PRODUCTION OF COUNTRY WIDE DTM FOR SERBIA AND MONTENEGRO

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ABSTRACT:

Project of building country wide DTM for Serbia and Montenegro is coming to its final phase. The project is based on scanning and vectorization of contours from existing 1:25000 topographic maps. Supplementing contour data with additional data sets available on map layers, such as hydrography and spot heights, is also planned within the project. Procedures and software tools for data acquisition, verification and processing were developed and implemented. Special attention was dedicated to the problem of high quality terrain surface modeling using contour data and all the other available information. The main concern was reconstruction and usage of all implicit information contained in contour data. Procedures based on TIN data structure were designed and implemented. Also, procedures and initial tests for the evaluation of the DTM quality are designed and started within the project. The paper reviews applied procedures, algorithms, current project status and some results.

1. INTRODUCTION

A project of establishment of completely digital production, maintenance, and usage of official topographic maps at scale 1:25000 has started in Serbia and Montenegro in 2002. One of the key components within this project was the production of the corresponding DTM for the whole state territory.

The resources for the realization of this project were rather limited. Solution was to use existing hardware, software and human resources as much as possible, and to develop solutions that will be tailored according to these resources. So, despite the recent developments of very efficient and cost effective systems for country wide DTM data acquisition such as InSAR and LiDAR, it has been decided to utilize already available data, because this approach required the minimum of initial investments.

Data that were already available were in a form of contour lines with additional spot heights, hydrography and terrain forms. Contour lines were directly plotted from stereo pairs mostly by using analog photogrammetric plotters. Map layers containing height data were scanned together with all the other map layers within a single campaign. Contours were digitized by using semi automatic digitization i.e. line following method. Software functions were developed for data verification and easy error detection and data editing. Various tools for data visualization and data editing were developed, including 3D visualization of large DTMs by using OpenGL.

Special attention was dedicated to the problem of surface reconstruction using contour data as a primary data form. The aim was to use all of the information contained in contour data implicitly. TIN based DTM modeling has been chosen. Some standard problems related to surface reconstruction using contour data are addressed. One of these is automatic detection of structure terrain lines. Also, special method for calculation of terrain normals at contour points is also implemented. The result was a high quality terrain surface reconstruction using TIN data structure. The developed software tools also contain all other DTM analysis functions useful for data verification and editing.

Procedures were designed and some tests were made in order to estimate the overall quality of the acquired DTM.

2. AVAILABLE DATA FOR PROJECT REALIZATION

Total area of the Serbia and Montenegro is 102350km^2. There have been some sporadic attempts to build country wide DTM for this area in the past, but the results were very questionable in terms of applied procedures and achieved quality.

Besides maps at 1:25000 scale, there were also some other data available that could be used for building country wide DTM. One of these sources is maps in 1:5000 scale. The other is DTMs acquired within orthophoto projects, also for 1:5000 mapping scale. However, these sources were not used for this project. The reason was that maps 1:5000 were only available for 40% of the state territory, mostly for the Vojvodina and some larger cities, and orthophoto projects were realized only for some larger cities. Since there were about 6500 map sheets in 1:5000 scale available, it is estimated that converting these maps to digital form would take too much time and resources. The ownership was also one of the issues. Of course, these data sources should be considered for updating DTM from 1:25000 maps later on.

There are 864 7.5’x7.5’ map sheets in 1:25000 scale covering the whole Serbia and Montenegro. Each map is composed of set of layers made on transparent material. These layers are the

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following: black color layer (map grid, objects, text, map sheet description, spot heights, etc), blue layer (hydrography), brown layer (contours and terrain forms), green layer (vegetation) and some other special layers (masks for hydrography, vegetation and road classifications). For building DTM only first three layers are used.

