FIG WORKING WEEK 2023

28 May - 1 June 2023 Orlando Florida USA

FIG Orlando Working Week 2023

Protecting Our World, Conquering New Frontiers

Quality investigations of different modelling approaches for laser scanning point clouds representing natural surfaces

Corinna Harmening & Ramon Butzer

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Motivation

Monitoring of natural phenomena

- Climate change causes considerable changes of natural surfaces, e. g.
  - Glaciers
  - Land slides
  - Farmland
  - Coastal areas
- Monitoring of natural surfaces to monitor the impact of climate change

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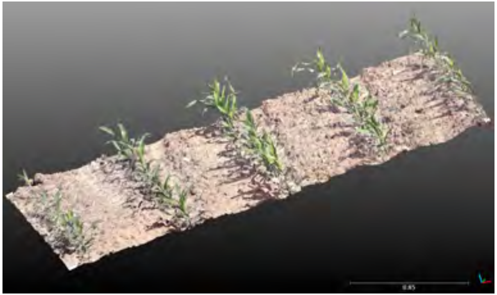
Motivation

Monitoring of natural phenomena

- Laser scanning
  - Fast and contactless data acquisition
  - Resulting 3D point clouds with high spatial resolution
- Objective: Derivation of e. g.
  - Volumetric changes
  - Characterizing parameters
- Challenges when analysing the acquired point clouds
  - Measurement noise
  - No corresponding data points in subsequently acquired point clouds
- Common strategy: Modelling of point clouds
  $\rightarrow$ Variety of difficulties for natural surfaces



Outline

Karlsruhe Institute of Technology

Outline

Data sets under investigation

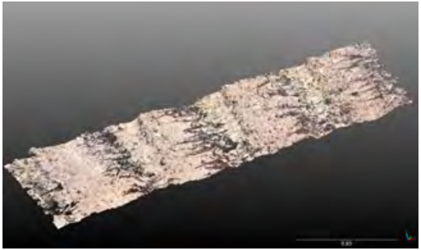
Soil erosion scene (Harmening et al., 2023)

- Acquired within a long-term soil erosion monitoring programme
- In southern Lower Saxony (northern Germany)
- Detection of small scale erosion under field conditions
- Installation of small plots (2 *x* 3 *m*) on managed cropland
- Field with late summer sowing (maize)
- Weekly scans of the plots (11th May to 8th June)

Data sets under investigation

Soil erosion scene (Harmening et al., 2023)

- Data preprocessing
  - Registration
  - Ground filtering



Data sets under investigation

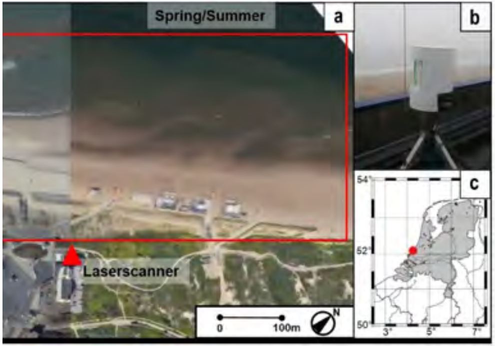
Soil erosion scene (Harmening et al., 2023) – Resulting point clouds

- Local structures
  - Sewing rills
  - Soil roughness
- Small data gaps (removed vegetation)
- Outliers (remaining vegetation)

Data sets under investigation

Kijkduin beach-dune (Vos et al., 2022)

- North Sea coast, The Hague (The Netherlands)
- Monitoring of the beach by means of permanent laser scanning
- Installation of a TLS on top of a hotel
  - 38 m height above mean sea level
  - Scanner overlooks the beach and dunes
- Hourly scans during a six-months period in 2016/2017
- Data preprocessing
  - Georeferencing
  - Consistency check against RTK-GNSS and ALS



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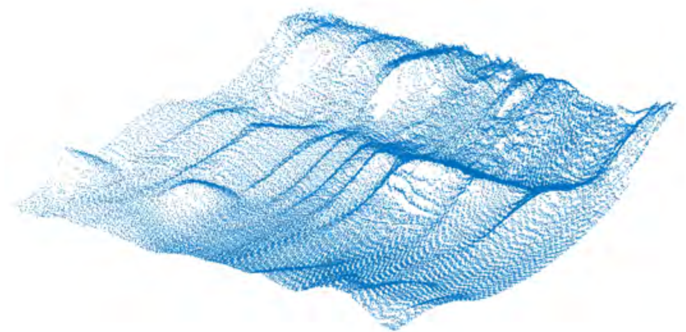
Data sets under investigation

