DATA INTEGRATION FOR THE DTM PRODUCTION

Tomaž Podobnikar
Dr. Zoran Stancic
Krištof Oštir
Scientific Research Centre of the Slovenian Academy of Sciences and Arts
Gosposka ul. 13
SI-1000 Ljubljana
Slovenia

ISPRS WG VI/3 and IV/3 meeting: Bridging the Gap, Ljubljana 2-5 February 2000

KEY WORD: digital terrain model, digital elevation model, interpolation, SAR interferometry, GIS, quality control

PURPOSE:

In the late 1970's Surveying and Mapping Authority of the Republic of Slovenia produced digital elevation model (DEM) with grid size of 100 m. The DEM was intensively used for numerous cartographic, GIS and planning purposes in the past, but nowadays it does not fulfill demands due to its poor spatial resolution and height accuracy. Therefore Surveying and Mapping Authority has started activities for better DTM production. After initial stages and some case studies, the expected quality of the new DTM was not achieved.
The main objective of this paper is to present and discuss the possibility of improving existent DEM of Slovenia. Many techniques are available to produce high accuracy DEM, but they are not always economical. Our strategy is to model hydrologicaly and morphologicaly correct DTM (digital terrain model) with high statistical and visual accuracy. We intend to use different approaches for modeling different physiographic regions of Slovenia. Special emphasis will be made to the integration of vector contour lines from maps, hydrographic elements and other break lines, automatically derived relief characteristic points, geodetic points, existing DEM 100, photogrametricaly captured data, SAR DEM, etc.
Results from the case study using this integrated data are very promising. DTM with 25 m grid size for selected regions in Slovenia with height accuracy of approx. 1 m for predominantly flat and urban areas, approx. 4 m for the hilly areas and about 10 m for the alpine areas.

1. INTRODUCTION

Spatial databases with adequate quality are essential for management of modern society demands. Morphology of relief is one of the most important characteristics of the natural environment. Digital approximation of its surface – digital terrain's surface model – is important for numerous cartographic, GIS and planning purposes.

The need for a better model resulted in many experiments, projects and expertises about the strategies of improvement and needs of new DEM / DTM (digital elevation model / digital terrain model) in last 10 years. The results of opinion pool indicated that the most of potential users would prefer to have DEM with grid between 10 and 20 m and with height accuracy between 1 and 3 m (Stanonik, 1995).

Few years ago, Surveying and Mapping Authority started activities for the production DEM with 25 m resolution. After initial stages and some case studies, the expected quality of the new DEM was not achieved. Maybe the main reasons of not satisfying results in DEM / DTM production in Slovenia are the diametrically opposite demands: simplification in production methods and making large - no economical projects for production.

Our approach is to integrate different available height data sources of Surveying and Mapping Authority, which have different quality. In last years more and more georeferenced databases form different sources have been available. In our case study special emphasis has been paid to the integration of vector contour lines from maps, hydrographic elements and other characteristic lines, automatically derived characteristic lines and points, geodetic points, DEM 100. We are also performing a reliable process of quality control of the model.

2. DEFINITION OF THE TERMS DEM / DTM

Definition of DTM / DEM is not an easy task. In the literature we can find many definitions, from simple to complex. The reasons of such disorder probably lies in different techniques of modeling, representation, recording and fields of interest of relief data applications.

In definition we consider the Earth surface as a continuous (indiscrete) phenomena, which is attempted to be represented with function(s). Such functions could be continuous mathematical or statistical. Digital terrain model can be understood as "digital description of the Earth's surface". It does not include only representation of the relief itself but also its description, as slope, aspect, contour lines, break lines, peaks, and the other characteristic points. The following components are needed for complete definition of the DTM (Martinoni and Bernhard, 1998):

- data elements,
- structural information,
- continuous functions,
- quality information,
- methods for implicit functions analyses.

Data elements may be understood as support to the model. They explicitly describe elevation with points, lines or areas in the belonging coordinate system. Data elements are often registered as grid or included in TIN.

