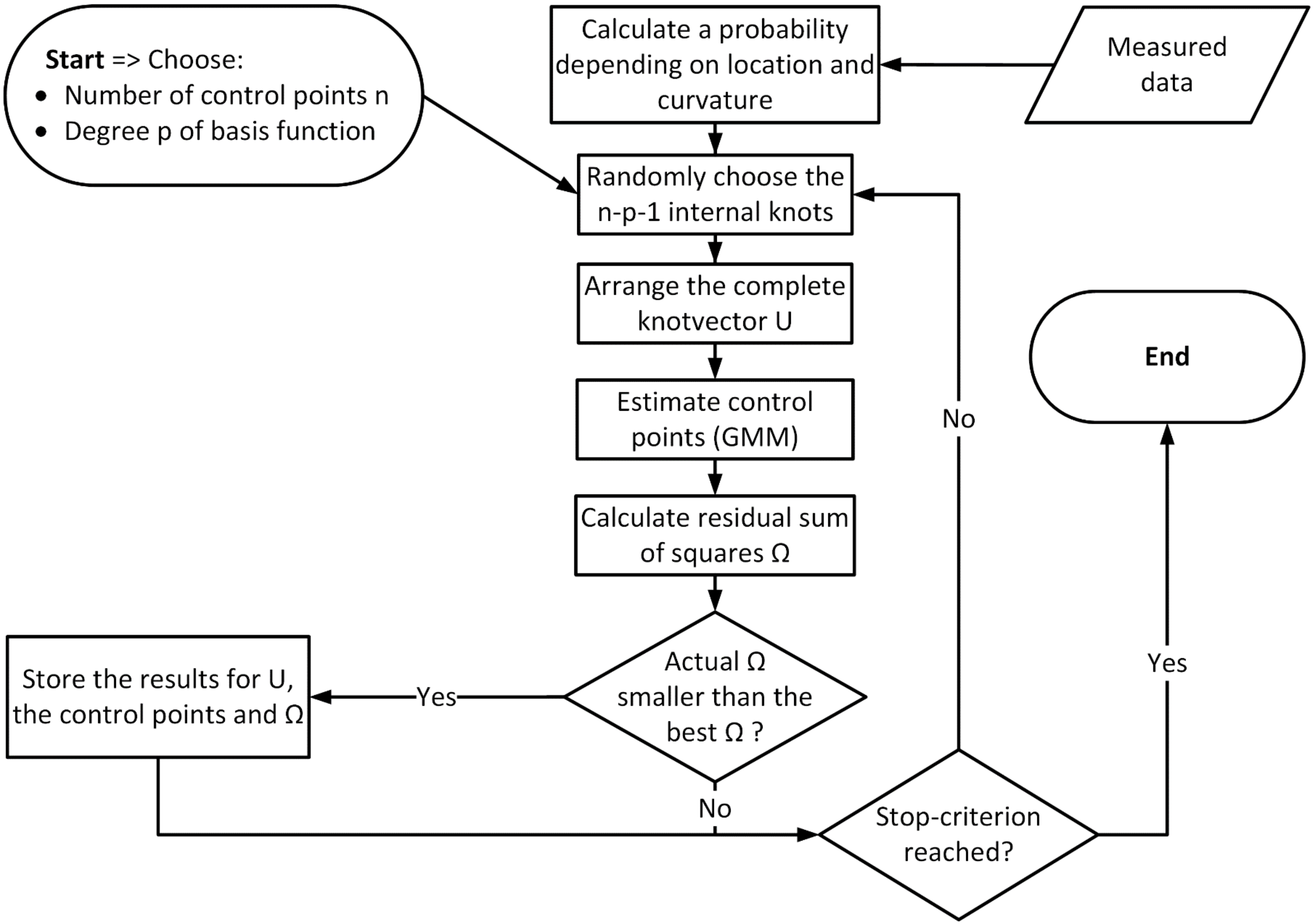
- Determination of basis function degree and number of control points
  - Model selection problem (cf. Burnham and Anderson 2002):
    - Information criterion
    - Significance test
- Location parameter u of the measured points
  - Choice (cf. Piegl and Tiller 1997)
    - Equally spaced
    - Chord length
    - Centripetal method
  - Estimation (cf. Lai and Lu 1996)