Kijkduin beach-dune (Vos et al., 2022) – Resulting point clouds

- Local structures (dunes)
- Data gaps (occlusions)



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Outline

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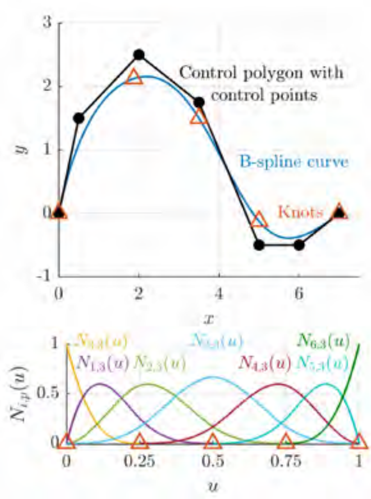
Tensor product B-spline surfaces

B-spline curves to model point clouds

$$\hat{\mathbf{C}}(u) = \sum_{i=0}^{n_{\mathbf{P}}} N_{i,p}(u)\mathbf{P}_i$$

$\hat{\mathbf{C}}(u)$	:	Estimated curve point
u	:	Curve parameter
$\mathbf{P}_i$	:	$(n_{\mathbf{P}}+1)$ control points
$N_{i,p}(u)$	:	i-th B-spline basis function of degree p



Tensor product B-spline surfaces

B-spline surfaces to model point clouds

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

$\hat{\mathbf{S}}(u,v)$	:	Estimated surface point
$u,\ v$	:	Surface parameters
$\mathbf{P}_{ij}$	:	$(n_{\mathbf{P}}+1)x(m_{\mathbf{P}}+1)$ control points
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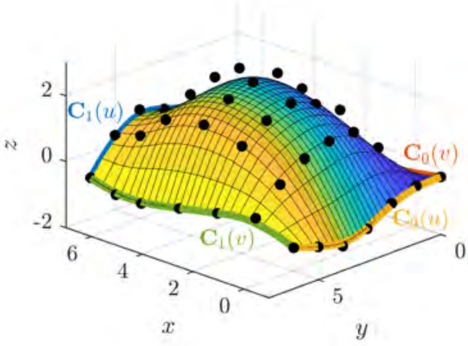

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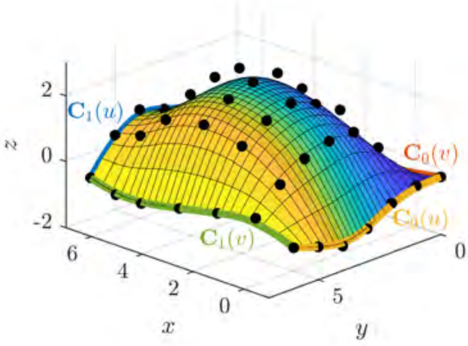

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u, v : Surface parameters

$\mathbf{P}_{ij}$: $(n_\mathbf{P}+1)x(m_\mathbf{P}+1)$ control points

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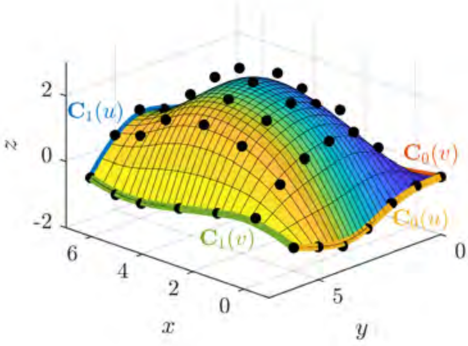

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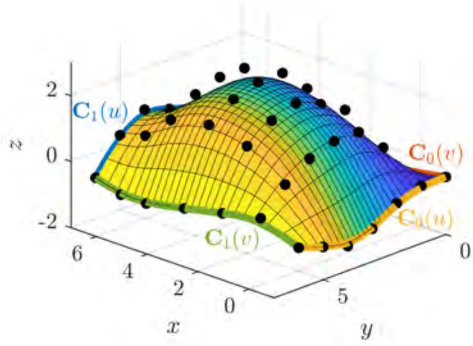
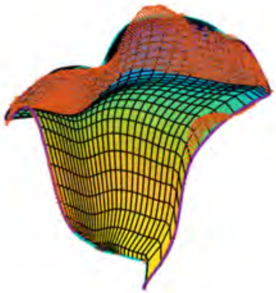


