
A comparative assessment on their suitability for wavelet-based analysis over complex terrains

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Background

- ongoing Swiss-Romanian research project (2013-2015), aiming to connect wind, terrain and vegetation modeling

- cross-disciplinary approach consisting in coupling 3 tracks:
  1. Large Eddy Simulation techniques
  2. 3D digital terrain representations
  3. Landscape models and vegetation patterns
Main research goals

1. Evaluating the response of the multi-resolution digital elevation models within wavelets analysis

2. Triangulated Irregular Network vs. regular grid: pros and cons for 3D analyses

3. Assessing and mapping of wind potential over complex terrains
State of the art

- **Wavelets:** Mallat (1989) was defining and developing the current wavelet transform; Datcu et al. (1996) used wavelets to estimate the fractal dimension of DEM; Beyer (2003) and Lashermes et al. (2007) extracted geomorphometric indicators (terrain inclination, curvature) from wavelet coefficients.

- **DEM grid wavelets:** Kalbermatten et al. (2010) realized a multi-scale analysis of topographic features by using the wavelet transform.

- **WTIN:** Wu & Amaratunga (2003) introduced a new multi-resolution data representation: the Wavelet Triangulated Irregular Network (WTIN). The model is based on second generation of wavelet theory (lifting schemes) and it is specially designed for geographical height field data.
1. Evaluating the response of the multi-resolution digital elevation models within wavelets analysis

- Defining the framework
  - scale-driven processes
  - hierarchy of topographical features

- Wavelets analysis – a tool for non-stationary signals
  - comparing cell-based DEM format and TIN
  - constraints on input data availability and algorithms
  - similar results?

  comparing study: Travers landslide from Swiss Jura
  - Sample data processed both as regular grid and TIN
Regular matrix of interpolated elevation data

Three different components:
- **Nodes** – computational model
- **Mesh** – network connection of nodes
- **Grid** - representations with cells

First generation of wavelets transform

(Kalbermatten, 2011)

* Hereafter DEM grid
Digital elevation models: regular grids

Relevant surface analysis layers to be used in the wavelet transform

- LAS file
- DEM grid
- Curvature
- Profile curvature
- Plan curvature
- Slope
Digital elevation models: TIN

- Finite set of points stored together with their elevation
- No point pattern and point density could vary over domain
- Any point will lie on a vertex, edge or in a triangle of the triangulation
- Wavelet TIN (WTIN) – second generation of wavelets (lifting schemes)

(van Kreveld, 1997)
Digital elevation models: TIN

Relevant surface analysis layers to be used in the wavelet transform

Las file

Slope

TIN

curvature?????
Digital elevation models: TIN

**TIN Curvature** (van Kreveld, 1997)

TIN does not distinguish between plan and profile curvature...

Every edge of TIN can be defined as convex, concave or flat:

- **convex region**: all incident ridges are convex
- **saddle**: incident triangles are different

$v$ = convex curvature
$c$ = concave curvature
$f$ = flat

Delaunay polygons

Similar region are erased to obtain terrain partition
2D Wavelet transform (Kalbermatten, 2011)

The necessary condition for a perfect reconstruction of the original signal (DEM grid, TIN) is that the wavelet transform must be continuous. Using a function with zero mean (Mallat, 2000), the transform can be applied to a two-dimensional signal (on each X, Y dimension the transform will be applied and it will result in 4 signals).

Original DEM 1m res -> 2nd decomposition level -> DEM 4m res

Continuous WT- using a function with zero mean (Mallat, 2000)
Scale space topologies (Kalbermatten et al., 2011)

Geomorphological features extraction
## Multi-resolution capabilities of digital elevation models

<table>
<thead>
<tr>
<th>DEM grid</th>
<th>TIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Suitable for direct use in scalable distributed GIS</td>
<td>- not suitable for direct use in scalable distributed GIS services because it does not have a natural multi-resolution structure</td>
</tr>
<tr>
<td>- May loose terrain accuracy and may change the related terrain attributes (slope, curbature, aspect...)</td>
<td>- need algorithms to efficient edge collapse/vertex split</td>
</tr>
</tbody>
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(Deng et al., 2006)

(Yang et al, 2005)
Proposed validation for wavelets approach for DEM grids and TIN
(adapted from Kalbermatten, 2010)

1. Statistical analyses:

- **Point-wise elements** – based on elevation (compute mean, median, maximum, standard deviation)
  - **Challenge**: slope, curvature

- **Surface roughness** – based on elevation, slope (Hurst coefficient)
  - **Challenge**: slope, curvature

- **Profile-based analyses** – based on elevation (compute mean, median, maximum, standard deviation)
  - **Challenge**: slope, curvature
Proposed validation for wavelets approach for DEM grids and TIN

(adapted from Kalbermatten, 2010)

2. Global autocorrelation:

- Moran’s coefficient, Geary’s ratio – based on elevation
  - **Challenge:** slope, curvature

3. Slope to elevation distribution

- Bi-variate distribution of slope-elevation – (weighted linear regression)
  - **Challenge:** other pairs: slope - curvature?
2. DEM grid vs. TIN: pros and cons for 3D analyses?

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>DEM grid</th>
<th>TIN</th>
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<tbody>
<tr>
<td>Variable resolution</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>X, Y location for surface details</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Fast transform (linear filter)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Multi-resolution capability</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Easy compression</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Interpolation scheme suitable for GIS applications</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Wavelet-based 3D geometric modeling technique</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>System resources</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>
Developing a conceptual multi-resolution analysis framework for numerical experiments over complex terrains

Building TIN and DEM based on LiDAR data processing for two areas in Switzerland and Romania

Integrating land cover models / meteorological measurements into WTIN

WindLand project framework, 2013-2015
Future goals

- To create an unique modeling framework for DEM grid and TIN based on the previous research works

- To identify all constraints and differences between the two terrain models

- To integrate other types of data (land cover and meteorological measurements) in order to assess and map wind modeling over complex terrains (WindLand project)
Key references


Project collaborators and partners:

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