Structural information may be explicit or implicit. They denote meaning of the data elements, relations between them, and significance of relations. Such relations are first of all topological and in addition also morphological, hydrological or derived.

Continuous functions are used for approximation of the modeled terrain surface. DTM is generally considered as a 2.5 D surface with only one elevation attribute. There are many possibilities for generating different functions, which are based on interpolation of structured data elements.

Quality information depends on semantic perception of structure of the real Earth surface. This is the nominal ground or desired level that is tried to reach with the highest level quality of captured and modeled data.

Methods for implicit functions analyses are partly connected with structural information data. But they are more generally connected with methods for analyses in GIS.

On the basis of this introduction the difference between DEM and DTM can be made. DEM includes only elevation data (look to data elements) that are generally not considered as terrain surface. In most cases DEM is grid data with elevation attributes, which is suitable to use for analyses in raster GIS. Term DTM includes more general information than DEM. DTM is a modeled surface structure which contains also other data of terrain as following: ridgelines, peak points etc. With simplification, the term DTM may be used in general.

3. PREPARATION FOR INTERPOLATION

3.1 Interpolation draft

DTM interpolation from many data sources – as in our case study – demands many data preparing and managing steps. Main modeling steps are shown by flowchart at figure 1 and described bellow.

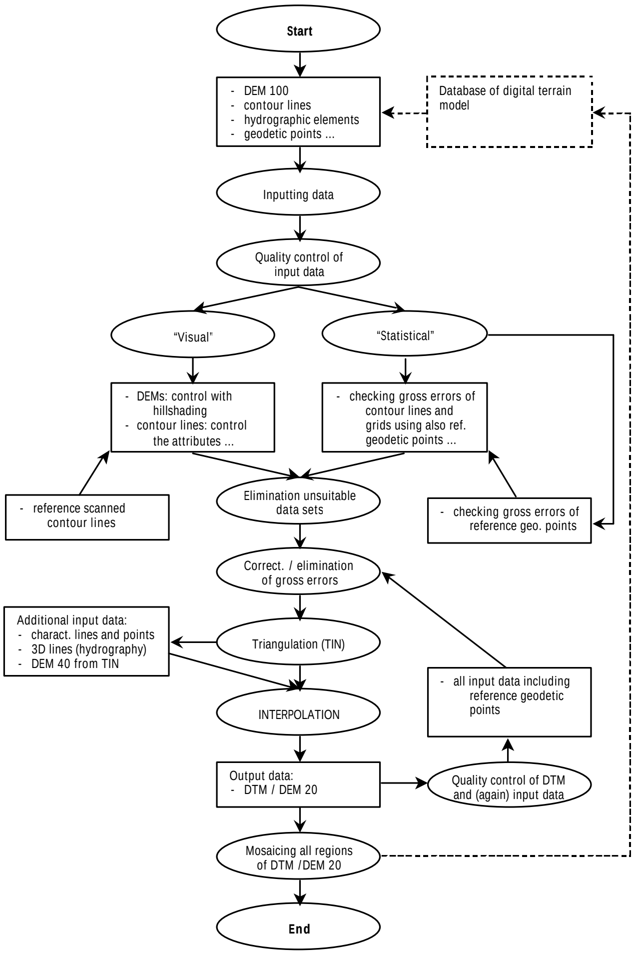

Figure 1: Flowchart of the DTM / DEM 25 modeling.

3.2 Selection of test regions

Relief morphology of Slovenia is quite heterogeneous and so it is not easy for terrain modeling. It can be roughly classified to alpine, karst, hilly and flat surface regions.

Case study for DTM modeling bases on a test data which has been chosen with respect of the mentioned morphological classes. Test regions were optimized to have as much as possible relief characteristic on relative small areas. In the selected areas we were also trying to include relevant quantity of available input data with the elevation attribute.