Iterative reparameterization (C. Harmening & H. Neuner, 2015)

Parameterization strategy

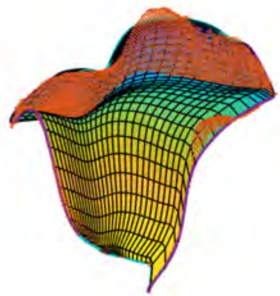
- Construction of a base surface



Iterative reparameterization (C. Harmening & H. Neuner, 2015)

Parameterization strategy

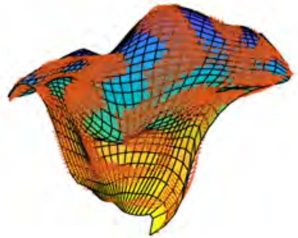
- Construction of a base surface
- Projection onto the base surface yields surface parameters



Iterative reparameterization (C. Harmening & H. Neuner, 2015)

Parameterization strategy

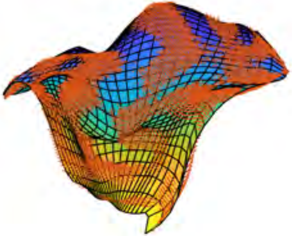
- Construction of a base surface
- Projection onto the base surface yields surface parameters
- Initial B-spline estimation



Iterative reparameterization (C. Harmening & H. Neuner, 2015)

Parameterization strategy

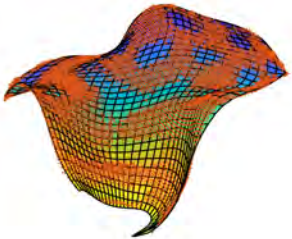
- Construction of a base surface
- Projection onto the base surface yields surface parameters
- Initial B-spline estimation
- Reparameterization



Iterative reparameterization (C. Harmening & H. Neuner, 2015)

Parameterization strategy

- Construction of a base surface
- Projection onto the base surface yields surface parameters
- Initial B-spline estimation
- Reparameterization
- Iterative procedure



Tensor product B-spline surfaces for point cloud modelling

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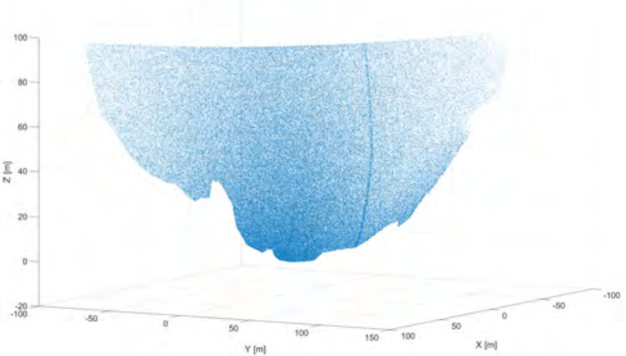
Point clouds representing artificial objects

- (Relatively) smooth surfaces
- Clearly defined boundaries
- Inner structures are satisfactorily captured by the boundaries
- Data gaps avoidable

$\rightarrow$ Successful approximation by means of tensor product B-spline surfaces



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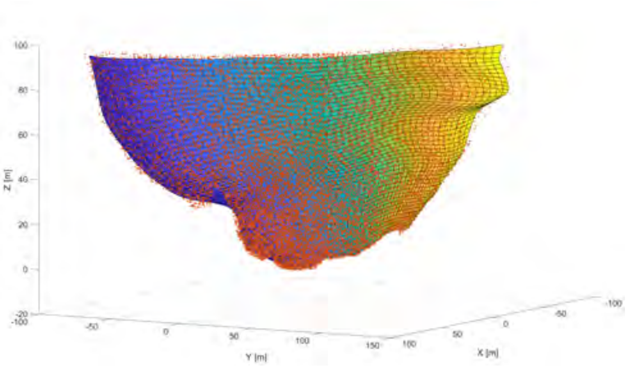

Tensor product B-spline surfaces for point cloud modelling

Point clouds representing natural objects

- (Relatively) rough surfaces
- No clearly defined boundaries
- Inner structures are unsatisfactorily captured by the boundaries
- Data gaps not always avoidable (occlusions)

$\rightarrow$ Approximation by means of tensor product B-spline surfaces not satisfying

