Detecting rigid body movements from TLS-based areal deformation measurements

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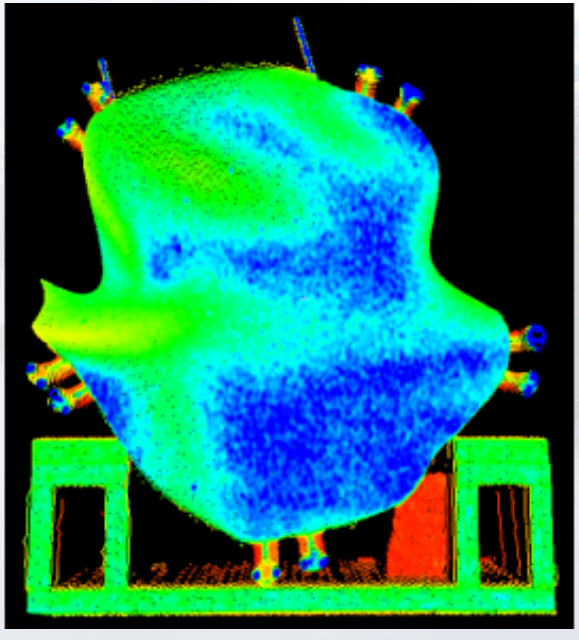
Motivation

Classical engineering geodesy

- Point-based
- Targeted discretization is necessary
- Only selected object points are regarded
- Point-based analysis strategies are available

TLS-based engineering geodesy

- Fast and contactless data acquisition
- High point densities
- Areal analysis strategies are required



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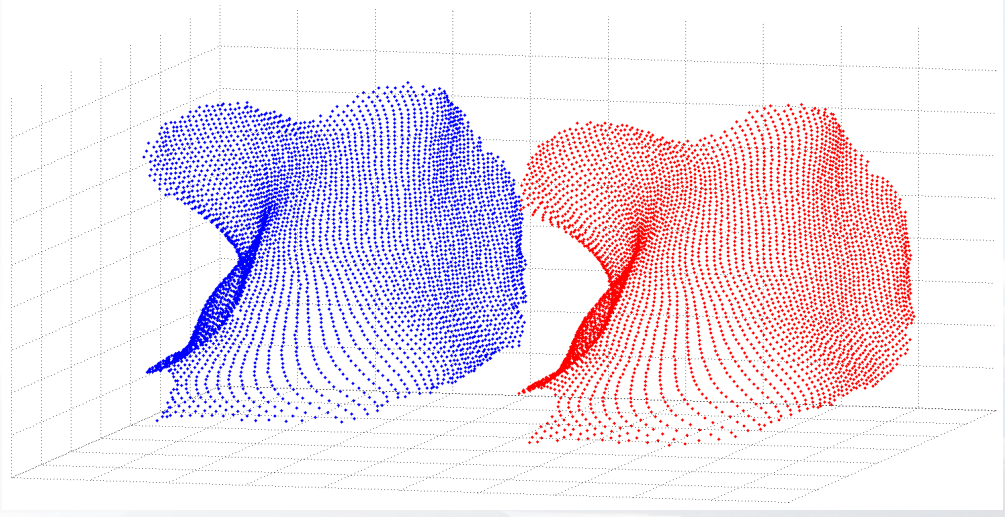

Areal deformation modelling

- Rigid body movement as a first step in areal deformation modelling
- Two laser scanner point clouds of different measurement epochs
- No point correspondences

  → How to determine the parameters of the rigid body movement?