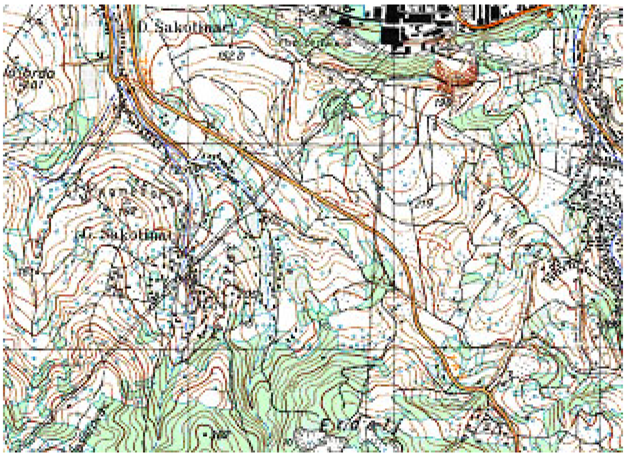

Figure 1. Topographic map 1:25000

One of the basic characteristics of 1:25000 topographic maps is that there is a very long cycle of updating these maps for the whole territory. Therefore, for some of these maps the last update was done twenty years ago. Fortunately, this is something that is not so dangerous when DTM that corresponds to 1:25000 maps is considered. Of course, there are certain areas such as open mine areas that would require special updating of existing map data.

The major data acquisition method for height data mapping for 1:25000 maps was aerial photogrammetry and most of the data was captured from 1955 to 1965. The aerial photography was done in 1:33000, 1:30000, and 1:26000 photo scales. Absolute orientation of photo models for some maps was done without prior aerial triangulation, so this could be one of the important sources of errors. Direct contouring in dynamic mode was mostly done by using analog photogrammetric plotters. Major contour interval is 10m, but in flat areas there are also contours on 5m and 2.5m interval.

3. DTM DATA ACQUISITION

Map layers containing height data were scanned together with all the other map layers within a single campaign. Drum scanner was used. Scanning resolution for most map layers was 508 DPI. This unusual scanning resolution is chosen to get map pixel with some logical metrics (0.05mm on map, 1.25m on the field).

There were two options for digitizing height data. One of them was to use separate map layers with height data, and the other was to use color paper map with all the layers merged. First option was preferable, and it was selected, because it was much more convenient to use automatic and semi-automatic procedures for contour vectorization without prior color separation, which was required for the merged color map. Disadvantage was that there were only four map corner marks available for georeferencing height map layers. This was the case for all the map layers, except for the black layer (contains map grid in Gauss-Krüger projection, and meridians and parallels). This was a problem, because it was not possible to use advanced methods for determination and removal of map distortions caused by distortions of the map material and scanning errors. Some tests were carried out and it has been estimated that these errors were about 4-5m (0.16-0.20mm on a map). Since it was not possible to detect and remove these errors using only four corner marks, these errors would contribute to the overall error budget of the DTM. For map layers with available map grid these errors were analyzed and systematic part of the total error, regardless of the source (map distortion or scanning errors) was successfully removed from the map image.

Contour vectorization was done by using semi-automatic, line-following technique. This was relatively fast, and most suitable considering the type of available contour maps. Contour heights were assigned manually to the digitized contours during vectorization. Problems that were experienced during this stage were related to the vectorization of maps for certain terrain types featuring lot of stones, extremely high slopes and lot of small pits. However, this process was rather straightforward in general, and it can be said that there were very few critical issues. Several workstations were dedicated for this task, working 16 hours per day. Also, all available spot heights are manually digitized. Spot heights data will be useful for improving DTM quality, but also for the detection of gross errors made during initial data capture and during contour vectorization and height assignment and spot height digitization. The whole process for contour vectorization and spot height digitization took about 18 months, including data verification.

Figure 2. Typical example of problematic area for contour vectorization from contour map layer

After all map layers with contours were vectorized contours were checked and their connections on map borders are corrected. This was done by using standard CAD tools.

