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DETECTION OF TERRAIN FEATURES EMBEDDED IN A PRE-PROCESSOR FOR TOPOGRAPHIC DATA

VOLKER BERKHAHN
Institute for Computer Science in Civil Engineering, University of Hannover, Callinstraße 34, 30167 Hannover, Germany

STEPHAN MAI
Department M1, German Federal Institute of Hydrology (BfG), Am Mainzer Tor 1, 56068 Koblenz, Germany

A terrain feature detection method based on a slope analysis is developed to identify breaklines. These breaklines are essential to specify b-spline surfaces approximating terrain features such as river embankments, dykes and dams. Based on these b-spline surfaces regular triangle meshes are generated with user specified edge ratio and element orientation. A Delaunay based refinement and coarsening approach is applied to generate irregular triangle meshes for floodplains and to concatenate regular triangle meshes. The developed methods are applied within a case study of the River Weser (Unterweser) in Northern Germany.

INTRODUCTION

Numerical simulations in hydrodynamics require discrete element meshes approximating the considered topography. This topography information is given by sounding data gained via different sounding methods. These sounding data are characterized by a very high density in general, different spreading of sounding data and, eventually, partially lack of information. In addition, most times these sounding data cover much more than the relevant area actually considered. Based on this sounding information digital terrain models (DTM) with equidistant supporting points are generated. DTM data imply implicitly information about terrain features such as floodplains, embankments and breaklines, which should be represented in the required discrete element meshes for numerical simulations.

This leads to the demand of a pre-processor analysing sounding data in order to identify terrain features. The key idea is the approximation of the topography by a rectangular high resolution grid, upon which a slope analysis can be performed very effectively via the one-over-distance method. In addition, this slope analysis grid leads to a significant data reduction compared with the initial amount of sounding data and enables an easy handling even with small size personal computers or laptops. The identification of embankments and breaklines is performed with a user specified limit slope value, which should be adapted carefully to the terrain features to be detected.

In order to avoid the grating of terrain features due to the rectangular analysis grid an interpolation scheme for slope values of arbitrary breakline points is developed. Thus, breakline points meet exactly the specified limit slope value. This involves the automatic detection of characteristic features in floodplains. The reduced set of DTM data and the identified terrain features are the input data for a hybrid meshing tool.

DATA ANLYSIS

The data of the case study describe the River Weser and floodplains between the cities of Bremen and Bremerhaven. The topography is given by a digital terrain model (DTM) with equidistant supporting points. The point distance of the DTM is 10 m. An overview of the entire data set is illustrated in figure 1.

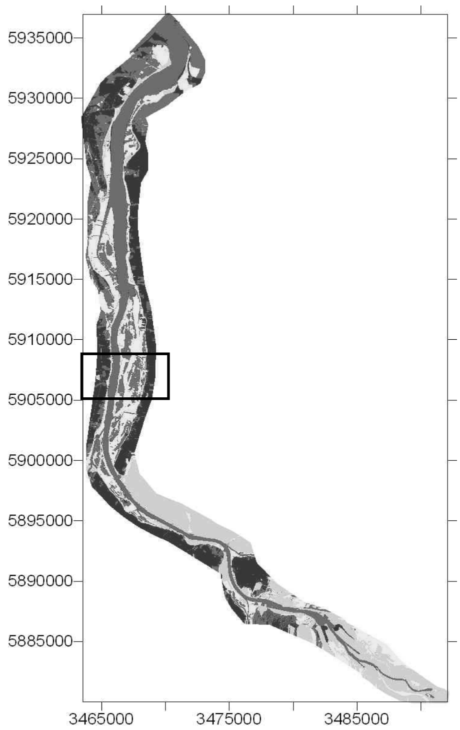

Figure 1. Overview of the digital terrain model for the River Weser (Unterweser).

The data set of the River Weser consists of 2,500,000 DTM points. In order to demonstrate the approach of processing topographic data a typical section of the River Weser is extracted. This area is marked by a black rectangle in figure 1. This extracted area of the river and floodplains is described by 43,200 DTM points and is shown in figure 2.

This illustration reveals the river bed with a sharp embankment on the left hand side and two embankments less sharp on the right hand side of the river. The floodplains are bordered by dykes on both sides of the river. In addition, a small dam is located in the floodplains on the right hand side. All these terrain features have a significant effect on the numerical hydrodynamic simulations and have to be identified in the DTM in order to build up an appropriate element mesh.