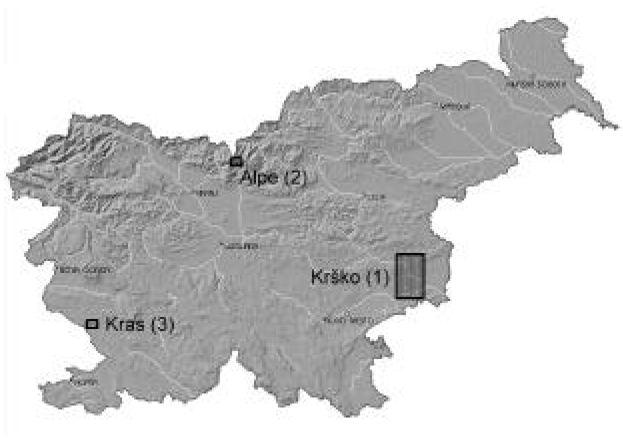

Figure 2: Test areas in Slovenia: Krško (1), Alpe (2) and Kras (3).

On figure 2 we can see three test areas for DTM modeling. The first (1) is hilly and flat surface which has dimension of 11,250 x 18,000 m. The other two are alpine –mountainous (2) and karst (3) regions with dimensions of 4,500 x 3,000 m.

4. DATA FOR DTM MODELLING

4.1 Description of potential data

We decided to use for case study only data that is available at Surveying and Mapping Authority of the Republic of Slovenia. The following are potential input data:

1) raster data;
    - digital elevation model with 100 m raster (DEM 100),
    - digital elevation model with 25 m raster (DEM 25),
2) spot heights;
    - trigonometrical geodetic points,
    - fundamental geodetic points,
3) vector lines and polygons digitized from topographic maps in scale 1 : 25,000;
    - contour lines,
    - hydrographic elements (lines of the streams and polygons of the lakes and sea) – without height attributes,
    - railways – without height attributes,
    - roads – without height attributes,
4) other data used only for visual control;
    - scanned raster contour lines from maps in scale 1 : 5000.

As raster orientated data DEM 100 is available with tested and known height accuracy from 3.3 to 16.1 m and DEM 25 with predicted height accuracy of 2 m. Planimetrical accuracy of DEM 25 and 100 should be around 1 m, but more probable it is around 5 m. Trigonometrical and fundamental geodetic points have theoretical planimetrical and height accuracy up to 1m, and contour lines planimetrical accuracy from 5 to 10 m and height accuracy about 10 m.

4.2. Selection of suitable data for modeling

For quality control of input data the international data standards (CEN), which contain some statistical parameters, are used. Unfortunately those parameters are not always sufficient for complex data tests. Visual tests are also very important for quality control of DTM. Some of them could not be replaced with statistical parameters. For example statistically one tested DTM could be better than other but on the second one could be clearly seen river beds, which are unclear on the first.

Statistical methods of quality control are mostly considered as objective while visual as subjective. The best choice is combination of both methods. Some of the statistical methods can be found in the following groups:

- evaluation of single data layers,
- evaluation with combination of more data layers,
- evaluation of data layers with regard to reference points, etc.

Some of the visual methods of DTM quality control are:

- inspection of characteristic points and lines,
- inspection of course of the hillshaded relief or slopes and aspects,
- implementation of Monte Carlo methods for example for visibility control, and much more (Podobnikar, 1999).

4.2.1 Implementation the visual quality control: After the first visual review of data we decided that lines of railways and roads without height attributes can not improve the final DTM 25. So we omitted them from additional trial.

Further control was done with comparative visual testing of both, DEM 100 and DEM 25. Figure 3 shows how much more detailed the DEM 25 is than DEM 100. But it is clearly seen that in the central part of DEM 25 are some flat triangular surfaces. The problem is that this part of DEM 25 has been interpolated from contour lines which are not presented at the very steep areas. After triangulation performed the mentioned holes were represented with large triangles. After comparing DEM 25 with DEM, generated from vector contour lines, we decided not to use DEM 25. The reason of such decision lies in similarity of the both datasets. DEM 25 was obviously generated from the same contour lines. On the other side DEM 100 has poor spatial resolution but visually it is correct dataset which is independent from DEM 25. We decided to use it in interpolation process.