4. SOFTWARE FOR DTM ANALYSIS

Since it was the necessary to provide as many workstations for DTM capture, verification and editing as possible, it was decided to use some relatively low-cost DTM software. The other requirements were related to the possibility of unlimited software customization and development of new algorithms for terrain modeling, verification and editing. The software that has met all of the above requirements was SurfIng. This software is part of the MapSoft GIS software. MapSoft is GIS software with extensive support to large scale mapping, specifically tailored for handling cadastral and topographic surveying maps. Various surveying data acquisition techniques are supported, as well as all the spatial data analysis functions required by surveyors. Software keeps the data within standard RDBMS using geo-relational data modeling approach, so the project size is practically unlimited. All the software was developed by the researchers from the Institute of geodesy, Faculty of Civil Engineering, University of Belgrade. It was planned to use MapSoft as a basic environment for the later development of special software for management with final country wide DTM data.

SurfIng is a complete solution for DTM data processing and analysis. It can perfectly operate autonomously or as a MapSoft module with high level of integration with other modules. As all the other MapSoft's modules it is developed by using Visual C++ and other advanced software development tools. It is a standard Windows application with rich and intuitive user interface and fast graphics.

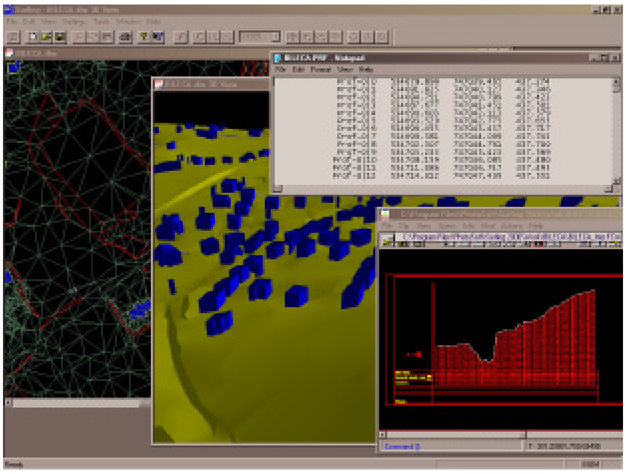

Figure 3. Surfing application for DTM analysis

DTM modeling provided by SurfIng is based on TIN (Triangulated Irregular Network). Constrained (optionally conforming) Delaunay triangulation is used as a basis for terrain surface reconstruction. Breaklines and other terrain form lines are fully supported. Terrain modeling is accomplished by using standard linear interpolation over triangles and also by using bicubic surface patches over triangles. The second method provides much better results. All standard DTM analysis functions are provided: height interpolation, profile and crossection interpolation, contour interpolation, volume calculations, 3D terrain visualization, data conversions, etc.

5. DATA VERIFICATION AND ERROR DETECTION

Considering large amount of data and lot of work done by operators during different stages of initial data capture and data digitization it is normal to expect errors to appear. At this stage of project realization, special attention is dedicated to the problem of gross errors detection and elimination. Some procedures are designed specially for these purposes. All of them were implemented using SurfIng DTM software environment.

Firstly, considering that contour interval was already known – it is less than 10m, it is possible to mark all the triangles with height difference larger than some specified value (usually 10m). Such triangles are indicating possible errors in contour heights. Some of these triangles are the consequence of missing contours. The reason could be the situation similar to the one illustrated on Figure 1. Each of these cases should be carefully examined and corrected.

Also, all the triangles where the difference between triangle face and bicubic surface patch is larger then some specified threshold are also marked. This usually indicates that there is no enough height data that could provide accurate terrain surface reconstruction, regardless of method of interpolation. Majority of these triangles belong to areas where horizontal triangles are located, i.e. triangles with all three vertices belonging to the same contour, or to contours with the same height. These areas are not treated at this stage, since they are going to be subject of the routines for automatic terrain form lines detection. Other cases are examined and corrected if needed.

