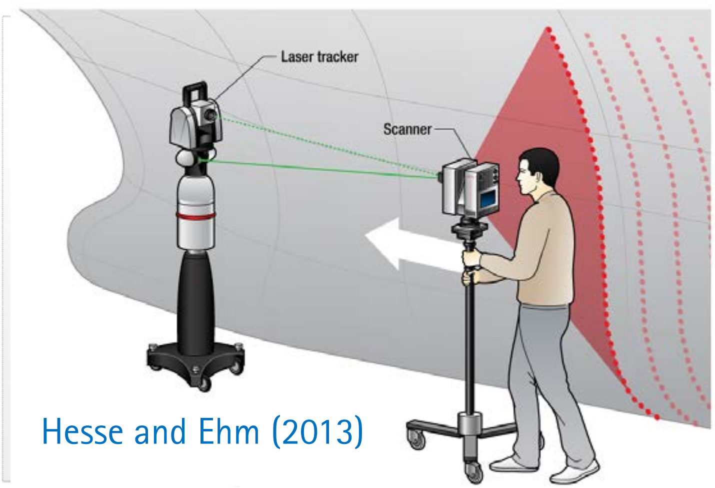
Introduction of the Geodetic Institute

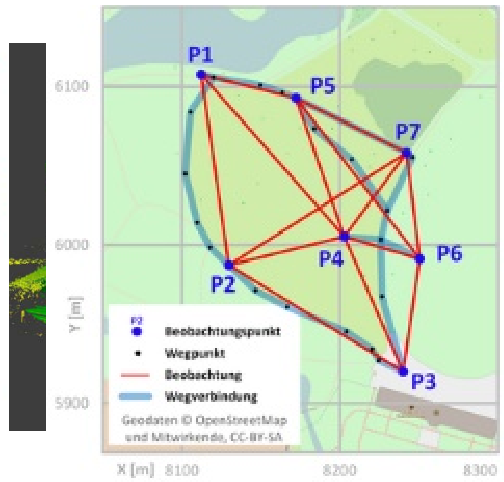
New generation of MSS

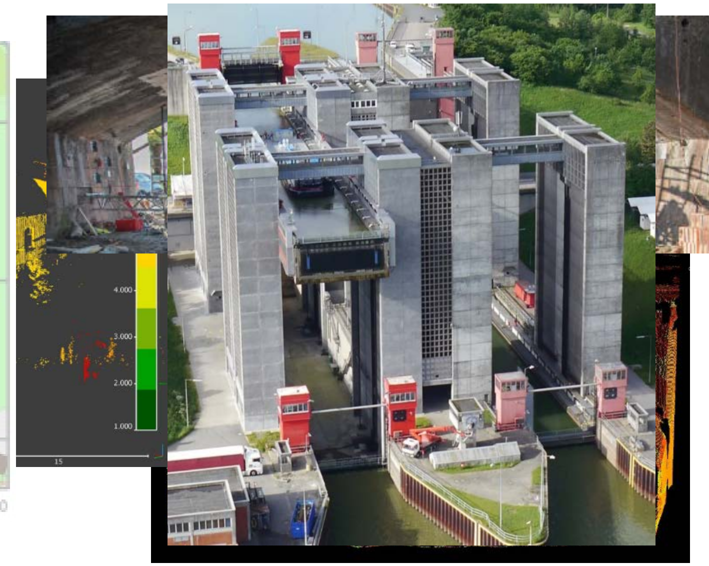
Expert based data analysis and quality processes

Interdisciplinary monitoring



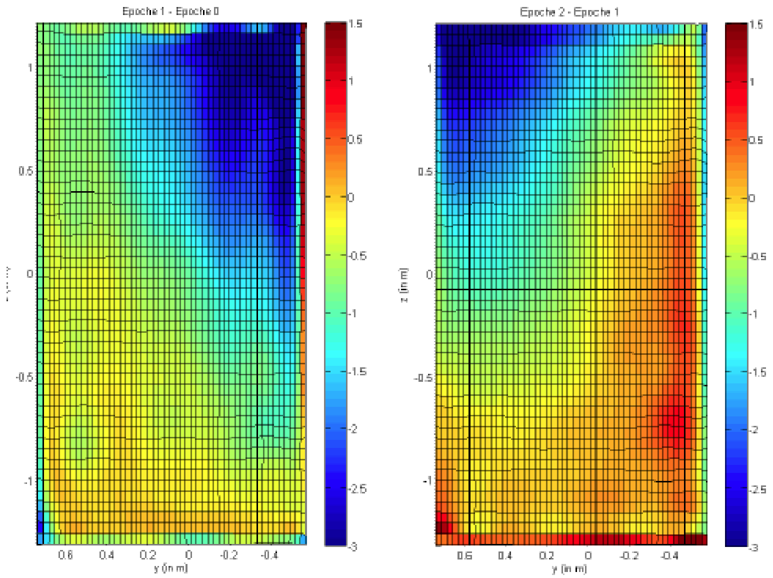
Hesse and Ehm (2013)

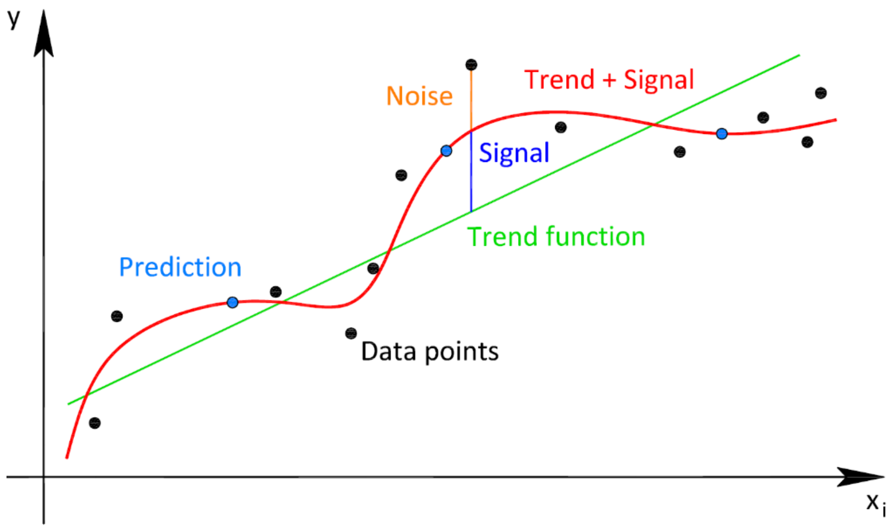




Engineering Geodesy and Geodetic Data Analysis

- Professorship since 01.01.1882 / 1927
- ca. 25 colleagues
- Head: Univ.-Prof. Dr.-Ing. I. Neumann