Outline

1. Motivation
2. Modelling of point clouds using B-spline surfaces
3. Detecting rigid body movements
4. Summary

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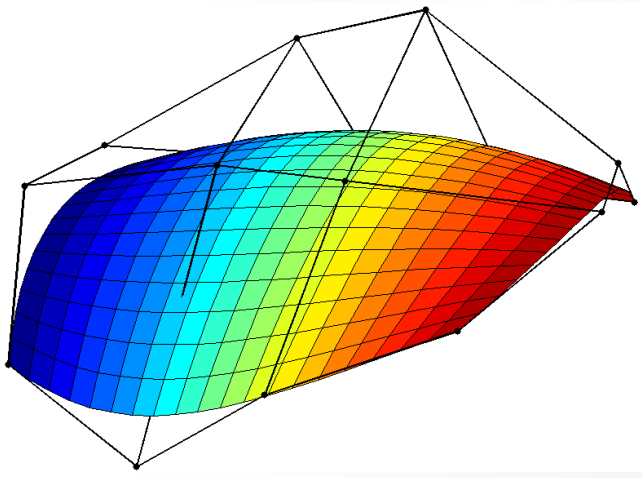
Modelling of point clouds using B-splines

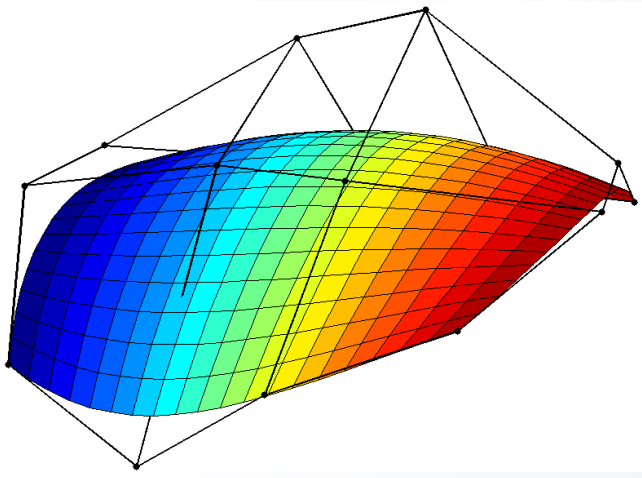


B-spline surface to model point clouds

$$\hat{\mathbf{S}}(u,v) = \mathbf{S}(u,v) + \mathbf{e} = \sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u)N_{j,q}(v)\mathbf{P}_{ij}$$

$\mathbf{S}(u,v)$	:	surface point
u, v	:	surface parameters
$\mathbf{e}$	:	residuals
$\mathbf{P}_{ij}$	:	$(n+1)x(m+1)$ control points
$N_{i,p}(u)$	:	i-th B-spline basis function of degree p
$N_{j,q}(v)$	:	j-th B-spline basis function of degree q

Modelling of point clouds using B-splines



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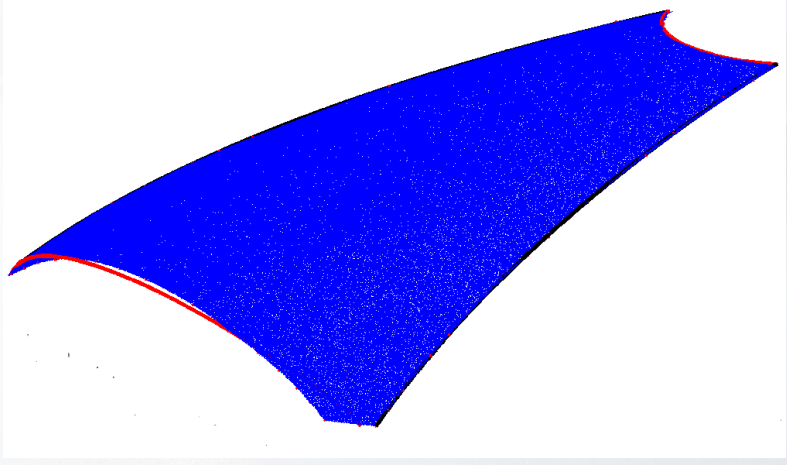
Parametrization with Coons Patch