- Point cloud's deviations clearly too large
- Systematic behaviour of the residuals
- Number of control points not arbitrarily increaseable (loops and artefacts)

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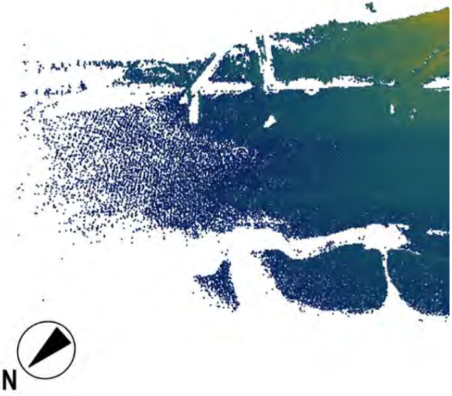

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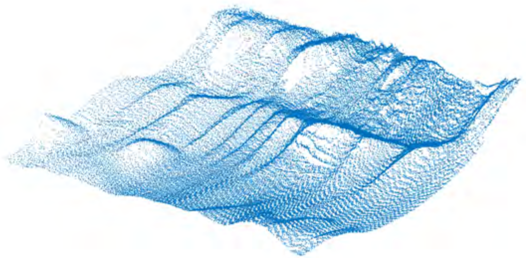

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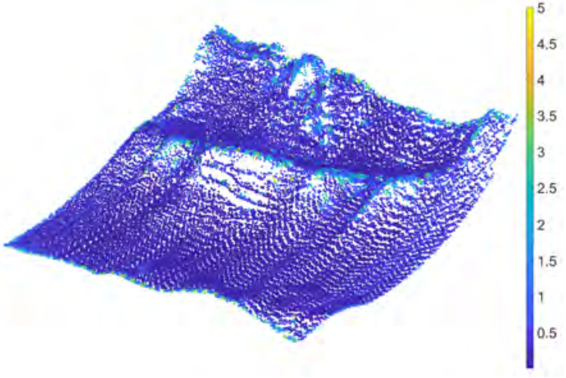

Euclidean residuals [m]

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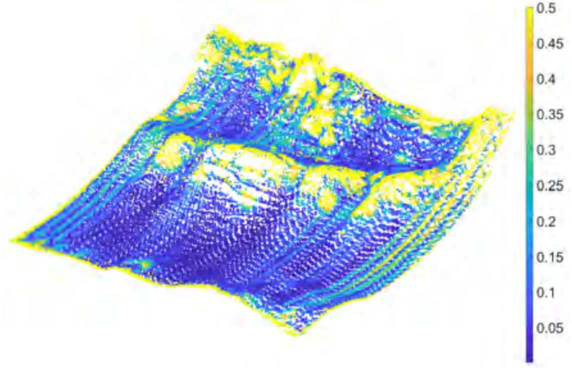


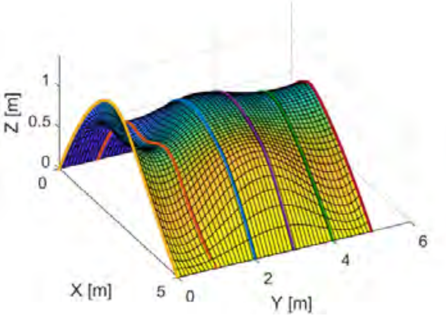
Euclidean residuals [m]

Outline

Construction of skinned B-spline surfaces

Motivation

- Tensor product B-spline surfaces: Infinite number of B-spline curves running into two different directions
  $\rightarrow$ Isoparametric curves
- "Weakness" of tensor product B-spline surfaces: "Global character"
  $\rightarrow$ Global definition of parameter groups
- Joint determination of isoparametric curves restricts flexibility of tensor product B-spline surfaces
- Here: Independent determination of isoparametric curves
  $\rightarrow$ Skinned surfaces