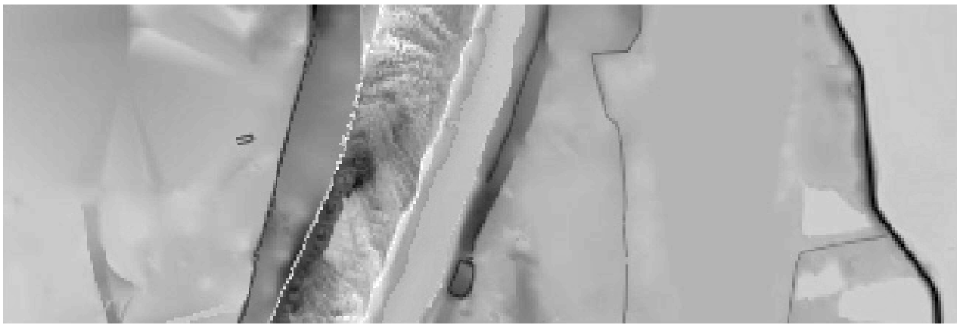

Figure 2. Extracted area of the River Weser and adjacent floodplains.

SLOPE ANALYSIS

In order to identify terrain feature a slope analysis of the topography is performed. Rath and Pasche [5] investigated several methods to determine slope values on a regular grid and recommend the one-over-distance-method presented originally by Jones [3]. The slope value of a grid point $\mathbf{d}_{ij}$ is determined by

$$S_{ij} = \operatorname{atan}\left(\sqrt{S_{iju}^2 + S_{ijv}^2}\right)180/\pi \quad \text{with} \tag{1}$$

$$S_{iju} = \frac{(z_{i+1\,j+1} + \sqrt{2}z_{i+1\,j} + z_{i+1\,j-1}) - (z_{i-1\,j+1} + \sqrt{2}z_{i-1\,j} + z_{i-1\,j-1})}{(4+2\sqrt{2})\Delta d}$$

$$S_{ijv} = \frac{(z_{i-1\,j+1} + \sqrt{2}z_{i\,j+1} + z_{i+1\,j+1}) - (z_{i-1\,j-1} + \sqrt{2}z_{i\,j-1} + z_{i+1\,j-1})}{(4+2\sqrt{2})\Delta d},$$

where z denotes the z-coordinate of the neighboring grid points and Δd is the edge length of the regular analysis grid.

TERRAIN FEATURE DETECTION

The set D_{emb} of grid points representing embankments is given by

$$D_{emb} = \left\{\mathbf{d}_{ij} \mid S_{ij} > S_{lim}\right\}, \tag{2}$$

where S_{lim} denotes a user specified limit slope value. Rath and Pasche [5] defined the set D_{break} of breakpoints by

$$D_{break} = \left\{ \mathbf{d}_{ij} \mid S_{ij} > S_{lim} \wedge (S_{i\pm1j} < S_{lim} \vee S_{ij\pm1} < S_{lim}) \right\} . \tag{3}$$

The set of breakpoints is a subset of the set of analysis grid points. Consequently, the resulting breaklines are zig-zag lines. In order to avoid zig-zag breakline, an interpolation scheme to determine breakpoints with the exact user specified limit slope value is defined. For an edge $\mathbf{d}_{i\text{-}1j}$ $\mathbf{d}_{ij}$ the breakpoint $\mathbf{b}_{i\text{-}1j}$ is determined by

$$\mathbf{b}_{i-1j} = \frac{S_{i-1j} - S_{lim}}{S_{i-1j} - S_{ij}} \mathbf{d}_{ij} + \frac{S_{lim} - S_{ij}}{S_{i-1j} - S_{ij}} \mathbf{d}_{i-1j} \quad \text{for } \operatorname{sign}(S_{ij} - S_{lim}) \neq \operatorname{sign}(S_{i-1j} - S_{lim}) . \tag{4}$$

The breakpoint $\mathbf{b}_{ij\text{-}1}$ for an edge $\mathbf{d}_{ij}$ $\mathbf{d}_{ij\text{-}1}$ is determined analogically. In order to achieve a moderate smoothing the points of the analysis grid are generated on a rectangular b-spline surface approximating the topography. Figure 3 illustrates the b-spline surface based slope analysis grid and the interpolated breakline points.