Projection onto a base surface with known parameters

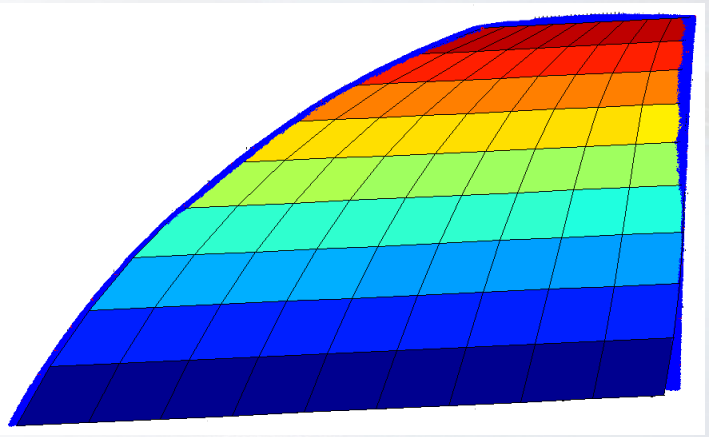
- Coons Patch as a base surface
- Starting point: four boundary B-Spline curves



Parametrization with Coons Patch

Projection onto a base surface with known parameters

- Coons Patch as a base surface
- Construction of three surfaces
  - Two ruled surfaces $\mathbf{R}^u_{i,j}$ und $\mathbf{R}^v_{i,j}$



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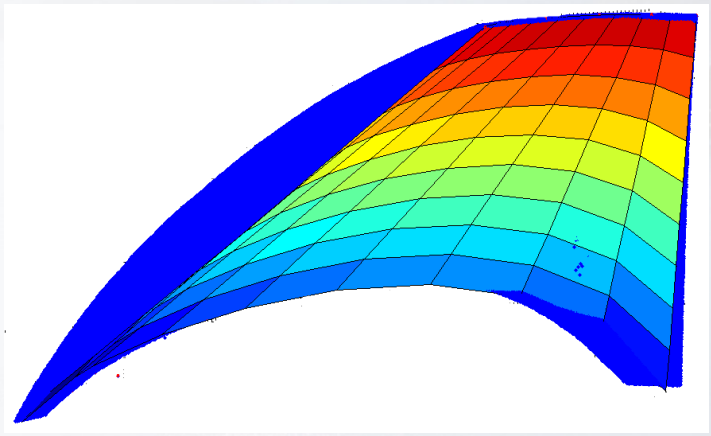

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- Coons Patch as a base surface
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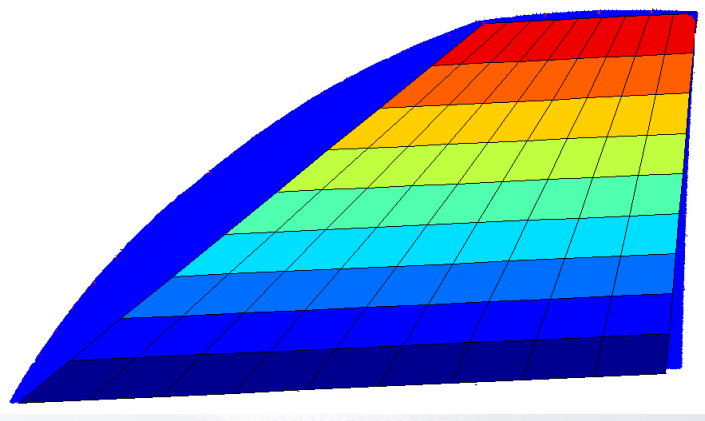
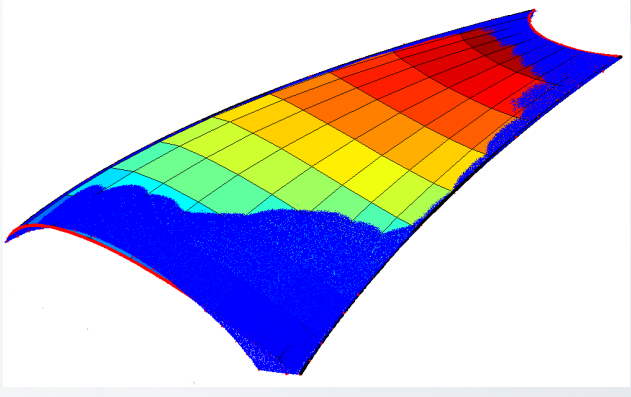
  - Bilinear interpolant of the four corner points $\mathbf{B}^{u,v}_{i,j}$