Construction of skinned B-spline surfaces

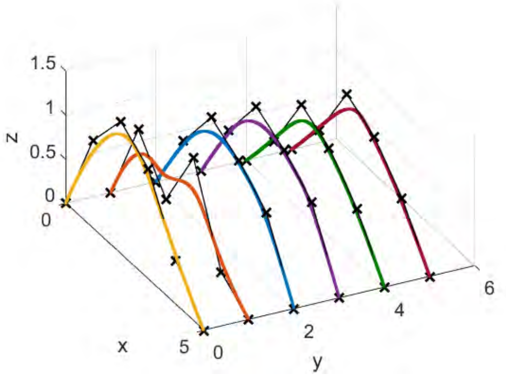
Skinned B-spline surfaces

- Given: $K+1$ section curves $\mathbf{C}_k(u)$
  - Usually planar cross sections
  - In u-direction of the surface to be constructed

$$\mathbf{C}_k(u) \quad = \quad \sum_{i=0}^{n_\mathbf{P}} N_{i,p}(u)\mathbf{P}_{i,k}, \quad k = 0, \ldots, K$$

- Skinning: Blending the curves together to form a surface
- Prerequisites for skinning:
  - All $\mathbf{C}_k(u)$ are defined on the same knot vector
  - All $\mathbf{C}_k(u)$ have common degree p

$\rightarrow$ Knot refinement and degree elevation



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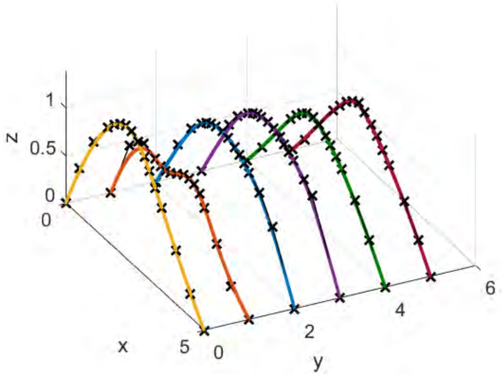
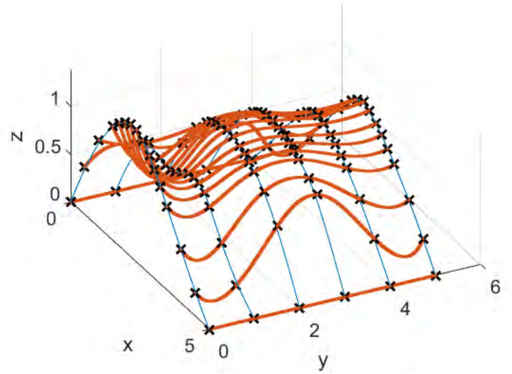


Construction of skinned B-spline surfaces

Skinned B-spline surfaces

- Construction of control curves
  $\rightarrow$ B-spline curves interpolating the control points of the section curves
- Control points of the control curves define control grid of the skinned surface
- Skinned surface:
  - Tensor product B-spline surface
  - Section curves are isoparametric curves on the surface
  - "Local character" $\rightarrow$ Increased flexibility
  - Price paid for flexibility: (Globally) increased number of control points



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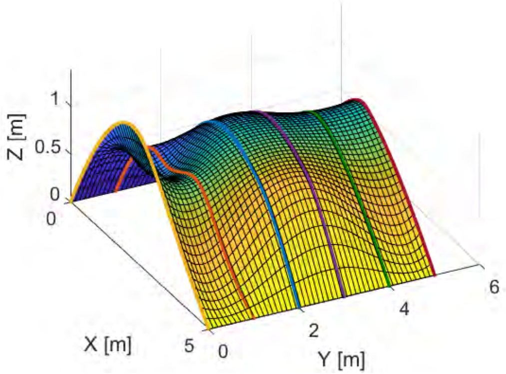
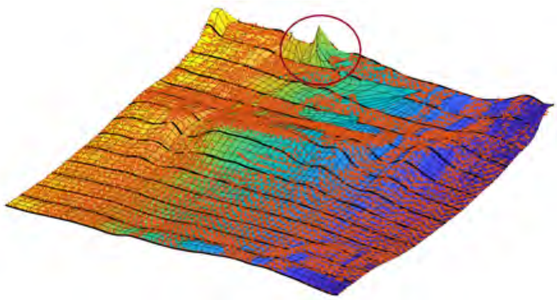


Construction of skinned B-spline surfaces

Skinned B-spline surfaces: Kijkduin beach-dune

- Skinned surface (15 section curves)
- Independent parameterization of the section curves
  $\rightarrow$ "Distortions" of the parameter grid causing artefacts
- Improved curve parameterization by taking parameterization of neighbouring curves into account
  $\rightarrow$ Regular parameter grid
- Satisfying approximation near the section curves
- Between the section curves: deviations between point cloud and surface



