Revealing Celtic Fields from LIDAR data using Kriging based fi ltering.

Celtic Fields.

Impression of a Celtic Field system. (Rob Beentjes)

Celtic fields are prehistoric agricultural field systems that are recognizable as rectangular patches of land of about 40 × 40 meter surrounded by low earth walls. The highlight of the use of Celtic fields was between 800 B.C. and 0 B.C. and they can be found in several countries in North-West Europe. In open land Celtic field systems are often still recognizable, even from the ground, although it is easier to distinguish them by color changes in areal photo's. Unfortunately it is very difficult to find Celtic field systems in forest areas, as small elevation differences or small color changes are completely masked by the forest cover.

Airborne laser altimetry for fi nding archaeological objects below trees.

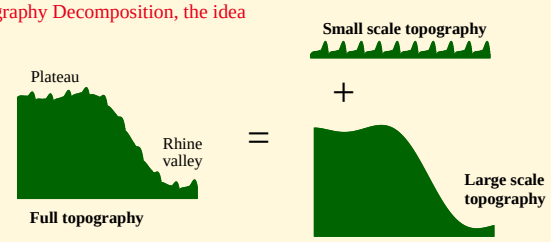
It turns out however that, even in forest areas, Celtic field systems can be found by analyzing airborne laser altimetry data. Several approaches exist to obtain the bare earth surface out of raw airborne laser scanning point clouds. After removing points that were reflected by trees or shrubs, the remaining points are assumed to represent the ground surface. In this way it is possible to look for archaeological features under the trees.

Airborne LIDAR.

Celtic fi elds, inside the circle, revealed by illumination.

In The Netherlands, the Dutch Ministry of Public Works initiated the setup of the so-called Actueel Hoogtebestand Nederland (AHN), that can be translated as 'Up to date height data base of The Netherlands'. This database consists of interpolated airborne laser altimetry data covering the whole of The Netherlands. This elevation model can be used for a large amount of applications, including many archaeological. The third author applied a technique based on illumination to visualize ancient Celtic fields, near Doorwerth, situated in the East of the Netherlands, out of AHN data. The gray figure shows the fields as exposed by the third author. By illuminating the ground surface points in a suited way in a software visualization program, some unknown field systems could be traced by the shadows of the micro-relief of the low earth walls.

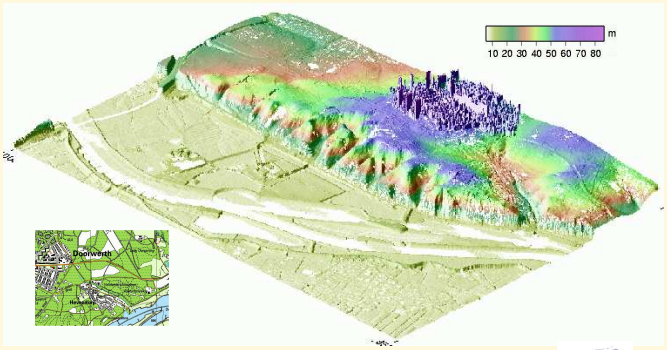
Topography Decomposition, the idea



We show that this approach can still be improved. In the original approach, the micro-relief is visualized with respect to the natural relief of the ground surface as represented by the laser data. By removing the large scale topography, the micro-relief becomes more prominent: only small-scale features like road beds, foot-paths and the earth walls surrounding the Celtic fields remain. The height difference of about 70 meter in the original data is reduced to about 50 centimeter in the small scale topographic data representing the micro-relief.

The filtering is done by means of the Geostatistical Kriging method, a special case of Best Linear Unbiased Prediction. In this method information on correlation between observations and relative quality of individual observations is used to attach weights to observations for a prediction at a certain location, e.g. near a Celtic field. If a long correlation distance is used, more weight is attached to more far observations, which will result in a representation of the large scale topography. Subtracting this large scale topography from the original data results in the small scale topographic data that in the end is used as input for the Celtic fields visualization.

Topography of the Doorwerth area.



Topography of the Doorwerth area with exaggerated heights in meters. The river Rhine is in the front, the village of Doorwerth is clearly visible on the plateau. The Celtic fields are situated on the plateau, on the right hand side of Doorwerth. The bottom-left figure shows an extract of a local topographic map. The first part of the Celtic field system was found in the forest on the North-East of the curved road. The new method shows that the field system continues on the South-East part of the road as well.

(Adapted) Ordinary Kriging.

Estimate the Best Linear Unbiased height $\hat{z}_0 = \sum_{i=1}^{n} w_i z_i$ from height observations $z_1, \ldots, z_n$ by solving the Ordinary Kriging system $\mathcal{C}_n \cdot \mathbf{w}_n = \mathbf{d}_n$ with

$$\mathcal{C}_n = \begin{pmatrix} C_{11}+N & \ldots & C_{1n} & 1 \\ \vdots & \ddots & \vdots & \vdots \\ C_{n1} & \ldots & C_{nn}+N & 1 \\ 1 & \ldots & 1 & 0 \end{pmatrix}, \quad \mathbf{d}_n = \begin{pmatrix} C_{10} \\ \vdots \\ C_{n0} \\ 1 \end{pmatrix}, \quad \mathbf{w}_n = \begin{pmatrix} w_1 \\ \vdots \\ w_n \\ \mu \end{pmatrix}.$$

C_{ij}	covariance between observations z_i and z_j
$\mathcal{C}_n$	Redundancy or Variance-Covariance Matrix
$\mathbf{d}_n$	Proximity vector
$\mathbf{w}_n$	Weight vector (incl. Lagrange multiplier μ)
N	Nugget effect

Topography Decomposition with Kriging

Assumption: topography $Z(x, y)$ can be written as

$$Z(x, y) = Z_L(x, y) + Z_s(x, y) + \text{white noise}$$

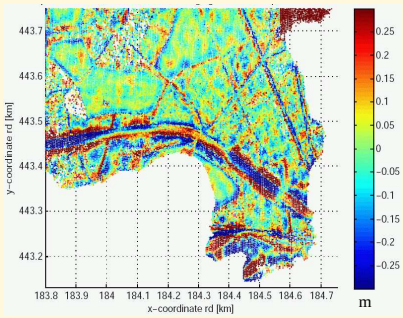
with $Z_L(x, y)$ the large scale topography and $Z_s(x, y)$ the small scale topography.

Idea. Estimate just the large scale topography $Z_L(x, y)$ by

- Adding a nugget effect N in the redundancy matrix to reduce influence of inter point covariances.
- *Not* adding the nugget in the proximity vector. In this way the exact solution at the observation locations is avoided.
- Using long range covariances to give more weight to far away observations.
- Predicting $\hat{Z}_S(x, y)$ at the observation locations by means of Kriging system with local neighborhood.

Moreover, the residuals $\hat{Z}_s(x, y) = Z(x, y) - \hat{Z}_L(x, y)$ represent the small scale topography.

Topography decomposition results



Scatterplot of the laser altimetry data residuals of the plateau after topography decomposition.

The Celtic fields pop up as yellow lines.

Apparently, the Celtic fields continue on the South of the prominent main road.

More information

More information like parameter settings and references can be obtained from the authors or in the full article:

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Astrid Humme, Roderik Lindenbergh and Chris Sueur
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