

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

Corinna Harmening & Ramon Butzer



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

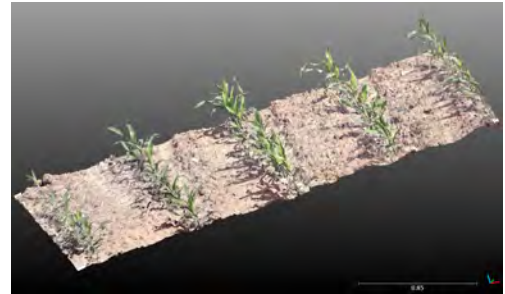


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Motivation

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
→ Variety of difficulties for natural surfaces



Outline

1. Motivation

2. Data sets under investigation

- Soil erosion scene
- Kijkduin beach-dune

3. State of the art: Tensor product B-spline surfaces for point cloud modelling

4. Improved point cloud modelling

- Construction of skinned B-spline surfaces
- Improved point cloud modelling by means of locally parameterized tensor product B-spline surfaces

5. Conclusion and Outlook

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Data sets under investigation

Soil erosion scene (Harmening et al., 2023)

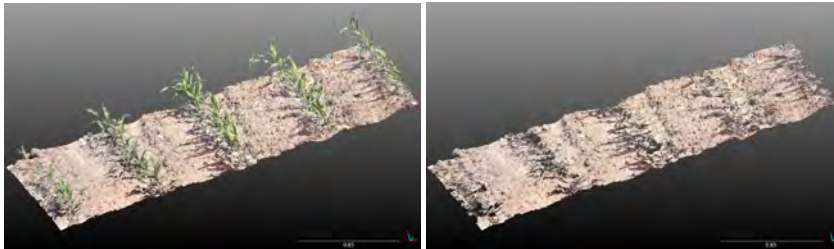
- Acquired within a long-term soil erosion monitoring programme
- In southern Lower Saxony (northern Germany)
- Detection of small scale erosion under field conditions
- Installation of small plots ($2 \times 3 \text{ m}$) on managed cropland
- Field with late summer sowing (maize)
- Weekly scans of 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

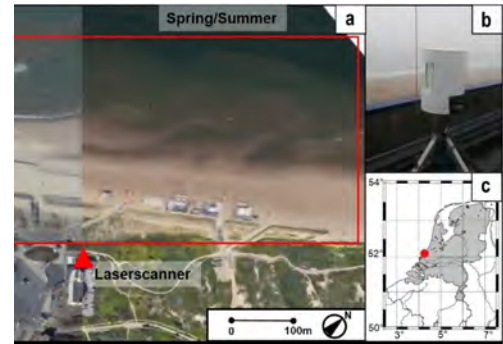
- Local structures
 - Sewing rills
 - Soil roughness
- Small data gaps (removed vegetation)
- Outliers (remaining vegetation)



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

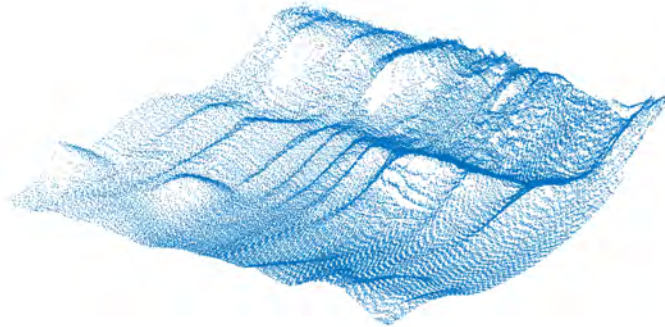


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Data sets under investigation

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

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



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Tensor product B-spline surfaces

B-spline curves to model point clouds

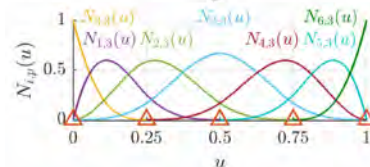
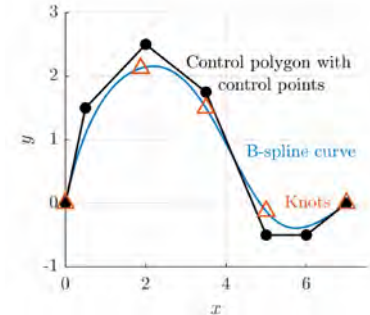
$$\hat{\mathbf{C}}(u) = \sum_{i=0}^{n_{\mathbf{P}}} N_{i;p}(u) \mathbf{P}_i$$