On the Methodology of Surface based Monitoring of Arbitrary Objects

4th of May 2019 in Tehran

I. Neumann

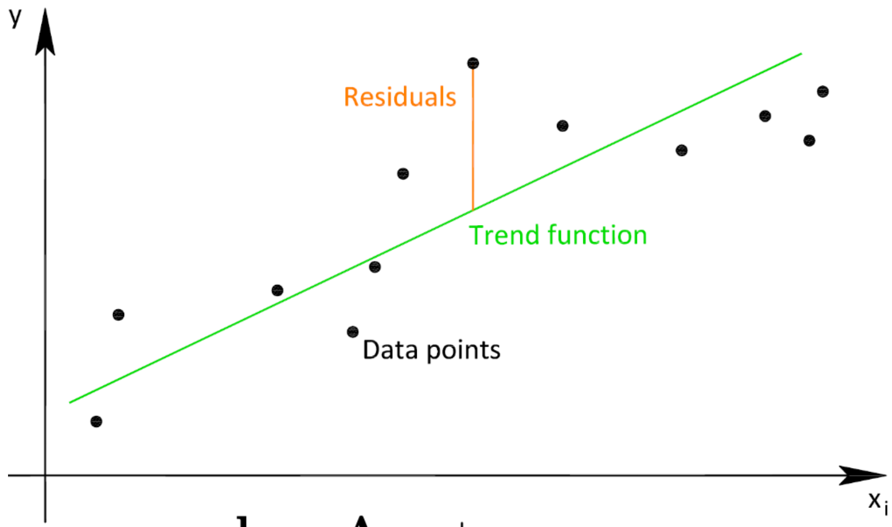
Geodetic Institut- Leibniz University Hannover

Characteristics of nowadays monitoring measurements

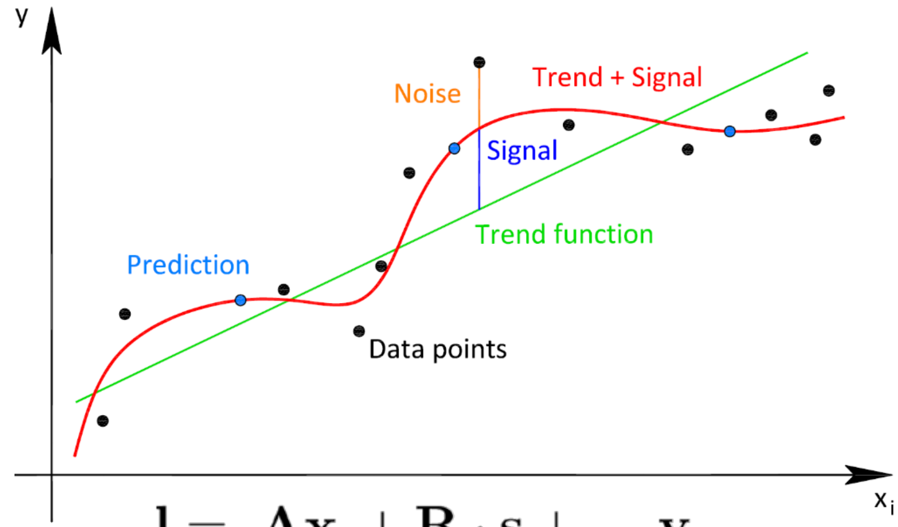
- Very detailed (surface based) 3D-measurements of objects
  - Laser scanning
  - Photogrammetry
  - (In)SAR, etc.
- Probability and number of outliers rises
  - Reflections
  - Automated processing
  - Even small percentages of outliers lead to large absolute numbers
- Quality aspects
  - Reliability of individual points is not given
  - Accuracy of individual points questionable
  - Generally often no quality values for measurements available

➡ New Methods of data analysis necessary!

Motivation



$$\mathbf{l} = \underbrace{\mathbf{Ax}}_{\text{Trend}} + \underbrace{\mathbf{v}}_{\text{Rauschen}}$$



$$\mathbf{l} = \underbrace{\mathbf{Ax}}_{\text{Trend}} + \underbrace{\mathbf{R}\cdot\mathbf{s}}_{\text{Signal}} + \underbrace{\mathbf{v}}_{\text{Rauschen}}$$

Deterministic methods : Trend paramters are estimated based on an adjustment (e.g. polynomials of higher order, B-Splines, …)

Stochastic methods :

Modelling of an additional signal (Collocation, Kriging,…)

Main content of the talk!

Agenda

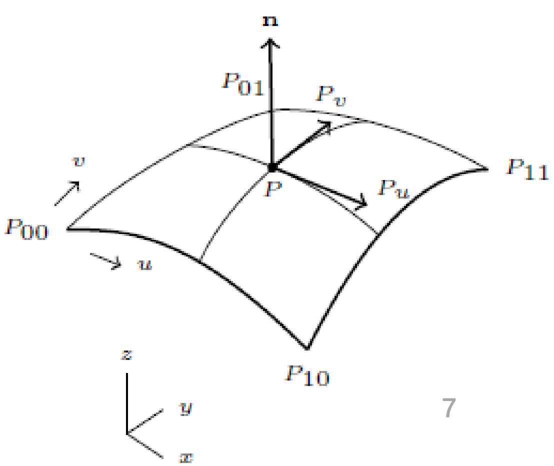
- Motivation
- **Deterministic surfaces (B-Splines)**
- Application examples
- Summary

Circumstances:

- **Irregular** distributed point clouds, e.g. 3D laser scanning
- **Continuous** representation of the object necessary
- Task: Surface reconstruction based on a stochastic point cloud
- **Filtering and Prediction!**
- Criteria for the selection of the surface representation
  - Accuracy
  - Consistency
  - Local support or adaptivity

Methodology of surface representations

- Two categories:
  1) Implicit functions: $f(x,y,z) = 0$
  2) Explicit or parametric representation: $x=f(u,v)$; $y=f(u,v)$; $z=f(u,v)$;
     - Bézier surfaces
     - B-Spline surfaces
     - Non-uniform rational B-Spline surfaces (NURBS)
- Advantages of the explicit representation:
  1) Correct point localization on the surface
  2) Partitioning of the object possible
  3) Handling of large datasets (recursion!!!)

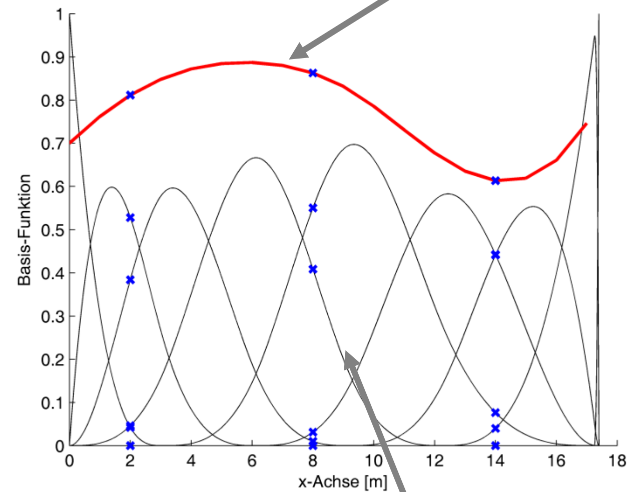


Parametric surface paramterization: B-Spline

- Functional model: Piecewise polynomial functions

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

$$\mathbf{x}(u) = \begin{bmatrix} x(u) \\ y(u) \end{bmatrix}$$



- P_i: Control points
- $N_{i,p}(u)$: Basis function of order p; rekursive calculation:

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

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

Parametric surface paramterization: B-Spline

- Extension to tensor product surface P(u,v)
  - Order of curves j and k is defined