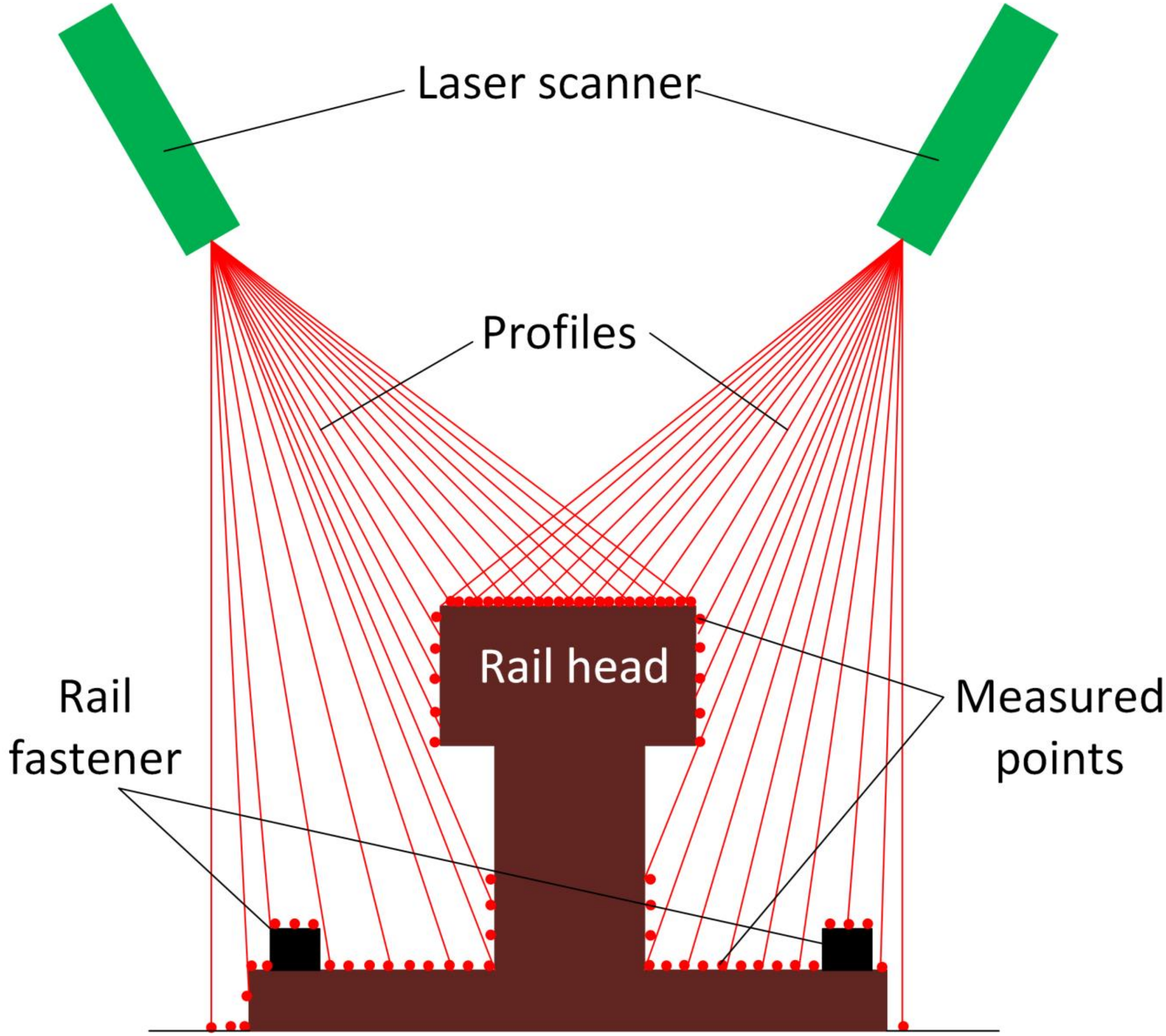
Modification parameters / Related work

- Determination of knotvector
  - Alignment to location parameter (cf. Piegl and Tiller 1997) **Basic**
  - Alignment to curvature of measured points (cf. Park and Lee 2007)
  - Estimation (cf. Schmitt and Neuner 2015)
  - Our approach:
    - Monte-Carlo-Method with probabilites depending on location and curvature **MCM**
- Estimation of control points
  - Estimator
    - Least squares (cf. Koch 2009)
    - M-estimator (Huber-, Hampel-)
    - L1-norm-estimator
  - Random sample consensus algorithm (RANSAC)

