Constraint Energies for the Adaptation of 2D River Borderlines to Airborne Laser Scanning Data using Snakes

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Motivation

Goal

- Integration of topographic vector data (e.g., ATKIS® roads) and DSM

Problem

- Discrepancies between the data sets due to
  - differences in time, surveying methods, and modeling
Objectives

- Method for adaptation of 2D vector data and ALS data
  - Considering object information in the ALS data (structure elements – break lines, distinctive points)
  - Using the ALS data for the adaptation without sophisticated feature extraction and subsequent assignment to single vector objects
  - Considering of the **semantics** of the objects
  - Calculation of shift vectors
  - Focus on objects with height related features: roads and rivers
Semantics in terrain modeling

Object representation

- Horizontal plane
  - Increasing terrain outside
- Tilted subplanes
  - Maximum slope and curvature
  - Decreasing heights and increasing terrain outside
- Height relations
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**Strategy using snakes**

**Adaptation of the vector objects to the ALS data**

- Initialization of the snakes using the 2D vector data (defining **internal energy** / topology)
- Definition of the **image energy** from ALS data or derived products
- Integration of additional object knowledge (**constraint energy**)
- Iterative energy optimization process – updating the position and shape of the snake with respect to the ALS data
- Goal: consistency of ALS features and vector data
Roads

**Initialization**

**Iterations**
This presentation is focused on rivers.
Snakes

- Parametric Active Contours (Kass et. al, 1988)

  - Parametric Contour $C(s) = (x(s), y(s))$
    - $s \in [0,1]$: arc length
  
  - Image $I(x,y)$

  - Energy functional $F(C(s))$
    \[
    F(C(s)) = \int_0^1 \left[ E_{int}(C(s)) + E_{img}(C(s)) + E_{con}(C(s)) \right] ds
    \]

  - Fit contour to the image such that $F(C(s)) \rightarrow \text{min}$
Snakes – Internal Energy

- Internal energy $E_{int}(C(s))$: geometric model of the object

$$E_{int}(C(s)) = \frac{1}{2} \left( \alpha(s) \cdot |C_s(s)|^2 + \beta(s) \cdot |C_{ss}(s)|^2 \right)$$

- with: $C_s, C_{ss}$: derivatives of $C$ with respect to $s$
  $\alpha(s)$: elasticity control
  $\beta(s)$: rigidity control

- Approximation of the derivatives by finite differences

$$\alpha\left( (C_i - C_{i-1}) - (C_{i+1} - C_i) \right)$$
$$+ \beta\left( C_{i-2} - 2C_{i-1} + C_i \right) - 2\beta\left( C_{i-1} - 2C_i + C_{i+1} \right) + \beta\left( C_i - 2C_{i+1} + C_{i+2} \right)$$
Snakes – Image Energy

- Image energy $E_{\text{img}}$ represents object properties
- 1. step: combined Image from ALS height and intensity data:

$$\text{Image} = a \cdot E_{\text{Int}} + b \cdot E_{\text{DSM}}$$

$a,b$ – weights

$E_{\text{Int}}$ – intensity image

$E_{\text{DSM}}$ – digital surface model
Snakes – Image Energy

- 2. Step: image energy $E_{img}$ from the combined ALS image:
  - Negative second derivatives of the Image

$$E_{img} = -\sqrt{\left(\frac{\delta^2 G}{\delta x^2} * I\right)^2 + \left(\frac{\delta^2 G}{\delta y^2} * I\right)^2}$$

G – Gaussian
I – combined Image
Snakes – Constraint Energy

- Integration of object or context knowledge using constraint energy

- Originally (Kass et. al, 1988): springs and volcanoes

- Three components in the proposed method:

\[ E_{con} = E_{Twin} + E_{Flow} + E_{Gradient} \]
Institute of Photogrammetry and GeoInformation

### Snakes – Constraint Energy

- Integration of object knowledge using *constraint energy*
  \[
  E_{con} = E_{Twin} + E_{Flow} + E_{Gradient}
  \]