Parametrization with Coons Patch

Projection onto a base surface with known parameters

- Coons Patch as a base surface
- Construction of three surfaces
  - Two ruled surfaces $\mathbf{R}^u_{i,j}$ und $\mathbf{R}^v_{i,j}$
  - Bilinear interpolant of the four corner points $\mathbf{B}^{u,v}_{i,j}$
- Coons Patch as a combination of these surfaces: $\mathbf{S} = \mathbf{R}^u_{i,j} + \mathbf{R}^v_{i,j} - \mathbf{B}^{u,v}_{i,j}$



Outline

Detecting rigid body movements

Rigid body movement

- Similarity transform of a single point of the point cloud:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{II} = m \cdot \mathbf{R} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{I} + \mathbf{t}$$

m	:	scale factor
$\mathbf{R}$	:	rotation matrix
$\mathbf{t}$	:	translation vector
I, II	:	measuring epoch

- The same similarity transform is present in the B-spline control points:

$$\mathbf{P}_{II} = m \cdot \mathbf{R} \cdot \mathbf{P}_{I} + \mathbf{t}$$

$\rightarrow$ In case of rigid body movements, the modelling with B-splines reduces the areal deformation problem to a classical point based one!

Simulation studies

Simulated rigid body movement

- Based on one measured point cloud
- Computational translation of this point cloud by means of the nominal values:

$$\mathbf{t} = [100\,mm, 250\,mm, -50\,mm]$$

- Computational rotation around the x-, y- and z-axis with the nominal angles:

$$\boldsymbol{\alpha} = [-7^\circ, 15^\circ, 45^\circ]$$

$\rightarrow$ Point cloud of the second epoch

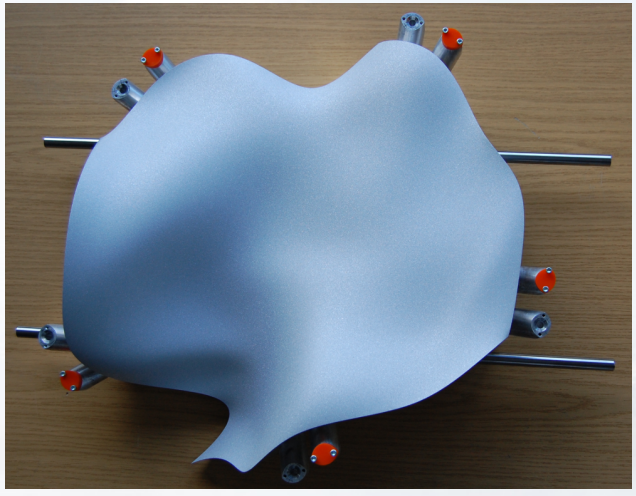
- Independent approximation of the two point clouds by means of B-splines
- Estimation of the transformation parameters from estimated control points:

$$\hat{\mathbf{t}} = [99.9999908\,mm, 249.999979\,mm, -50.000011\,mm]$$

$$\hat{\boldsymbol{\alpha}} = [-7.0000034^\circ, 15.0000042^\circ, 44.9999974^\circ]$$

$\rightarrow$ Only numerical inaccuracies

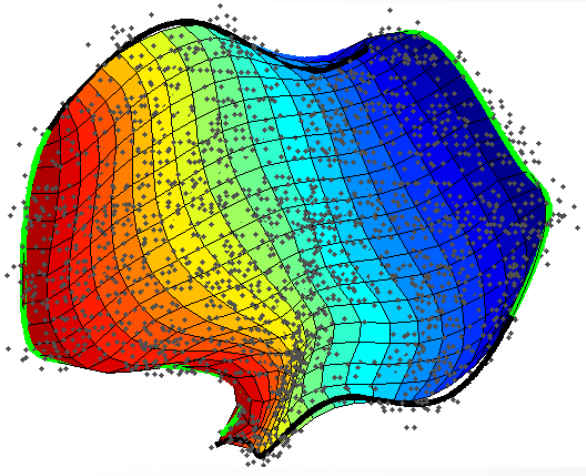
Practical measurements



Measured rigid body movement

- Based on a test specimen with B-spline form
- External points allow a definite placement of a lasertracker reflector
- Scanning of the specimen at two different locations
- The lasertracker measurements give the nominal transformation parameters