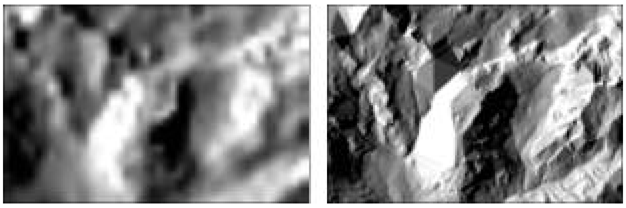

Figure 3: Comparing hillshaded DEMs: DEM 100 on the left and DEM 25 on the right for the Alpine test region (2).

Next visual control was the comparison of vector contour lines (from maps 1: 25,000) with scanned contour lines (from maps in scale 1: 5,000). With visual overlay of both datasets we wanted to perceive difference of two (different generalized) sets of contour lines. Because we do not have a database of elevation values for both datasets, we can comment only the detail differences. It is paradoxical that in general the contour lines from scale 1 : 5000 are not much more detailed than the those from scale 1: 25,000 (figure 4). We even noticed that in some cases contour lines in larger scale are more detailed than in small ones. The reason probably lies in inhomogeneous capturing of data in scale 1: 5000, while vector contour lines are much were captured more “compactly”.

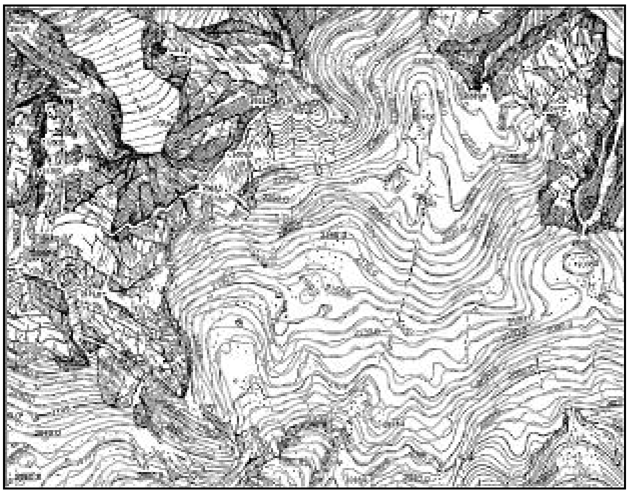

Figure 4: Comparison of two contour data sets for alpine region (2): In black are scanned contour lines in scale 1 : 5000 which are overplayed with vector contour lines in scale 1 : 25,000.

We also performed visual methods for elimination of gross errors from the contour lines sets. It was done with comparison of contour lines derived with interpolation from vector ones with vector ones, and visual searching of the gross errors (figure 5).

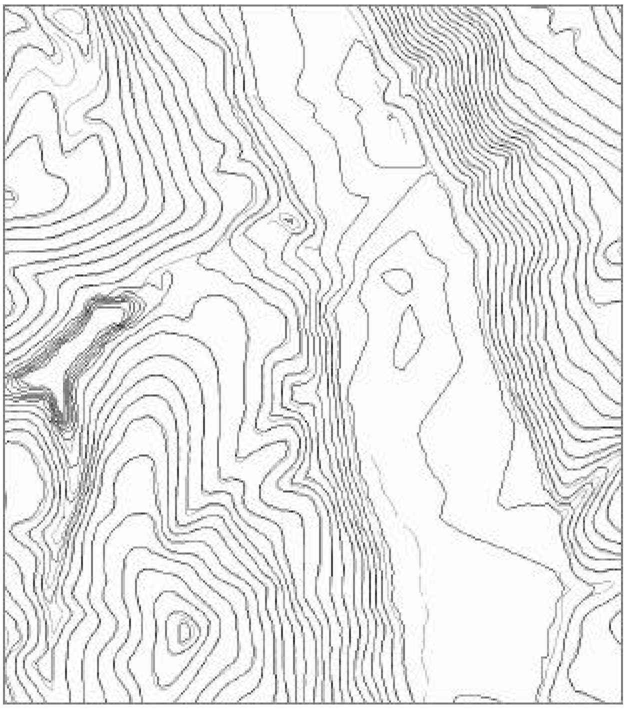

Figure 5: Computed contour lines (in black) over original vector contour lines (in gray). On the left where two sets of contours doesn't fit, it is remarkable gross error.