$\hat{\mathbf{C}}(u)$: 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

$$\hat{\mathbf{S}}(u; v) = \sum_{i=0}^{\mathcal{X}^{\mathbf{P}}-1} \sum_{j=0}^{\mathcal{Y}^{\mathbf{P}}-1} N_{i;p}(u) N_{j;q}(v) \mathbf{P}_{ij}$$

$\hat{\mathbf{S}}(u; v)$: Estimated surface point

$u; v$: Surface parameters

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

$N_{i;p}(u)$: i -th B-spline basis function of degree p

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Tensor product B-spline surfaces

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Parameterization strategy

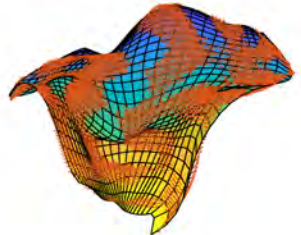
- Construction of a base surface

Parameterization strategy

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

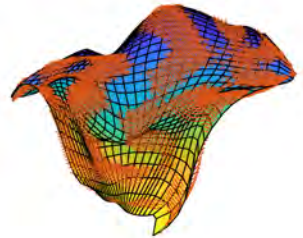
Parameterization strategy

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



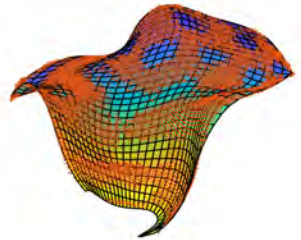
Parameterization strategy

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



Parameterization strategy

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

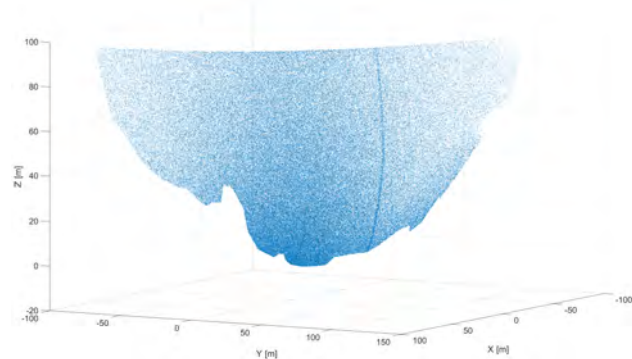


Tensor product B-spline surfaces for point cloud modelling

Point clouds representing artificial objects

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

→ Successful approximation by means of tensor product B-spline surfaces

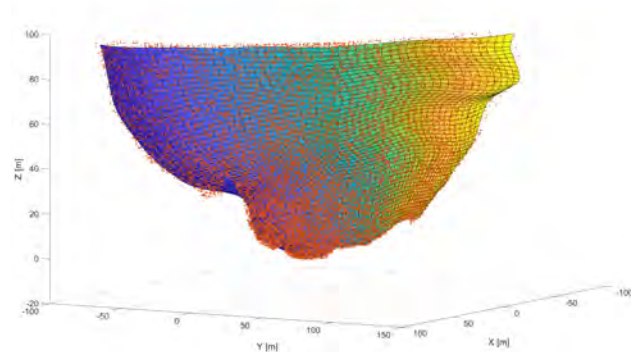


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Tensor product B-spline surfaces for point cloud modelling

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)

→ 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)