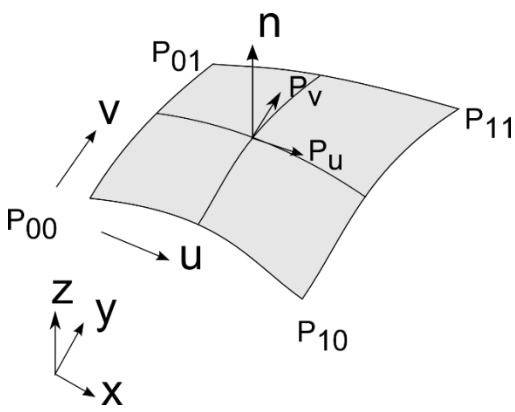
$$S(u,v)=\sum_{i=0}^{m}\sum_{j=0}^{n}P_{i,j}N_{i,k}(u)N_{j,l}(v)$$

$$U=\{u_1,u_2,...,u_{m+k}\}\text{ und }V=\{v_1,v_2,...,v_{n+l}\}$$

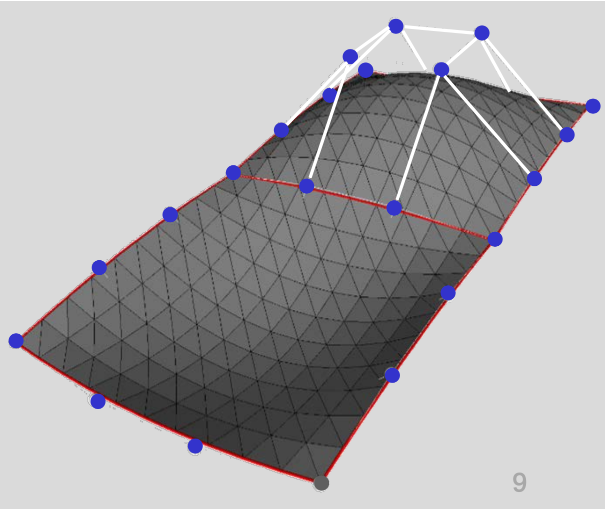
  - Control points $P_{i,j}$ span a bi-directional control point network
  - Bézier surces as a special case:
    - Bernstein polynomials $N_{i,k}(u)$ und $N_{jl}(v)$

$$N_{i,k}(u)=\frac{n!}{i!(n-i)!}u^i(1-u)^{n-i}$$

$$N_{j,l}(v)=\frac{l!}{j!(l-j)!}v^j(1-v)^{l-i}$$



x=f(u,v) y=f(u,v) z=f(u,v)



B-Spline Approximation

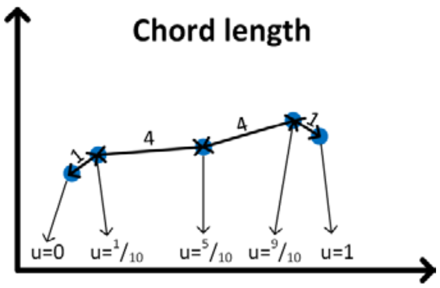
Determination of n and p

- Model selection problem[1]
- Information criterion[2]
- Significance test[3]
- VC Dimension[11]

See:
- [1]Burnham & Anderson (2002)
- [2]Gálvez et al. (2015)
- [3]Liu & Wang (2004)
- [11]Harmening & Neuner (2016)
- …

Location parameter $\bar{u}$

- Choice[4]
  - Equally spaced
  - Chord length
  - Centripetal method
- Estimation[5]



See:
- [4]Piegl & Tiller (1997)
- [5]Lai & Lu (1996)
- …

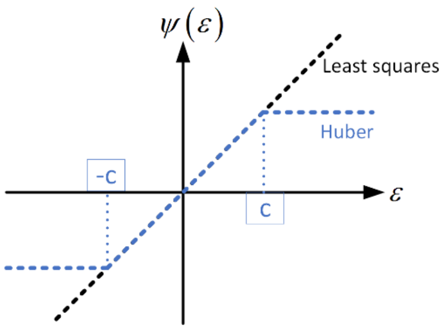
Knotvector U

- Align to $\bar{u}$ [4]
- Align to curvature[6]
- Estimation[7]
- Genetic algorithms[8]
- Artificial Immune systems[2]
- Estimation of distribution[9]
- Evolutionary Monte Carlo Method[12]

See:
- [4]Piegl & Tiller (1997)
- [6]Park & Lee (2007)
- [7]Schmitt & Neuner (2015)
- [8]Yoshimoto et al. (1999)
- [2]Gálvez et al. (2015)
- [9]Zhao et al. (2011)
- [12]Bureick et al. (2016)
- …

Estimation of control points P

- Least squares[4,10]
- M-estimators[12]
- L1-norm-estimator
- RANSAC



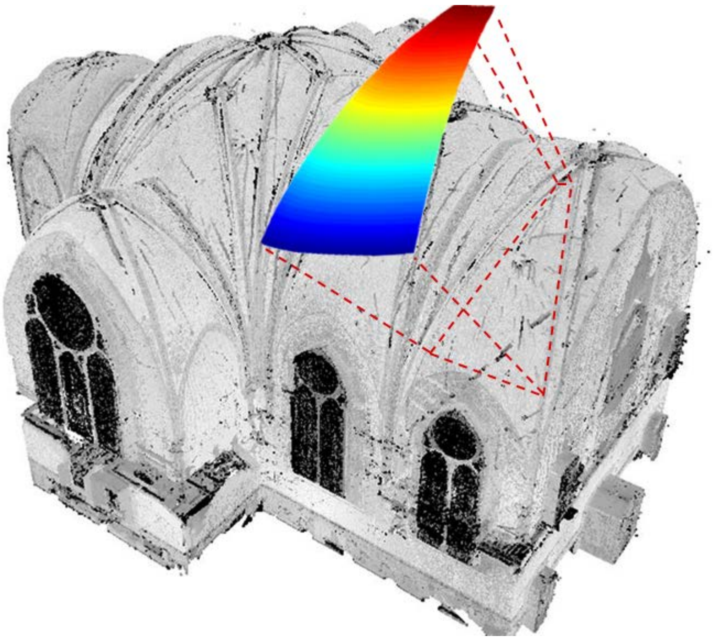
See:
- [4]Piegl & Tiller (1997)
- [10]Koch (2009)
- [12]Bureick et al. (2016)
- ….

Agenda

- Motivation
- Deterministic surfaces (B-Splines)
- **Application examples**
- Summary

Health Monitoring of buildings
(e.g. Schmitt et al., 2014)

- Objects with cracks / damage
- Organize repair work:
  - Classification of damages
  - Concept of repair work
- Interdisciplinary collaboration (IfMa, IfB, ...)
- GIH: Sampling of 3D point cloud and geometrical approximation.