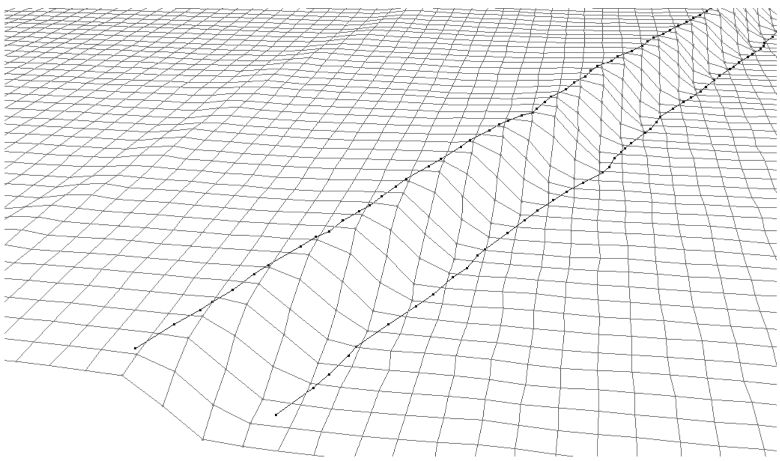

Figure 3. Slope analysis grid and interpolated breaklines for a limit slope value of 10 degrees.

The z-coordinates in the three dimensional view of figures 4 to 7 are scaled by the factor of 5 in order to clarify the detected terrain features and the generated hybrid element mesh. Figure 4 demonstrates the identified breaklines for limit slope value of 5 degrees. Figures 3 and 4 reveal the well identified sharp embankment of the river. The identification of this sharp embankment works fine with any limit slope value between 10 and 5 degrees. On the other hand figure 4 reveals the neglect of terrain feature such as smooth embankments, dykes and dams.

For the identification of smooth embankments and dykes the limit slope value is reduced to 3 degrees. The small dam in the floodplain is identified by a limit slope value of 1.5 degrees as shown in figure 5. On the other hand, for this level of limit slope value the river bed and embankments are unidentifiable. This emphasizes the need of a well adapted limit slope value depending of the terrain feature to be identified.

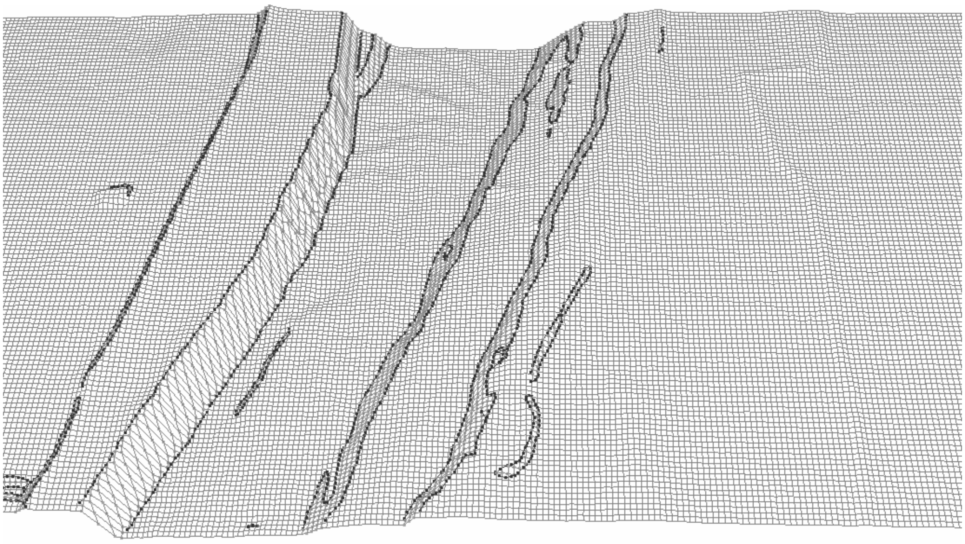

Figure 4. Detected terrain features for limit slope value of 5 degrees.