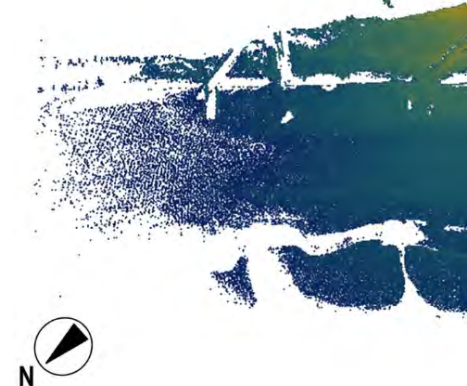
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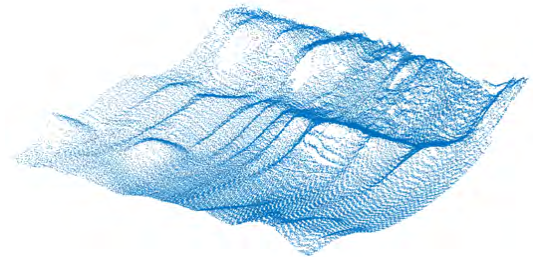
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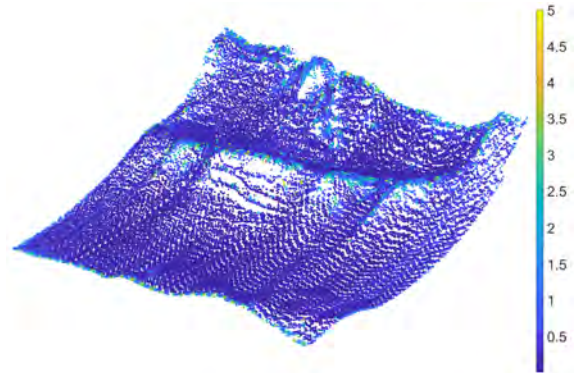
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Euclidean residuals [m]

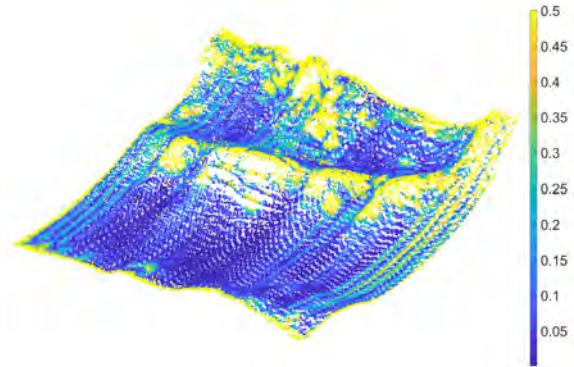
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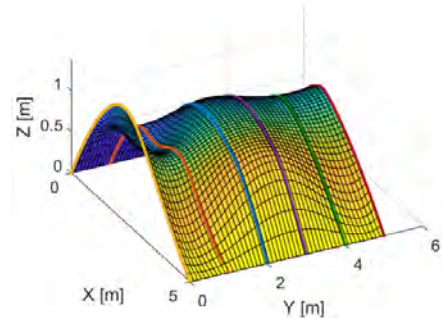
- Construction of skinned B-spline surfaces
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5. Conclusion and Outlook

Construction of skinned B-spline surfaces

Motivation

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



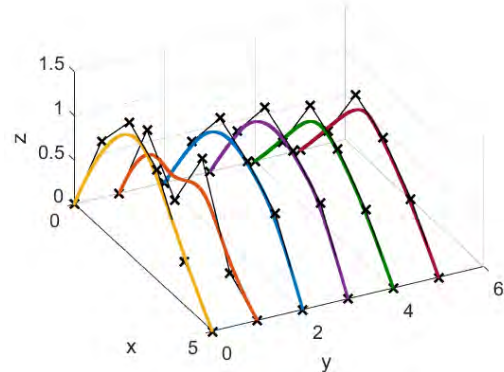
Construction of skinned B-spline surfaces

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

$$\mathbf{C}_k(u) = \sum_{i=0}^{p-1} N_{i;p}(u) \mathbf{P}_{i;k}; \quad k = 0; \dots; K$$

- 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
 → Knot refinement and degree elevation