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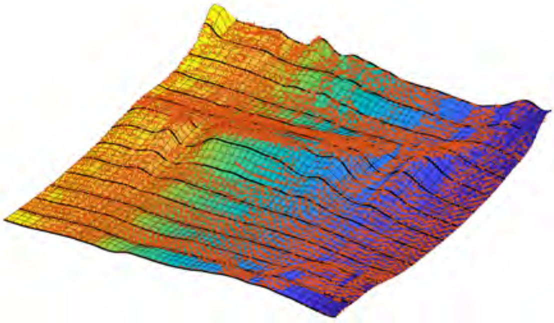
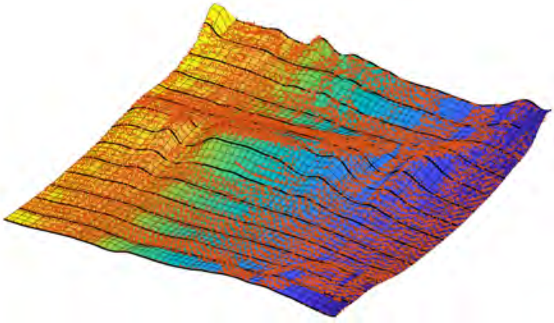


Outline

Locally parameterized tensor product B-spline surfaces

Skinned B-spline surfaces as base surfaces

- Construction of two skinned surface
  - Skinned surface in u-direction $\mathbf{S}_u(u, v)$
  - Skinned surface in v-direction $\mathbf{S}_v(u, v)$
- Allocation of surface parameters u by projecting the point cloud on $\mathbf{S}_u(u, v)$
- Allocation of surface parameters v by projecting the point cloud on $\mathbf{S}_v(u, v)$
- "Local" base surfaces
  $\rightarrow$ Locally parameterized B-spline surfaces



Locally parameterized tensor product B-spline surfaces

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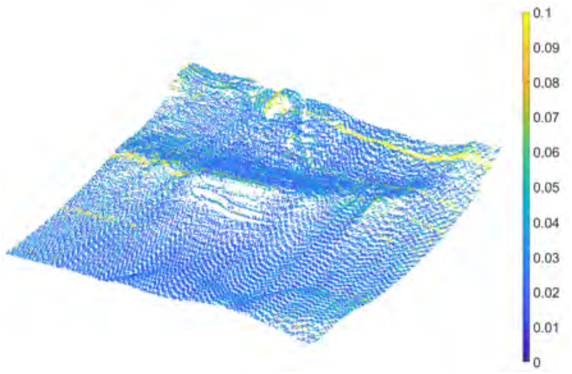
Locally parameterized B-spline surfaces

- Point cloud's deviations considerably smaller
- Parallel to few section curves: Systematic behaviour of the residuals
  $\rightarrow$ Influence of the dependent curve parameterization
- However: At the moment no iterative reparameterization
  $\rightarrow$ Further improvements expected
- Number of control points further increasable without emerging artefacts



Euclidean residuals [m]

Results

MSE

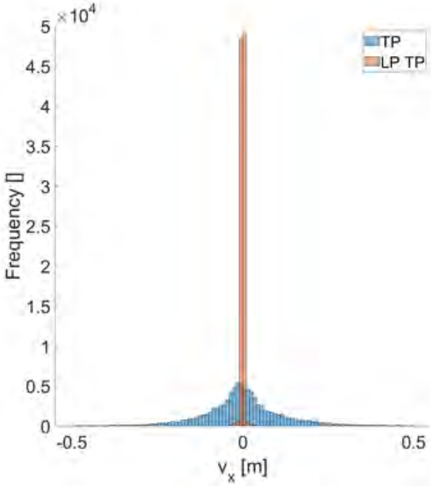
$n_P = m_P$	TP	LP TP
25	0.3705	0.0234
26	0.3681	0.0226
27	0.3628	0.0224
28	0.3514	0.0219
29	0.3528	0.0213
30	0.3506	0.0211
31	0.3447	0.0207
32	0.3342	0.0206
33	0.3376	0.0204
34	0.3265	0.0206

MSE [m] (Beach)