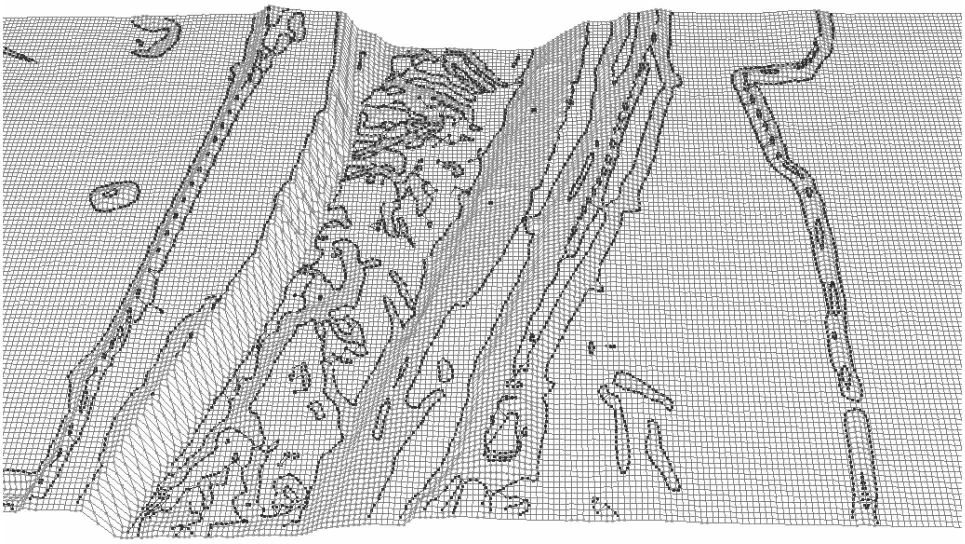

Figure 5. Detected terrain features for limit slope value of 1.5 degrees.

HYBID MESHING APPROACH

The objective of the hybrid meshing scheme presented by Rath et al. [6] and Berkhahn et al. [2] is to combine the advantages of regular meshes based on b-spline surfaces and irregular triangle meshes generated by a Delaunay refinement and coarsening. Due to specific requirements concerning specified edge ratio and element orientation, river embankments, dykes and dams are represented by regular element meshes (see Berkhahn et al. [1]). In contrast to this, floodplains are covered by irregular triangle meshes. For this separate consideration of embankments, river bed and floodplains the identified breaklines are essential.

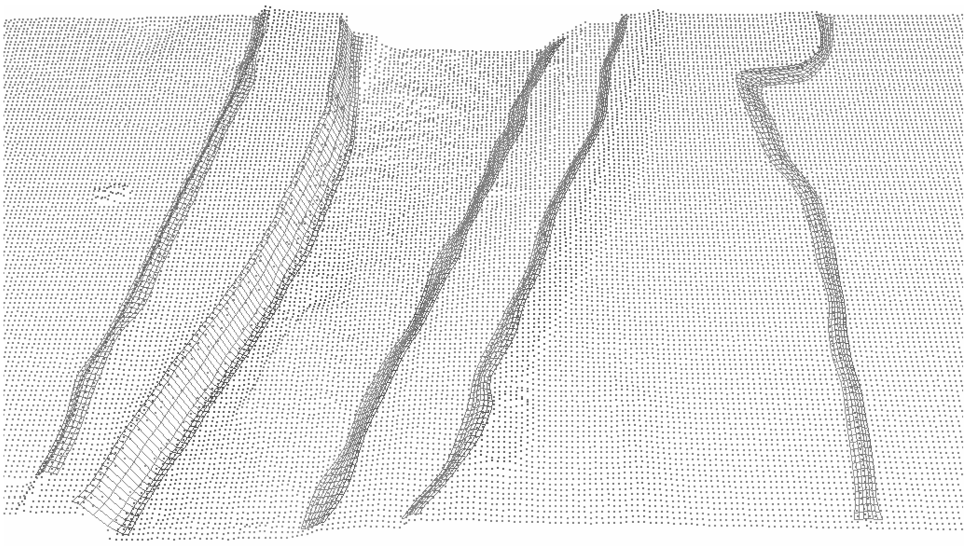

Figure 6. DTM points and b-spline surfaces approximating identified terrain features.

Figure 6 shows the b-spline surfaces representing the river embankments, dykes and dams. A segmented b-spline surface $\mathbf{b}(u,v)$ (see Farin [4]) approximating embankments is defined by

$$\mathbf{b}(u,v) = \sum_{i=0}^{N}\sum_{j=0}^{M} \mathbf{d}_{ij} N_i^K(u) N_j^L(v) \quad \text{with} \quad u \in [u_K, u_{N+1}] \quad \text{and} \quad v \in [v_L, v_{M+1}], \tag{5}$$

where $\mathbf{d}_{ij}$ denotes a regular grid of control points. The b-spline functions $N_i^K(u)$ and $N_j^L(v)$ are of the degree K and L respectively. The boundaries u_j and v_j of all parameter segments are gathered in knot vectors $\mathbf{u}$ and $\mathbf{v}$

$$\mathbf{u} = [u_0, \ldots, u_{N+K+1}]^T \quad \text{and} \quad \mathbf{v} = [v_0, \ldots, v_{M+L+1}]^T. \tag{6}$$