4.2.2 Implementation the statistical quality control: With visual tests some gross errors were eliminated. Further the heights of reference geodetic points (trigonometric and fundamental) were tested with simultaneous comparing with DEM 100 and 25. Points with gross errors were eliminated.

We wanted to confirm the elimination of DEM 25 as input data set by statistical comparison with other DEM, generated from contour lines. The results show that the RMS errors are almost identical for all three tested regions.

For statistical elimination of attribute gross errors of the contour lines many methods were used. Some of the effective methods use parameters from comparative datasets. We overlaid DEM generated from contour lines with DEM 100 or simultaneous compared both DEMs with referenced geodetic points. We used also "robust estimation" method based on linear prediction interpolation method (Pfeifer). We did many statistical tests for improvement the datasets.

The result of data tests were improved datasets and parameters of RMS error of each thematic layer with regard to reference geodetic points. Table 1 shows RMS errors for DEM 100 and (interpolated) contour lines for different morphological classes as first parameter and average deviation of the reference geodetic points from DEM 100 and contour lines as second parameter. We can see that in all cases reference geodetic points are in average above DEM and contour lines. The reason is that geodetic points are mostly on the peaks, where interpolated data is always lower because of the missing characteristic points for interpolation.

Morph. classes	DEM 100	Contour lines
Flat surface (1)	2.0 m / 0.7 m	1.5 m / 0.3 m
Hills (1)	10.0 m / 8.5 m	5.0 m / 2.5 m
Mountainous (2)	30.0 m / 12.0 m	10-40 m / 3.0 m
Karst region (3)	7.0 m / 4.8 m	4.0 m / 2.0 m

Table 1: Morphological classes from three test regions (1-3) with parameters: RMS error / average deviation from the reference points.

5. ACQUISITION OF ADDITIONAL DAT A FOR INTERPOLATION

With initial quality control we produced a good database including parameters for interpolation:

- DEM 100,
- contour lines,
- reference trigonometrical and fundamental geodetic points.

The next step is to produce characteristic lines and points.

5.1 Extraction of height attributes for streamlines

From hydrographic elements – lines of streams – we tried to acquire elevation attributes by interpolation and extrapolation of lines of streams between contour lines (Heitzinger and Kager, 1998). The results were generally not satisfying (figure 6). The reason is that contour lines, digitized from topographic maps were broken on the crossings with other topographical features, in our case with hydrographic streams.

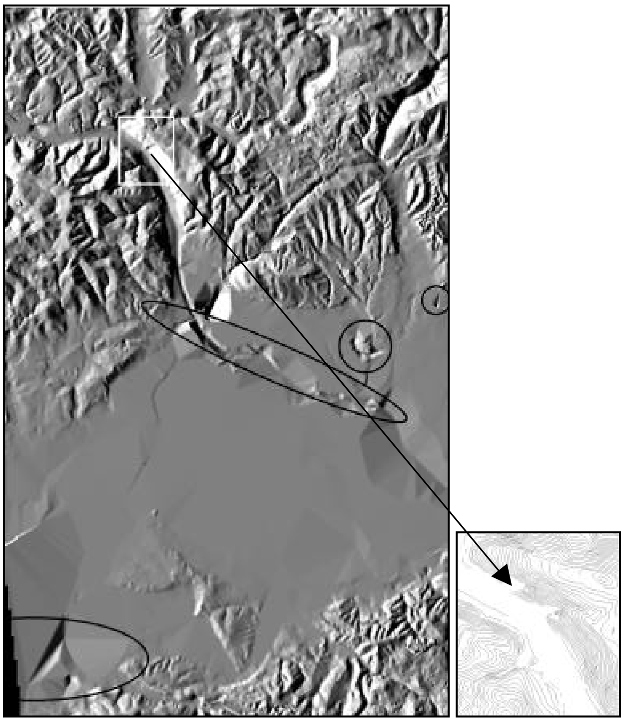

Figure 6: Problems in interpolation with hydrographic elements (left – the biggest mistakes are marked with ellipses) caused with deficient contour lines in the river beds (right) for the region Krško (1).