3D point cloud of building (Schmitt et al., 2014)

➡ Finite Element modeling (Institute of Solid Construction)

Modeling with B-Spline Surface
(Schmitt et al., 2014)

- Adjustment in Gauss-Markov model

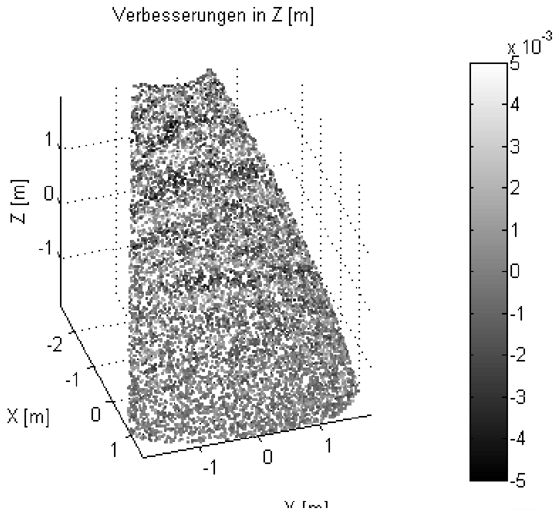
$$\sum_{k=1}^{h}\sum_{l=1}^{h}|Q_h - S(uk_k, vl_l)|^2 \rightarrow min.$$

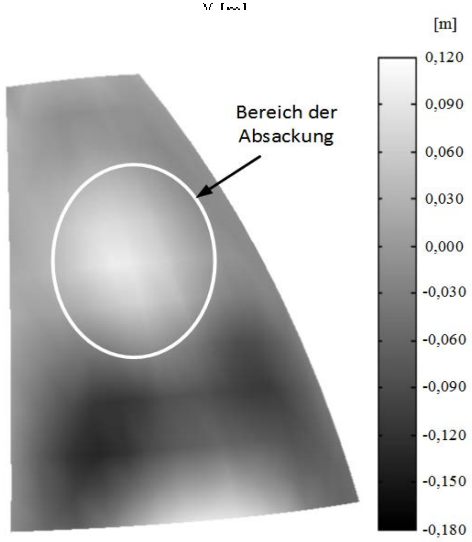
- Parameterization of measured point

$$X_h, Y_h, Z_h \rightarrow \lambda_k, \varphi_l \rightarrow uk_k, vl_l$$

- Choice of the complexity of the surface
- Difference to standard modelling in FE model

→ B-Spline surface can explain occurring forces and cracks!

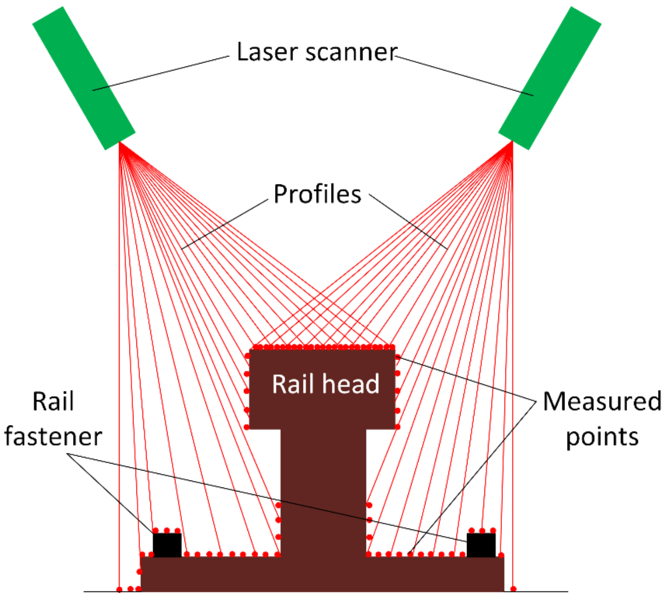


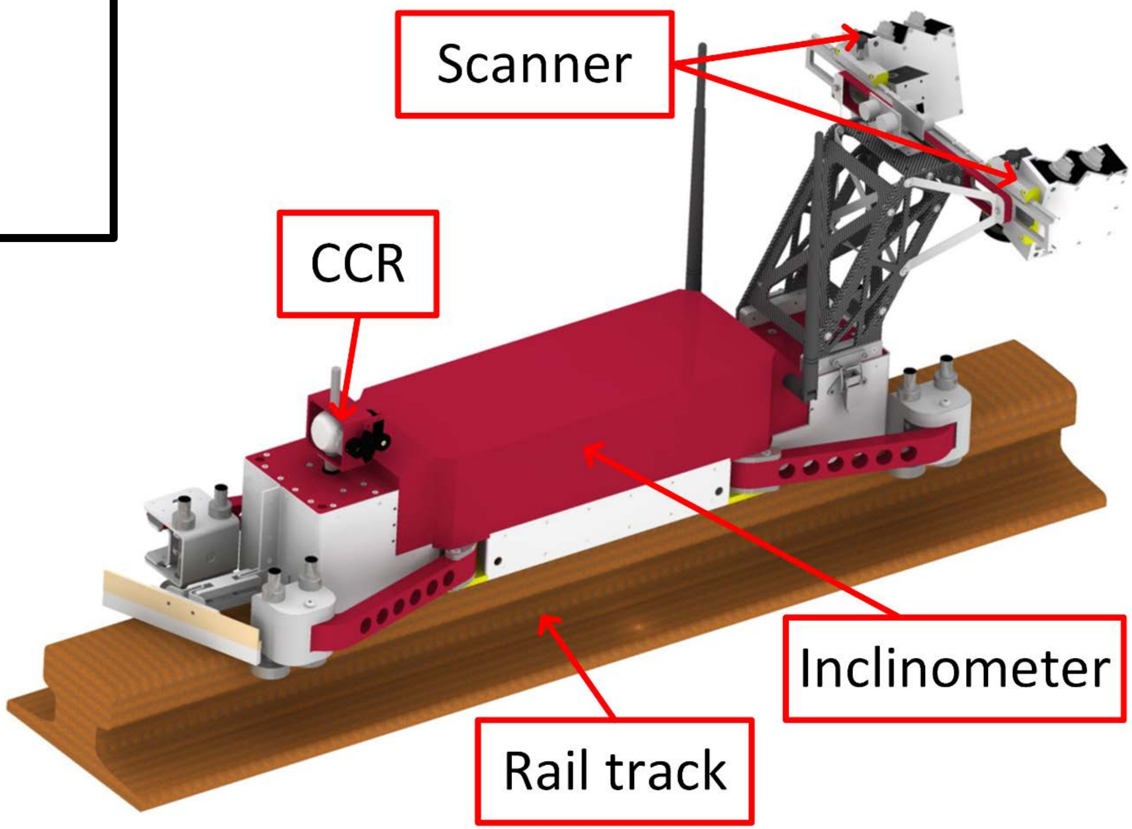


(Schmitt et al., 2014)