- **First component**: Twin snakes for river borderlines (Kerschner, 2001)
  \[
  E_{Twin} = \kappa_{Twin} \cdot (d(v_i) - d_0)^2
  \]

- Connection of the opposite borderlines using a predefined distances (e.g., from GIS data)

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[Diagram of initialization and solution]
Integration of object knowledge using constraint energy

\[ E_{\text{con}} = E_{\text{Twin}} + E_{\text{Flow}} + E_{\text{Gradient}} \]

• Second component: Flow direction of the river (downhill)

\[ E_{\text{Flow}} = \kappa_{\text{Flow}} \cdot w_{\Delta h_i} \cdot h(v_i) \]

• with

\[ w_{\Delta h_i} = \begin{cases} |h_{i-1} - h_i| & \text{if } h_{i-1} - h_i < 0 \\ 0 & \text{else} \end{cases} \]
Integration of object knowledge using *constraint energy*

\[ E_{\text{con}} = E_{\text{Twin}} + E_{\text{Flow}} + E_{\text{Gradient}} \]

- Third component: gradient direction at the embankments
- Choose the most probable edge for each snake node

\[ E_{\text{Gradient}} = \kappa_{\text{Gradient}} \cdot d(v_i) \]
Snakes – Constraint Energy

- Integration of object knowledge using **constraint energy**

\[ E_{con} = E_{Twin} + E_{Flow} + E_{Gradient} \]

- Third component: gradient direction at the embankments

\[ E_{Gradient} = \kappa_{Gradient} \cdot d(v_i) \]
Energy minimization

- Functional minimization: variational calculus
  \[ F(C) = \int_0^1 E(s, C, C_s, C_{ss}) ds \rightarrow \min \]

- Solution: Euler’s differential equation

- Iterative Solution (discretisation in time)
  \[ AC_t + \frac{\partial E_{img}(C_{t-1})}{\partial C} = -\gamma(C_t - C_{t-1}) \]

  \( A \) – internal energy, \( \gamma \) – step size
## Data

- **ALS data – 3D point cloud**
  - Optech ALTM 3100
  - Flying altitude: 1000 m
  - Point density: 4 Pt/m²
  - First/Last echo mode
  - 0.15 m (height), 0.3 m (horizontal accuracy)

- **2D vector data**
  - German ATKIS Digital Landscape Model (DLM)
  - 3-5 m horizontal accuracy (roads and rivers)
  - Object knowledge in attributes
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**Data – DSM**

![Image of DSM data for a geographic area]
Data – Airborne Laser Scanning
(backscattered intensity)
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### Examples

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<th>$k_{\text{Twin}}$</th>
<th>$k_{\text{Flow}}$</th>
<th>$k_{\text{Gradient}}$</th>
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<td>Shift: 10m</td>
<td>0.16</td>
<td>1.2</td>
<td>3</td>
<td>0.2</td>
<td>10</td>
<td>0.05</td>
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<tr>
<td>Shift: 20m</td>
<td>0.16</td>
<td>1.2</td>
<td>3</td>
<td>0.2</td>
<td>10</td>
<td>0.05</td>
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<th>shift: 15 m</th>
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<td>8.90</td>
<td>13.34</td>
<td>17.77</td>
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<td>1.15</td>
<td>1.23</td>
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RMS of point to line distances (m)

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<td>8.16  8.13</td>
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<td>3.01  2.53</td>
<td>1.04  2.42</td>
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Conclusion

- Active contours for the adaptation of 2D river borderlines to ALS features
- Flexible algorithm for different line objects (rivers, roads)
- Promising results with simple definition of the image energy
- Different possibilities for the integration of object knowledge
- The two borderlines support each other due to twin energy
Outlook - Object Knowledge

- **Bridges** – strong features in DTM, hints for river
- Increasing the transferability of the weights
- Combined road and river networks

example for bridge energy for roads
Thank you for your attention!

Questions?