5.2 Extraction of characteristic points and lines

Much better results were reached by detection and extraction of topographic features (ridges, summits, saddles, drainage lines and valleys) from contour lines. We applied one some possible methods which produce appropriate results. This expert system bases on TIN (triangular irregular network), created from contour lines. Principle of extraction characteristic lines is founded on determination and connection previously detected horizontal triangles of TIN to ridge or drainage lines. With interpolation and extrapolation considering contour lines, missing characteristic points are determinated (Heitzinger and Kager, 1998).

Figure 7 shows that we can get quite good results also for the karst region (3), where the relief morphology is very complex. Especially generated characteristic points as bottoms of the sinkholes leads to most distinctive improvement to interpolated karst relief.

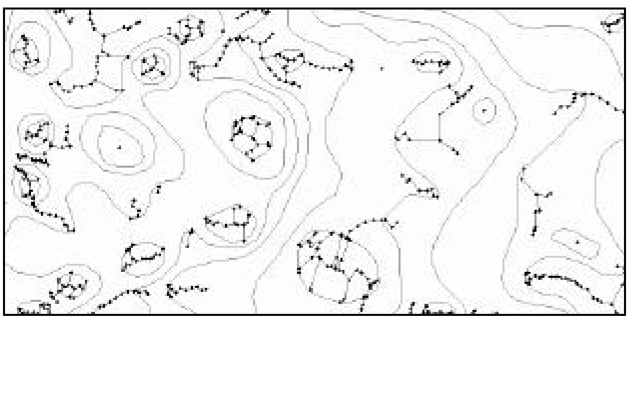

Figure 7: Extracted characteristic points and lines at karst region (3) are shown as black points and lines. Grey lines are vector contour lines.

A side product of TIN was also a DEM with resolution of 40 m, which bridges missing data of contour lines, especially at the alpine regions where large "holes" appear without of any data. Additional datasets produced from contour lines which were used for interpolation are:

- characteristic topographic points,
- characteristic topographic lines,
- DEM 40 from TIN.

6. DTM MODELING

For modeling of a DTM 25 the program package SCOP, which is independent program system for the computation and utilization DTM, was used. The main advantage of this software is ability to use data with different accuracy in the interpolation process, what was our very important preliminary condition. Module SCOP.TRI includes powerful tool for enhancement of contour line data with characteristic points and lines. Method for robust estimation in module SCOP.DTM can be useful for correction of gross errors in input data (Ecker, 1999). And not the least, the SCOP produces DTM with relevant structure.

6.1 Interpolation methodology

Interpolation method used is known as "least squares interpolation" or "linear prediction". In geostatistics the method is known as "kriging" (Kraus, 1998). Method bases on interpolation with least squares which requires the search for the minimal variance.

Practically and shortly, this local interpolation method works with so-called computing units. It is attempting to find suitable function (theoretical surface) regarding to influence of the particular points, to which filter value (variance) has to be assigned. Filter values also control a degree of smoothing the surface.

The data for interpolation was divided to particular classes with regard to type and accuracy. For each class different filter values were used for interpolation:

1) bulk points;
   - DEM 100,
   - DEM 40 from TIN,
2) spot heights;
   - geodetic points (in this case used only as reference),
   - characteristic topographic points,
3) form line points;
   - contour lines
   - characteristic topographic lines,
4) break lines (we haven't any data for them).

The lowest filter values were assigned to spot heights and the highest to bulk points. Geodetic points were used only as reference points for testing of input data.

6.2 Results of DTM modeling

The results of modeling the DTM / DTM 25 are very promising. Table 2 shows difference between accuracy of the vector contour lines and produced DTM 25. Parameters indicate improvement for all morphological classes, especially for Alpine areas. Implication of characteristic points above all in interpolation, caused also reduction of average distance according to reference points, except at flat areas where these points usually aren't present.