Another method for error detection is interpolation of heights on points with known heights. Such points are available on black map layer in a form of spot heights. These points are digitized manually. It is possible to use these points as control points for DTM, providing that they were not included in process of building DTM. Considerable errors were detected using this method. Most of them were related to errors during initial data capture and map production.

Visual DTM data verification is also used during this stage. It is done by comparing interpolated contours and digitized ones, and also by 3D visualization of DTM. SurfIng supports second option by rendering large DTM data sets in near real-time. This is accomplished by using oct-tree DTM data (triangles) indexing and frustum view culling for fast selection of triangles that has to be rendered.

All of these data verification options are accompanied by simple correction of detected errors. Data editing is done directly on data that are kept within MapSoft's database.

6. TERRAIN SURFACE RECONSTRUCTION

Procedures described in the previous chapter were primarily designed with the purpose of detecting and correcting large, i.e. obvious errors. Definite verification and quality assessment of acquired DTM is possible only after final terrain surface is reconstructed. A lot of methods have been developed for generating high quality DTM. Some of these methods are general-purpose (linear prediction, finite element method) and some are specially designed or modified to use contour data in the best way. It is widely accepted that the best results are achieved by using linear prediction since it is based on sophisticated statistical analysis of data. However, even for this method, there are certain issues that have to be taken care of when contour data are used (Heitzinger, 2001).

6.1 Surface normal calculation for contour data

It is necessary to use all available information from maps that could improve terrain surface reconstruction. Some of these information are given implicitly by contours (Schneider, 1998). This information could be generated by using rules applied during map making process and by respecting the very nature of contours. Some of these are: limited terrain height in areas bounded by contour(s) of given height(s), existence of terrain form lines in areas where set of contours abruptly change direction, maximum slope direction is perpendicular on contour segments, etc.

SurfIng's algorithm for building high quality DTM is based on TIN and bicubic Bezier's surface patches over triangles. No special data filtering is currently supported, i.e. calculated terrain surface interpolates data points. Therefore, this method is very sensitive to distribution of data points and their height values, so this must be taken into consideration. Also, estimation of surface normals at these points is highly critical, as this has a great influence on calculated terrain surface. Generally, surface uses Akima's method for estimating surface normals, by averaging surface normals of all TIN triangles joining at given data point. However, this method is not suitable for contour points. Another approach is used. It is based on assumption that direction of steepest slope is perpendicular to the contour. Slope is estimated by calculating profile containing given contour point in the direction of the steepest slope (Figure 4)..

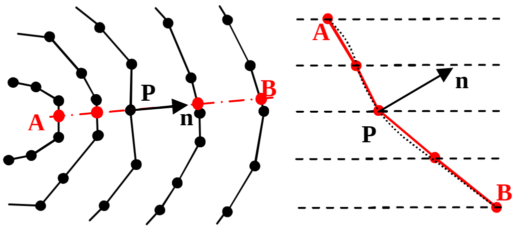

Figure 4. Calculation of surface normals for contour points

Profile is calculated using intersection between neighboring contours and the profile line. Slope could be estimated by using smooth curve set through given point and all intersecting points, or simply averaging slopes for upper and lower contour profile intersections. The similar approach is proposed in (Schneider, 1998). This method provides much better results for contour data than original Akima's method

6.2 Extraction of specific geomorphological elements from contour data

The second problem that is typical for TIN based terrain surface reconstruction using contour data is related to regions with flat triangles. It is well known, that these reagions are actually implicating that there are some special terrain forms (local minimum and maximum, ridge, drainage, saddle). There are several published algorithms for automatic extraction of specific geomorphological elements using contour data and TIN (Auman 1990; Heitzinger, 2001; Peng 1996; Schneider, 1998; Thibault, 2000). Some of these algorithms based on vector data processing techiques are implemented within SurfIng.