Practical measurements



Datum problem of B-splines

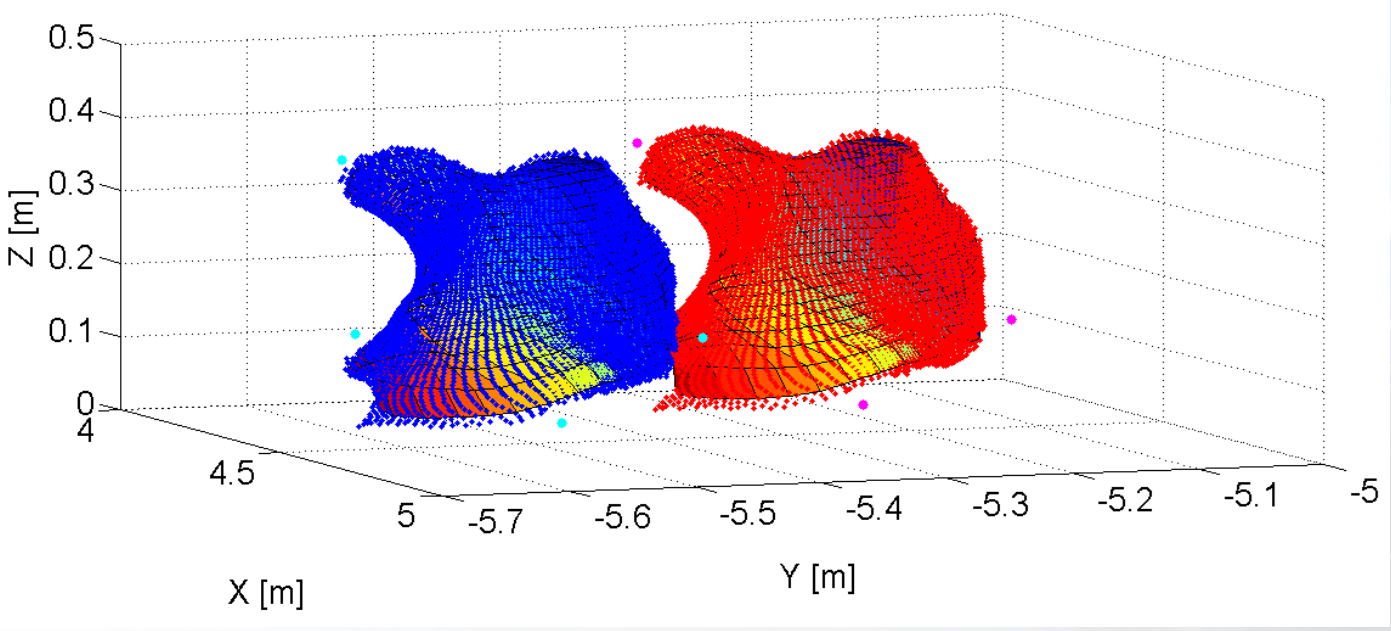
- Two different point clouds
- Different boundaries result in different parameter lines: → Datum of B-splines
- The datum and as a consequence the parameter lines have to be identical

Solving the datum problem

- Determination of corresponding boundary points by means of the ICP algorithm
- Only these points are used to determine the boundary curves

  → Parameter lines are nearly unchanged

Practical measurements



Parameters	Nominal	Measured	Std
tx [m]	-0.263	-0.251	0.011
ty [m]	0.100	0.110	0.009
tz [m]	0.000	0.001	0.001
rz [gon]	- 2.2115	- 2.0675	0.1252

Outline

Summary

Summary

- Areal approach to determine rigid body movements of point clouds
- Modelling of each acquired point cloud by means of B-spline surfaces
- A priori determination of appropriate surface parameters
- The rigid body movement of the point cloud can be retrieved from the rigid body movement of the estimated B-spline control points

Thank you for your attention!

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