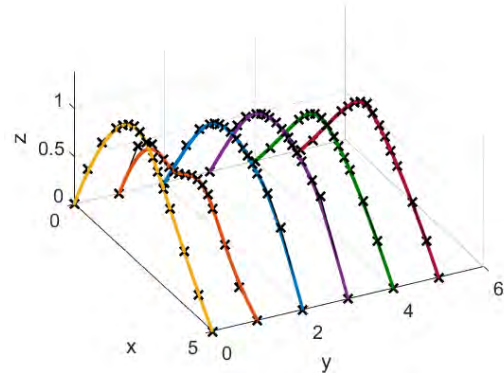
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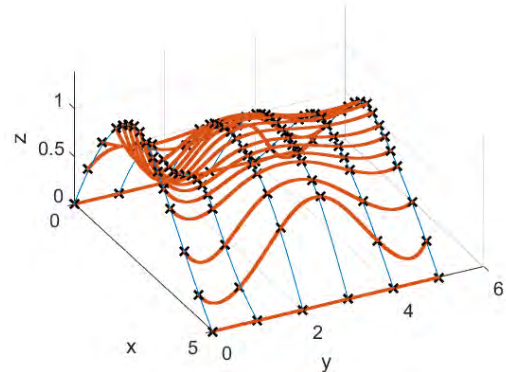
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Construction of skinned B-spline surfaces

Skinned B-spline surfaces

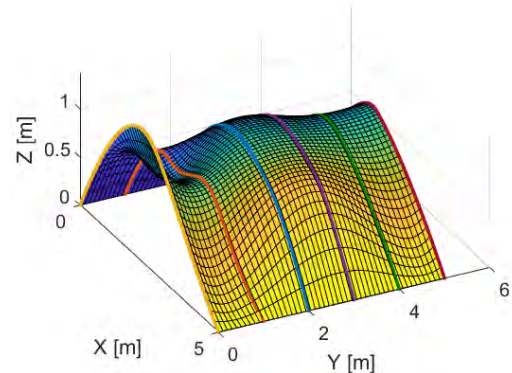
- Construction of control curves
 - B-spline curves interpolating the control points of the section curves
- Control points of the control curves define control grid of the skinned surface
- Skinned surface:
 - Tensor product B-spline surface
 - Section curves are isoparametric curves on the surface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



Construction of skinned B-spline surfaces

Skinned B-spline surfaces

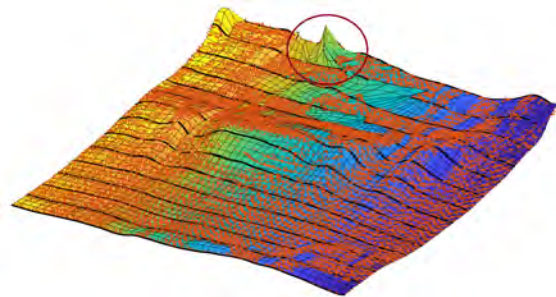
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Construction of skinned B-spline surfaces

Skinned B-spline surfaces: Kijkduin beach-dune

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



Construction of skinned B-spline surfaces

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Locally parameterized tensor product B-spline surfaces

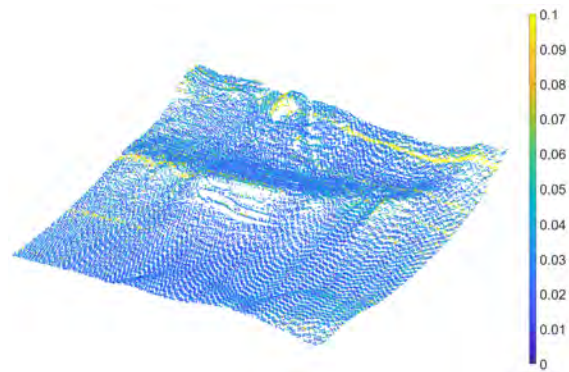
Skinned B-spline surfaces as base surfaces

- 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
 - Locally parameterized B-spline surfaces

Locally parameterized tensor product B-spline surfaces

Locally parameterized B-spline surfaces

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



Euclidean residuals [m]