The most promising and also simple for implementation is the one based on skeleton construction, i.e. Medial Axis transform (Thibault, 2000). This approach is based on Delaunay triangulation (Figure 5, green lines) and it's dual Voronoi diagram (Figure 5, red lines). Requirement for algorithm is that data are well-sampled. This means that all contour segments (Figure 5, brown, thick lines) are preserved within Delaunay triangulation without special constraints, i.e. the result should be conforming Delaunay triangulation. If contour data is undersampled, additional densification of contour points (splitting of sontour segments) is necessary. Ridge, drainage and saddle lines are constituting skeleton (Thibault, 2000). Problem of finding skeleton is reduced to local test of each Voronoi/Delaunay edge pairs. For each pair, it is either that Voronoi edge is part of the skeleton (Figure 5, red thick lines) or Delaunay edge is part of the crust (Figure 5, brown thick lines), but not both. Criterium is the following: if there is circle set through Delaunay edge vertices that does not contain any Voronoi vertices then Delaunay edge is part of the crust (Figure 5, green, dotted circle case). Otherwise, Voronoi edge is part of the skeleton (Figure 5, blue circle case).

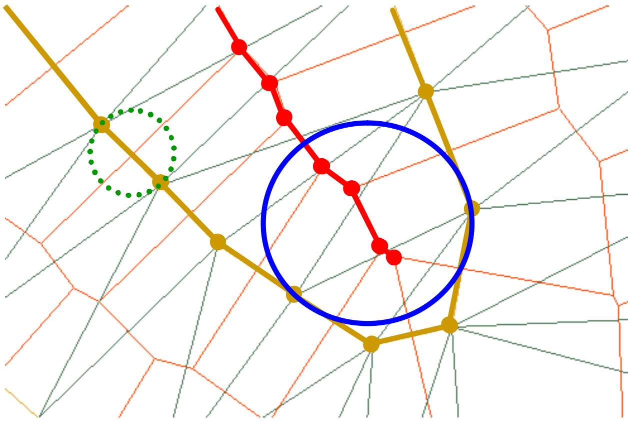

Figure 5. Criterium for extracting skeleton (red) and crust (brown)

The results of the algorithm implemented within SurfIng are shown on Figure 6, where extracted terrain lines are shown in red.

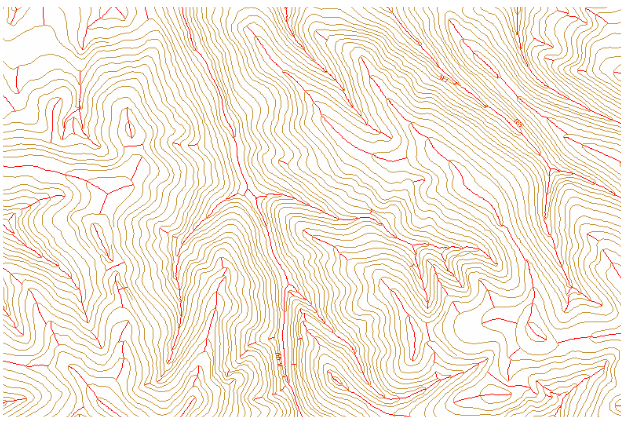

Figure 6. Detected structure lines (red) and digitized contours (brown)

Heights for extracted line points are calculated by linear interpolation between points where given line crosses the nearest contours. This approach is selected because it is rather robust, comparing to the option of calculating these heights from DTM (calculated bicubic surface patches). Extracted line segments are connected, smoothed, and included into TIN. New surface normals and surface patches are also calculated and this is final DTM based on contours. From Figures 7 and 8 it is obvious that these elements contribute significantly to the morfological quality of the DTM.