Methodology MCM

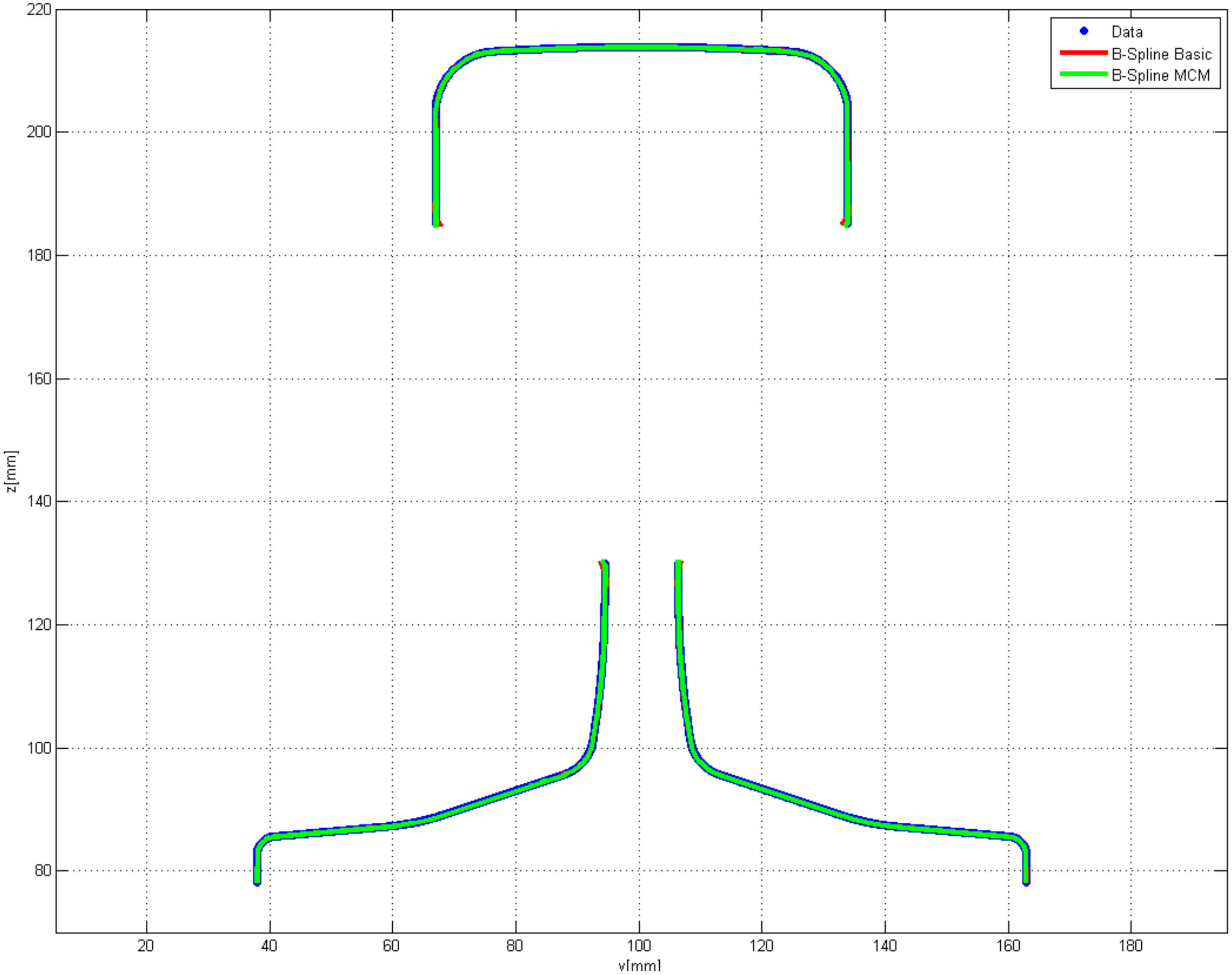


Results

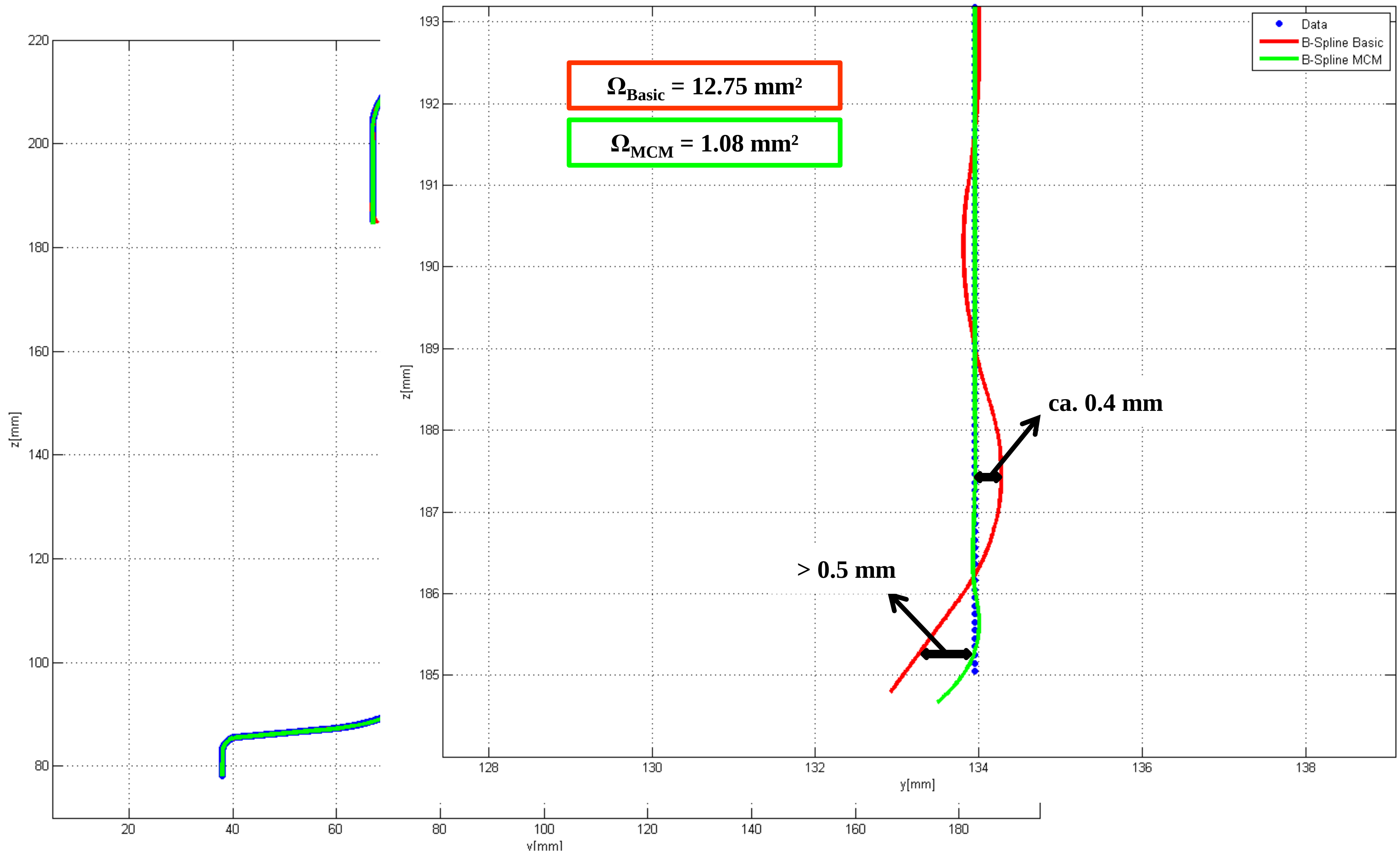


Laser scanner
Profiles
Rail head
Rail
fastener
Measured
points

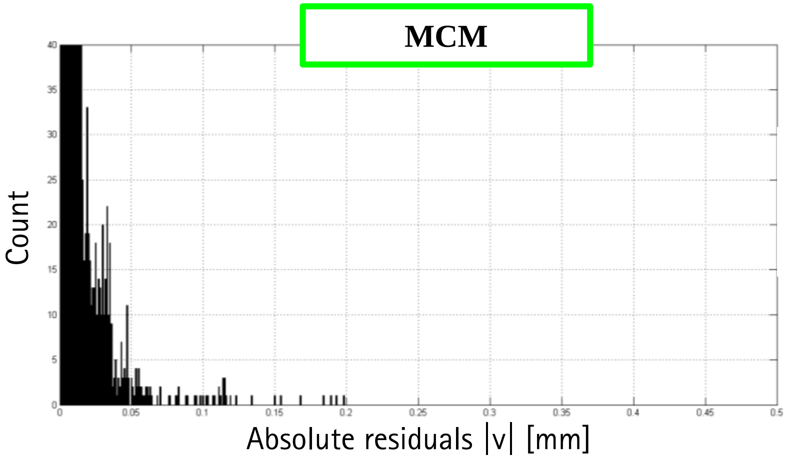
Results

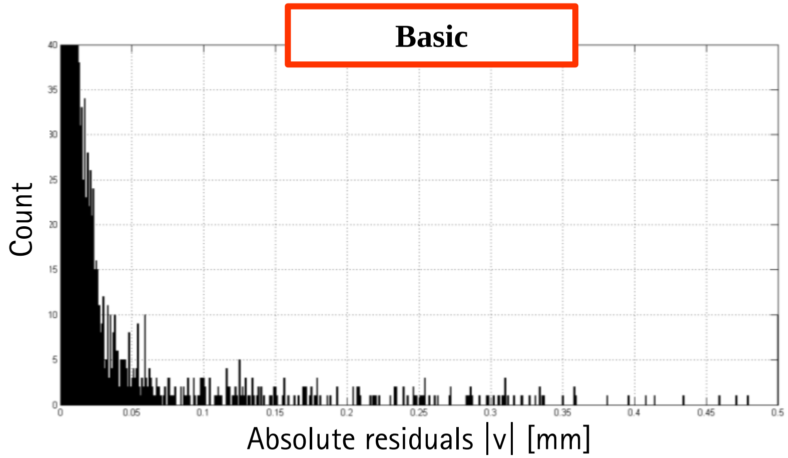


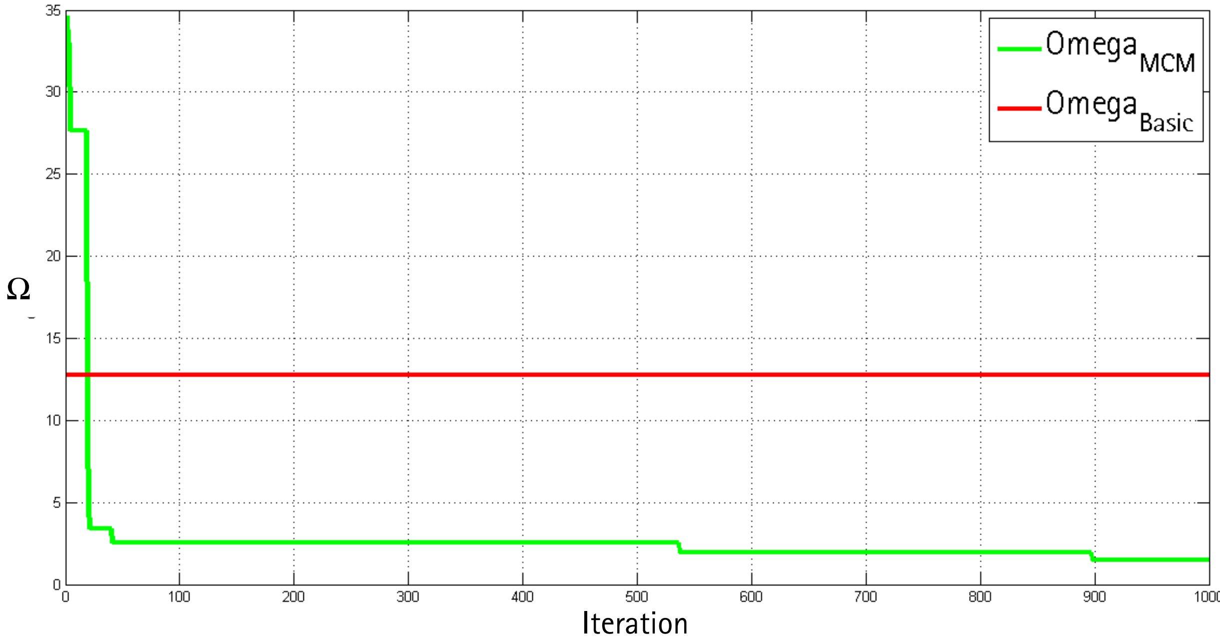
Degree: p = 2
Control points: n = 100



Ω_Basic = 12.75 mm²
Ω_MCM = 1.08 mm²
ca. 0.4 mm
> 0.5 mm
Data
B-Spline Basic
B-Spline MCM
z[mm]
y[mm]
193
192
191
190
189
188
187
186
185
128
130
132
134
136
138
220
200
180
160
140
120
100
80
20
40
60
80
100
120
140
160
180


MCM
Count
Absolute residuals |v| [mm]


Basic
Count
Absolute residuals |v| [mm]


Omega MCM
Omega Basic
Ω
Iteration
0 5 10 15 20 25 30 35
0 100 200 300 400 500 600 700 800 900 1000

Summary/Outlook

- For same number of parameters MCM obtains significant better results
  - Especially when data gaps occur
- Computational cost is higher
- Applicable for modelling of the local earth gravity field?

- Extension to B-Spline surfaces
- Integration of further prior knowledge
  - CAD-Modell
  - Previous profiles / measurements

Leibniz Universität Hannover

Thank you for your attention.

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M.Sc. Johannes Bureick, Dr.-Ing. Hamza Alkhatib and Prof. Dr.-Ing. Ingo Neumann

Geodetic Institute, Leibniz Universität Hannover, Germany

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

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