The b-spline functions are defined by

$$N_i^0(u) = \begin{cases} 1 \text{ for } u \in [u_i, u_{i+1}[\\ \quad 0 \text{ else} \end{cases} \quad \text{for} \quad i = 0, \ldots, N+K \quad \text{and} \tag{7}$$

$$N_i^r(u) = \frac{u - u_i}{u_{i+r} - u_i} N_i^{r-1}(u) + \frac{u_{i+r+1} - u}{u_{i+r+1} - u_{i+1}} N_{i+1}^{r-1}(u) \quad \text{for} \quad \begin{array}{l} r = 1, \ldots, N+K \\ i = 0, \ldots, N+K-r \end{array}. \tag{8}$$

Nodes $\mathbf{n}_{ij}$ of the regular element mesh are generated on a b-spline surface by user specified parameter distances Δu and Δv

$$\mathbf{n}_{ij} = \mathbf{b}(u_K + i\Delta u, v_L + j\Delta v) \quad \text{for} \quad \begin{array}{l} 0 \le i \le (u_{N+1} - u_K)/\Delta u \\ 0 \le j \le (v_{M+1} - v_L)/\Delta v \end{array}. \tag{9}$$

A Delaunay based refinement and coarsening scheme similar to the approaches presented by Rupert [7] and Shewchuck [8] is developed by Berkhahn et al. [2] in order to cover floodplains and to concatenate regular element meshes. First of all, a Delaunay triangulation is performed for the original point set, which involves all DTM, all identified breakline points and all nodes of regular element meshes. All DTM points are erasable and moveable during the coarsening and smoothing procedure of the triangle mesh. All other points are regarded to be fixed during the coarsening and final smoothing procedure.

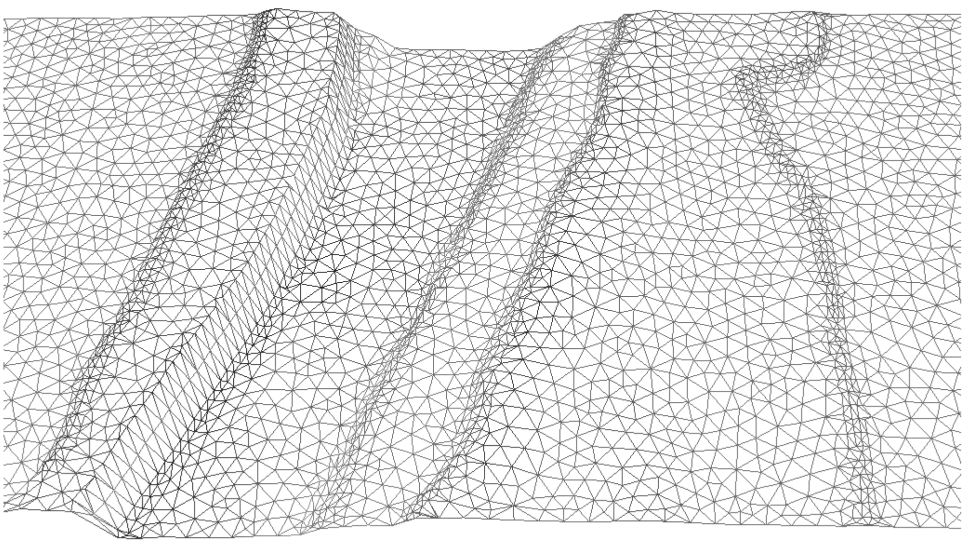

Figure 7. Hybrid triangle mesh with regular elements in areas of detected terrain features.

The coarsening procedure replaces all points of a triangle or of a single edge by the corresponding centre point if an edge length falls below a user defined limit value of the minimal edge length. The refinement procedure adds the corresponding centre point if the edge length of a triangle or a single edge exceeds the user defined limit value for the maximum edge length. Finally, a Laplace smoothing is performed for all points not regarded to be fixed. Figure 7 shows the generated hybrid triangle mesh. In this three dimension view the z-coordinates are scaled by the factor of 5.

CONCLUSION

In this contribution the authors demonstrate an approach to identify characteristic features in digital terrain features. The user specified limit slope value has to be adapted carefully to the features to be detected. The identified breaklines are used to define the boundaries of regular meshing areas within a hybrid meshing scheme. In areas, such as river embankments, dykes and dams, the edge ratio and element orientation can easily be modified since the element nodes are generated on approximating b-spline surfaces. Finally, a Delaunay based coarsening and refinement method is developed to generate irregular triangle meshes for floodplains and to concatenate regular triangle meshes.

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