Figure 7. Shaded terrain without automatically extracted geomorfological elements

Figure 8. Shaded terrain with automatically extracted geomorfological elements included in DTM

The final objective is to obtain geomorfological elements that would enable DTM generalization and also data reduction. Namely, it should be possible to build new DTM by interpolating semi-regular (similar to progressive and composite sampling) grid of heights from final contour DTM and to supplement it with extracted terrain forms, without significant loss of DTM quality. It is to expect large data reduction. Results show that the quality of extracted terrain forms is quite sufficient for contour DTM improvement, but it has to be enhanced if one wants to get sound basis for DTM data reduction and generalization. Better connection of extracted line segments into longer strings is desirable. Also, classification of these forms regarding their significance for DTM quality is required.

7. CURRENT PROJECT STATUS

All the map layers with contours are vectorized and corrected on map sheet edges. Almost all map layers with spot heights are also digitized. Digitization of layers with hydrography is in progress. It is still open question how to integrate these data within DTM in the best way.

Verification of contour data is in progress. This also includes some initial DTM quality assessment. Available data for this are provided by orthophoto projects. These are based on aerial photogrammetry and mostly for 1:5000 mapping scale. As it can be seen form Figure 9, there is a large area (Belgrade is included) covered with these data. It is to expect that there are going to be more data available from unfinished (currently in progress) and future orthophoto projects and from other sources as well for contour DTM quality assessment.

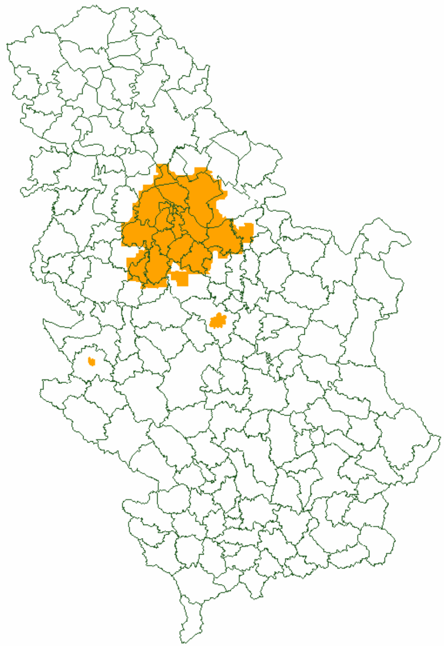

Figure 9. Available 1:5000 DTM for quality assessment of 1:25000 DTM (Serbia without Montenegro)

Few initial tests have shown that the accuracy of acquired contour data DTM is in the expected range. For flat terrains RMSE is about 1-2m, while there is significant loss of accuracy for hilly terrains where RMSE is ranging from 5 to 10m. This decrease in accuracy is mostly related to errors in photogrammetric measurements for wooded areas. However, further, more extensive testing is required in order to verify these preliminary estimates. It is to expect realization of these test in the next few months.

8. CONCLUSIONS

Even though it could be argued that building country wide DTM using existing maps is obsolete method, it is still justified in cases of limited resources. Efforts spent in the past on capturing these data are enough reason by itself. Having in mind meticulous procedures used for making these maps it is natural to expect that DTM made by using such data should meet standards for 1:25000 mapping scale. First quality tests confirm this assumption. The prerequisite for achieving required DTM quality was to use sophisticated procedures for terrain surface reconstruction by using contour data and all the other available information.

However, there are still many things to do in order to finish the production of DTM for Serbia and Montenegro and to put it into full exploitation. These include:

- Improvement of algorithms for geomorfological elements extraction and terrain surface reconstruction
- Thorough DTM quality assessment
- Design and building of country wide DTM database
- Specification of procedures for update and initial updating of country wide DTM database
- Specification and development of standards and procedures for DTM data distribution, etc.

Finally, it should be emphasized that key objective of this project was to satisfy urgent requirements of great number of prospective users, but also to initiate further developments and activities in this area. This should include deployment of other DTM acquisition technologies such as LiDAR, InSAR and digital photogrammetry. These technologies should be used for updating existing one or building completely new country wide DTM for Serbia and Montenegro.

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