MSE

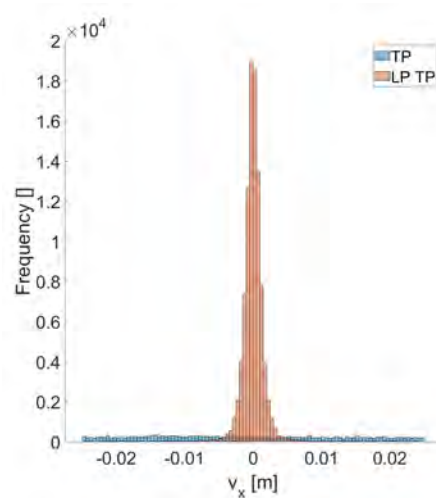
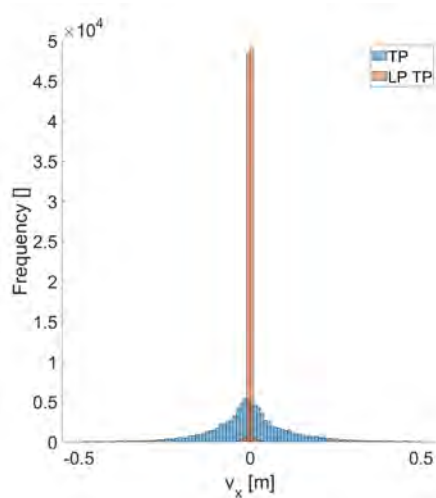
$n_p = m_p$	TP	LP TP
25	0.3705	0.0234
26	0.3681	0.0226
27	0.3628	0.0224
28	0.3514	0.0219
29	0.3528	0.0213
30	0.3506	0.0211
31	0.3447	0.0207
32	0.3342	0.0206
33	0.3376	0.0204
34	0.3265	0.0206

MSE [m] (Beach)

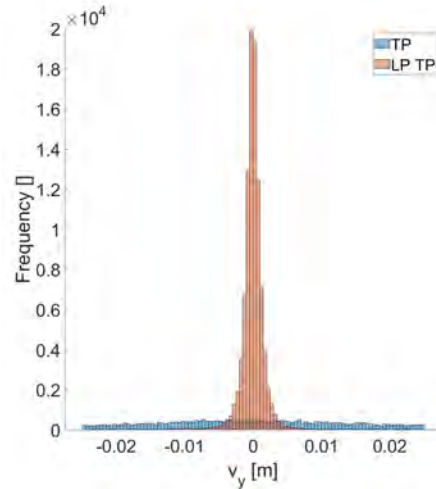
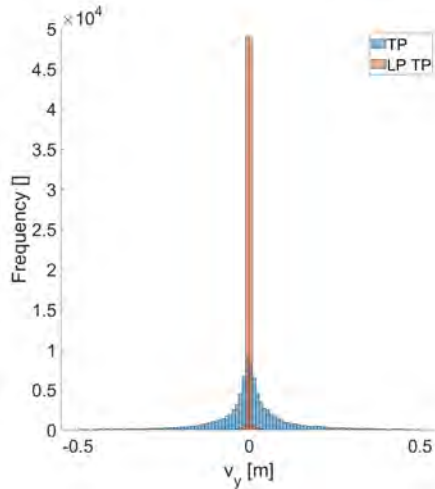
$n_p = m_p$	TP	LP TP
20	0.0055	0.0039
21	0.0054	0.0038
22	0.0052	0.0038
23	0.0050	0.0038
24	0.0050	0.0037
25	0.0049	0.0036
26	0.0048	0.0036
27	0.0047	0.0036
28	0.0049	0.0034
29	0.0048	0.0034

MSE [m] (Soil erosion)

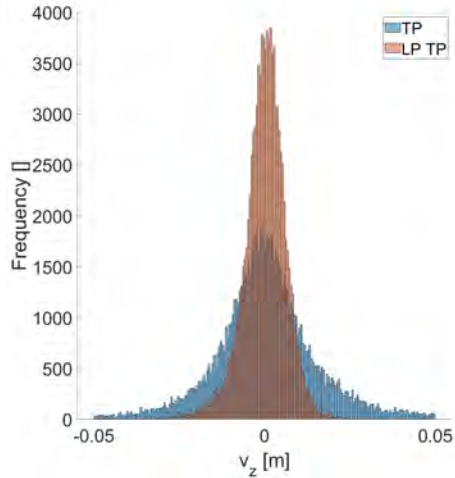
Results



Results



Results



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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
- 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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