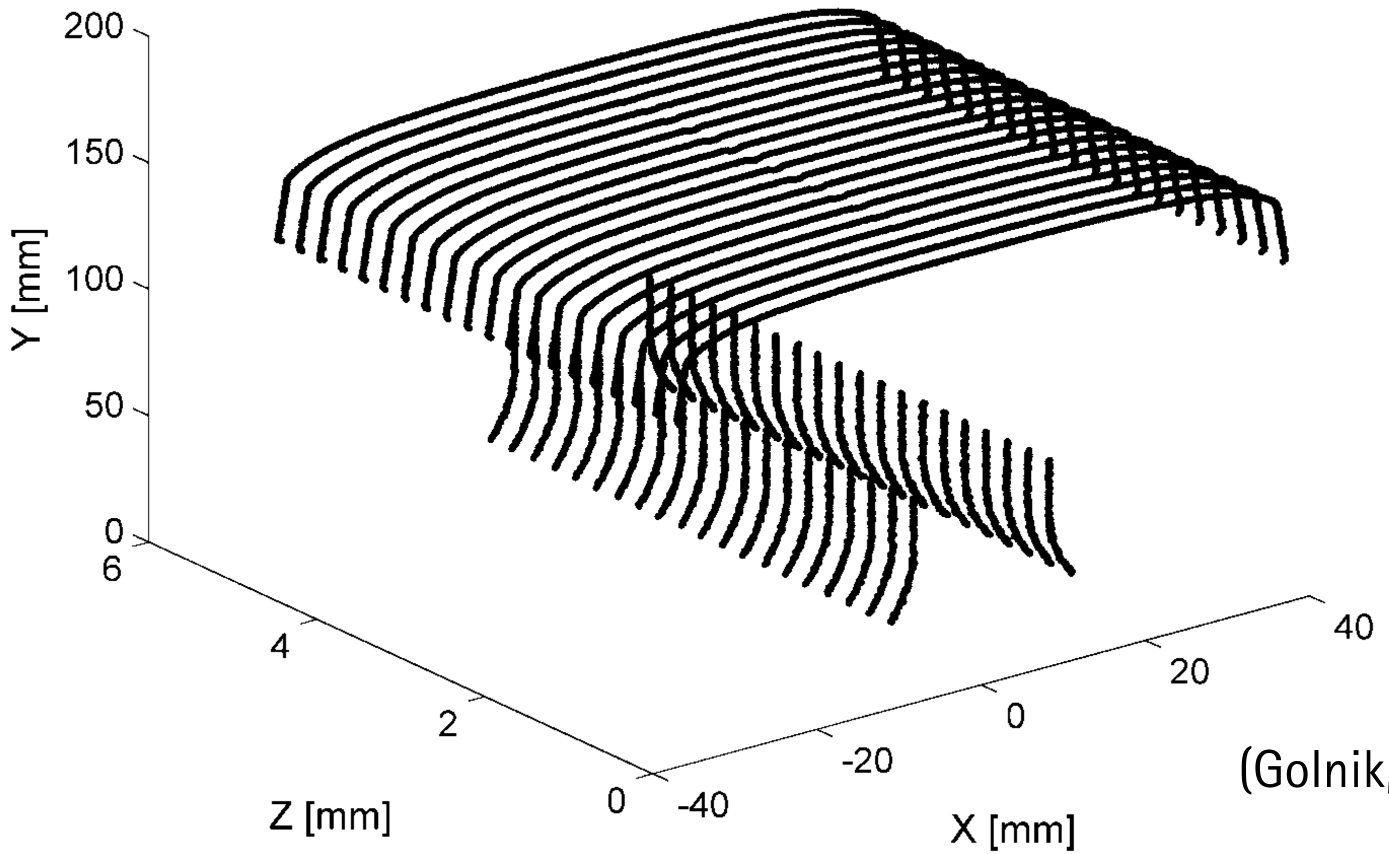
Advanced Rail Track Inspection System

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





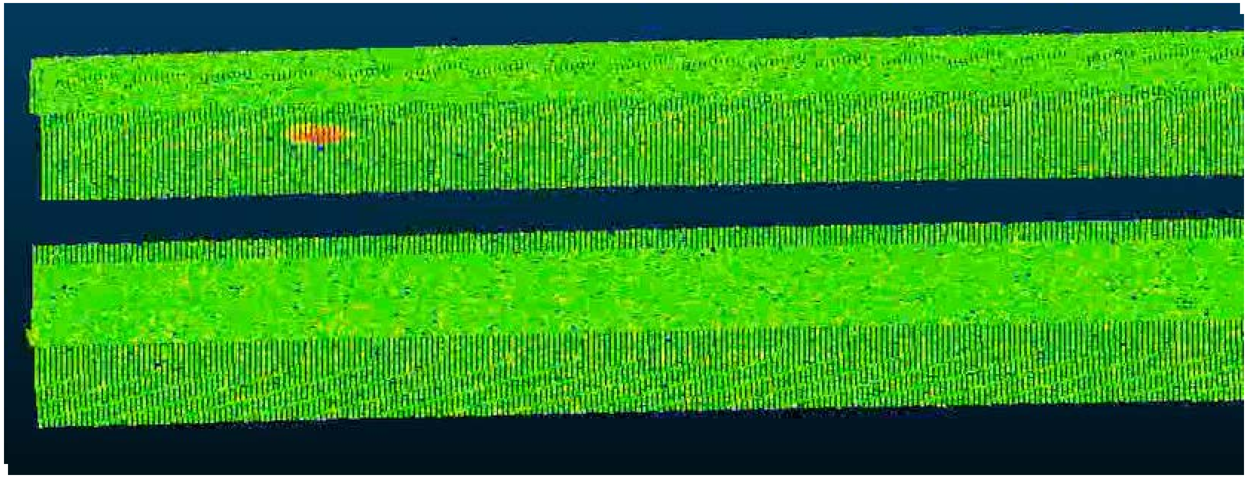
Test data



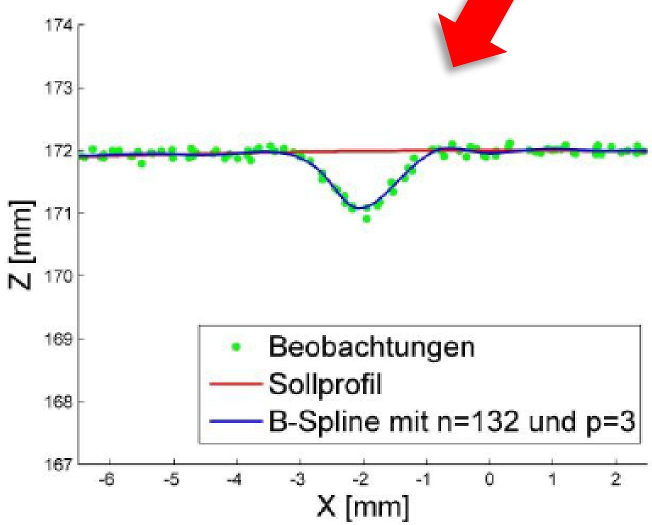
(Golnik, 2016)

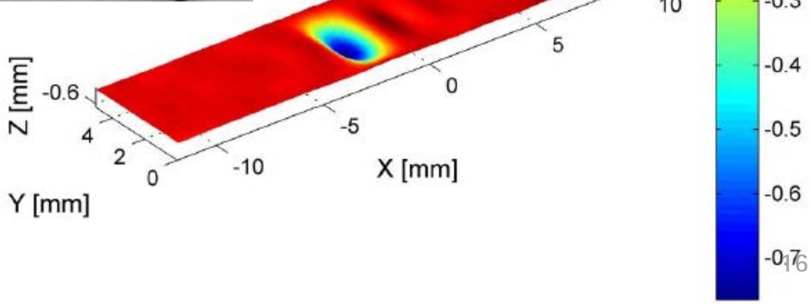
Applications (2)