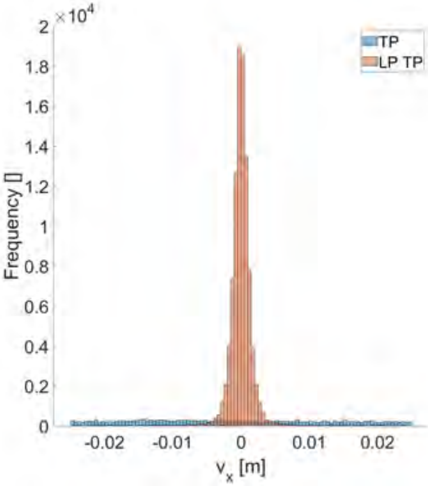
$n_P = m_P$	TP	LP TP
20	0.0055	0.0039
21	0.0054	0.0038
22	0.0052	0.0038
23	0.0050	0.0038
24	0.0050	0.0037
25	0.0049	0.0036
26	0.0048	0.0036
27	0.0047	0.0036
28	0.0049	0.0034
29	0.0048	0.0034

MSE [m] (Soil erosion)

Results

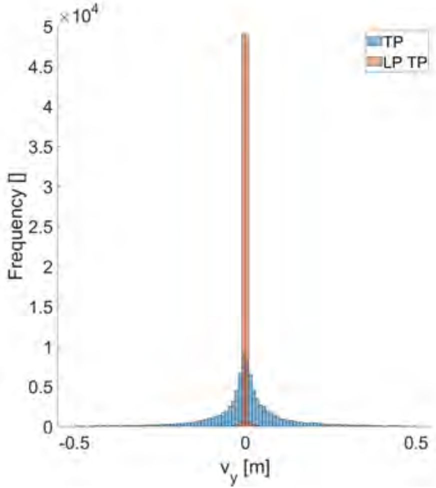


×10^4
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
Frequency []
v_x [m]
TP
LP TP

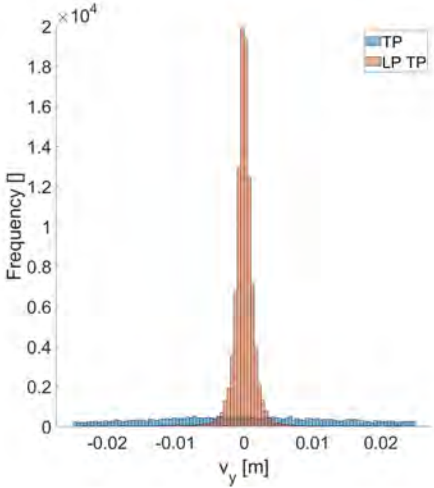


×10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.02
-0.01
0
0.01
0.02
Frequency []
v_x [m]
TP
LP TP

Results



×10^4
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Frequency []
TP
LP TP
-0.5
0
0.5
v_y [m]



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2
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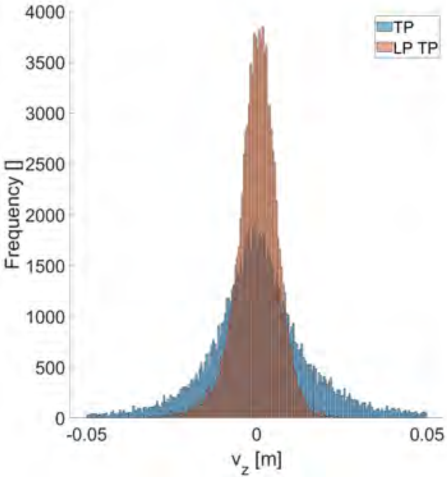
TP
LP TP
-0.02
-0.01
0
0.01
0.02
v_y [m]

Results



TP
LP TP
Frequency []
4000
3500
3000
2500
2000
1500
1000
500
0
-0.05
0
0.05
v_z [m]

Outline

Conclusion and Outlook

Conclusion

- Classically parameterized tensor product B-spline surfaces not suitable to model point clouds representing natural surfaces
- Introduction of locally parameterized tensor product B-spline surfaces
  - Skinned surfaces as base surfaces for parametrization
  - Local but dependent curve parameterization when constructing skinned surfaces
  - Maintenance of compact tensor product representation
  - No local refinement necessary
  - Satisfying point cloud approximation with small number of control points

$\rightarrow$ Information about the surface's shape stored in the surface parameters

Conclusion and Outlook

Outlook

- Reduction of systematics in the residuals
  - Iterative Reparameterization
  - Improvement of depending curve parameterization
- Automatic determination of number and directions of section curves
- Increase of the robustness
- Comparison with locally refined B-spline surfaces
  - Hierarchical B-splines
  - LR B-splines
  - ...

Thank you for your attention!

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