How can we obtain curves and surfaces from point clouds

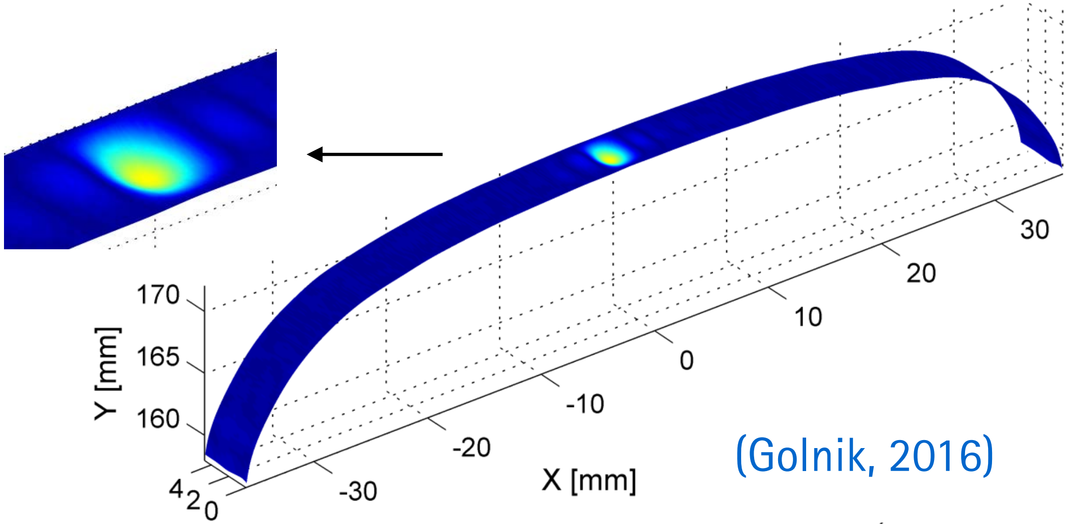


HOW?

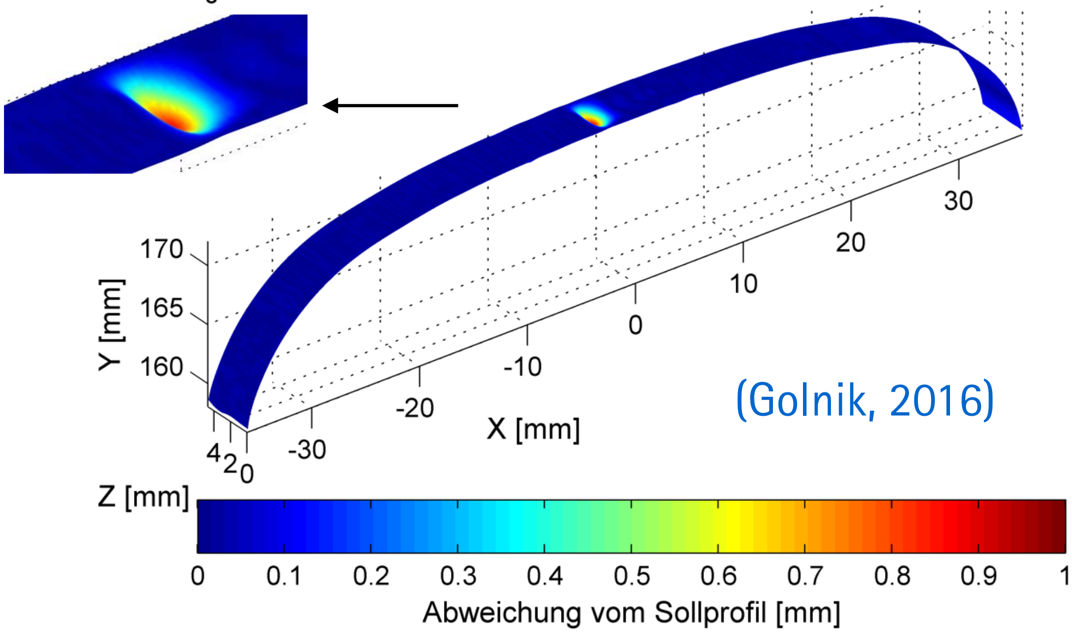




Applications (2)



(Golnik, 2016)

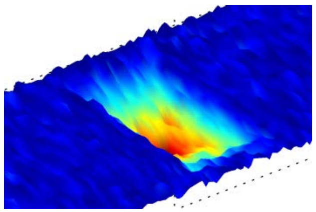


(Golnik, 2016)

Modell after Piegl & Tiller (PT):

- $\Omega = 302{,}46\ mm^2$
- 1,7 seconds

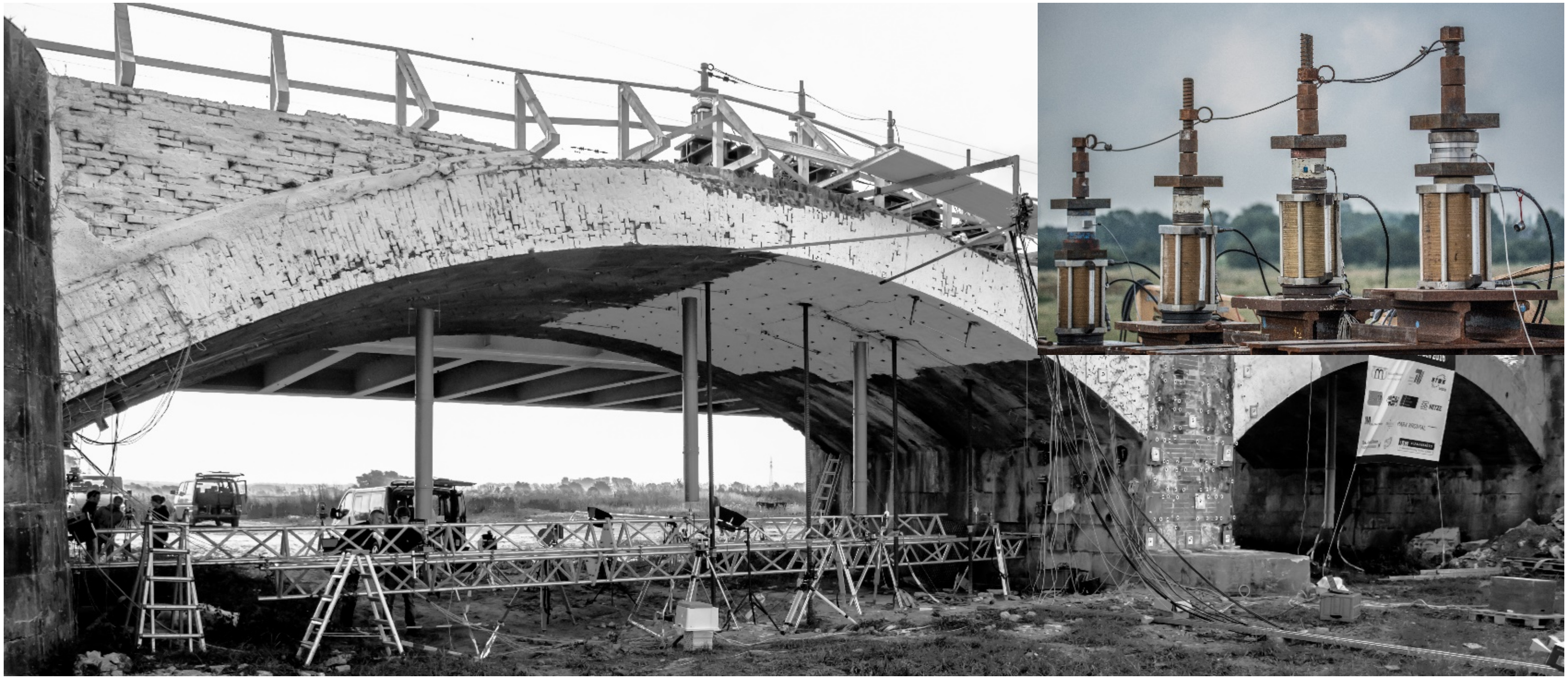
Measurements



Modell after PT with MCM:

- $\Omega = 250{,}09\ mm^2$
- 5,4 seconds

3D point cloud based monitoring of a masonry arch bridge

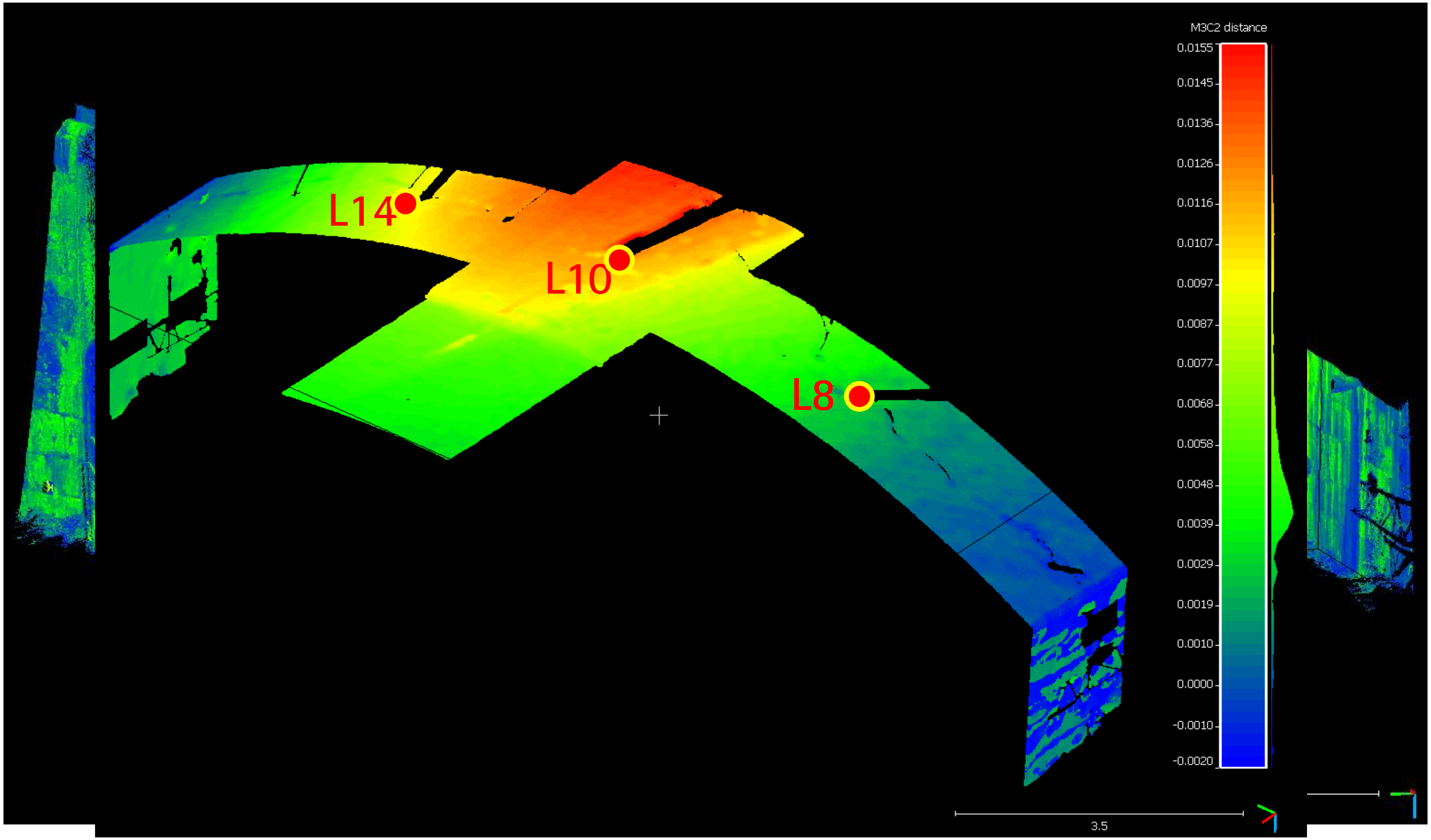


- Aim: Experimental investigations of the structural behaviour of the bridge by means of load testing

Data acquisition by means of laser scanner Z+F Imager 5006

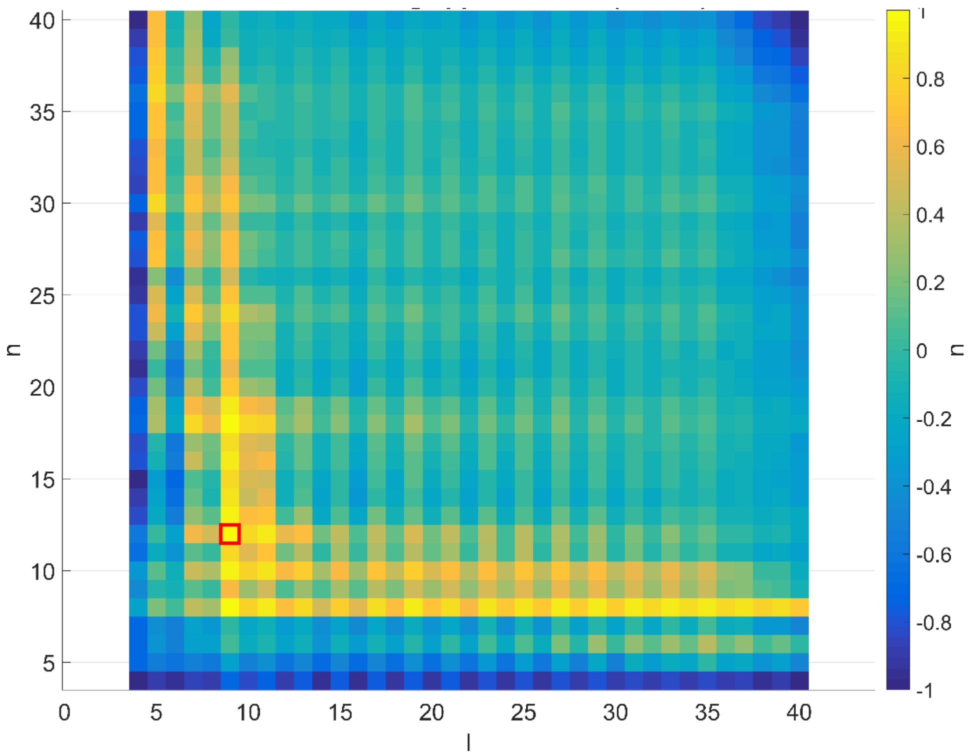
- Epoch-wise 3D point cloud of the bottom side of the arch
- Data acquisition time per epoch approx. 7 minutes
- Modelling of the arch point cloud by B-Spline surfaces

B-Spline modelling of the point cloud

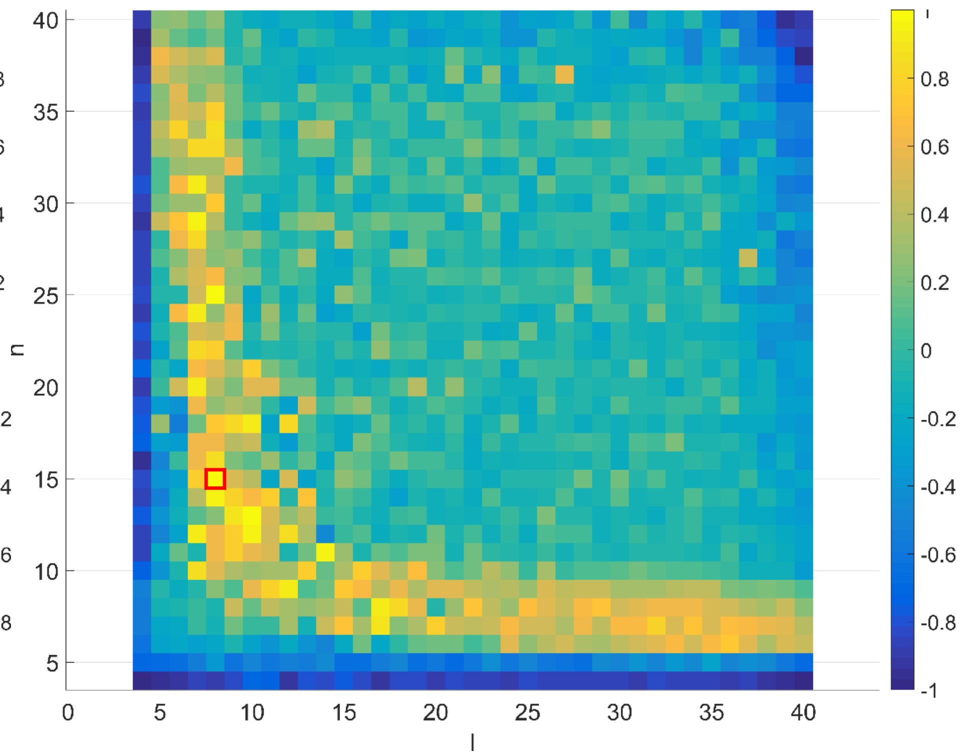


Results for Clarke's test for two different knot vector determination techniques

Knot placement technique

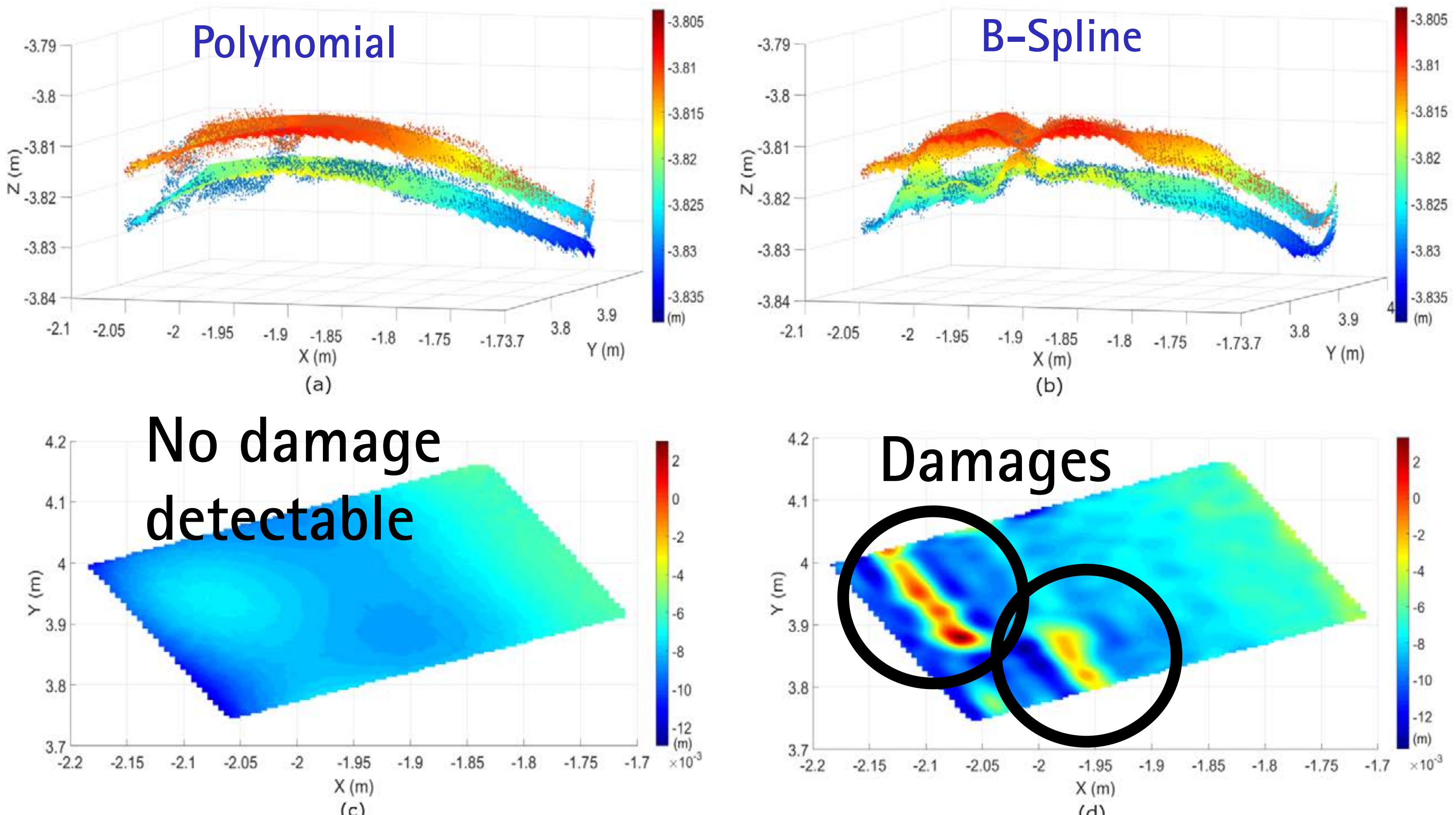


Monte Carlo technique



(Zhao et al., 2018)

Geometrical damage detection by B-Spline surfaces



(Zhao et al., 2018)

- Motivation
- Deterministic surfaces (B-Splines)
- Application examples
- **Summary**

Summary

- Many methods are available for the geometrical modeling of point clouds → B-Splines are a very good choice!
- Surface methods are the only possibility for
  - judging accuracy and reliability of the results
  - for continuous modelling of an object
  - still allowing for local adaptation
- Heterogeneous data and spatial-temporal extension easily possible
- B-Spline allow for recursive estimation of the data (regression analysis) → arbitrary large data sets usable

Thanks a lot for the attention

References of the GIH in surface based monitoring

2013-2019

2019

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