Morph. classes	Contour lines	DTM / DEM 25
Flat surface (1)	1.5 m / 0.3 m	1.2 m / 0.3 m
Hills (1)	5.0 m / 2.5 m	4.0 m / 2.0 m
Mountainous (2)	10-40 m / 3.0 m	10.0 m / 2.7 m
Karst region (3)	4.0 m / 2.0 m	3.0 m / 0.5 m

Table 2: Morphological classes from three test regions (1-3) with parameters: RMS error / average deviation from the reference points.

Figure 8 shows evidently improvement of interpolated DTM 25 (the right picture) at the areas without contour lines. There are not noticed large triangles. For the other three test regions improvements are better statistically than visually perceived.

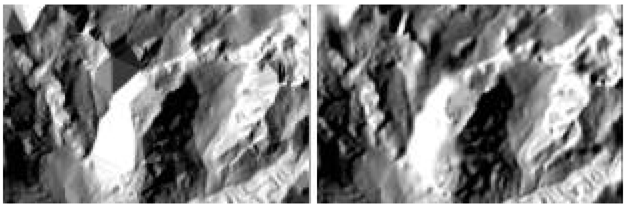

Figure 8: Comparison of hillshaded DEMs: On left side is DEM, interpolated from contour lines only and on the right DTM 25 for the Alpine test region (2).

7. FURTHER PLANS

Results of the case study with only few datasets – basically contour lines and DEM 100, show possibility for drastical improvement of old DEM 100 and also current (not yet completely finished) DEM 25.

For the next stage special emphasis will be done to improvement of interpolation parameters and simultaneously add new available data with high accuracy. There are many data available in digital databases which haven't been used, but they will be sources for modeling in the future on test regions:

- local DEMs available for Slovenia including DEM produced with SAR interferometry,
- register of the buildings,
- other geodetic points (cadastre, polygon, etc.),
- hydrology (streams and lakes) and more.

The next will be data for improving morphological details and other possibly data for general condensing input data:

- photogremmetrically or otherwise captured characteristic data – points and lines for terrain details,
- densification (condensing) of the model with scattered data as it is laser altimetry at urban and other areas, interesting for potential users or with DEM produced with SAR interferometry.

After testing the quality of output DTM 25, reference geodetic points will be also included in the model. Interpolation process will be improved by using different interpolation techniques with regard to relief morphology.

For DTM surface generation it is necessary to produce a "DTM database" that must have the ability to be updated with every improved new data and enable to quickly produce the desired DTM / DEM (Rihtaršic and Fras, 1991). Such organization of data will lead to "dynamic DTM database" for DTM production and back to multiscale, "elastic grid" DEM production, suitable for GIS analyses.

8. CONCLUSION

First, preliminary results, using integrated data approach in the case study are very promising. DTM / DEM with 25 m grid size was produced for selected regions in Slovenia with height accuracy of approx. 1 m for predominantly flat and urban areas, 4 m for the hilly areas and 10 m for the alpine areas.

With condensing additional, different quality data, height accuracy could be for about 1/4 - 1/3 better than from case study and general grid of 20 m would be reasonable to cover whole area of Slovenia for the first next stage.

With methods presented in the article we can relatively easy, cheaply and in short time produce the requested high quality DTM for all Slovenia.

Acknowledgment

Special thanks go to Prof. Dr. Karl Kraus and his team from Institute for Photogrammetry and Remote Sensing at Vienna University of Technology for advices and access to SCOP program package. We are much obliged to Surveying and Mapping Authority of the Republic of Slovenia for realizing the project to produce DEM 25 with SAR interferometry.

References

Ecker, R., 1999. Homogenisierung digitaler Geländmodelle unterschiedlicher Genauigkeit mittels linearer Prädiktion und robuster Schätzung. Austria, pp. 8.

Heitzinger, D., Kager, H., 1998. High quality DTMs from contourlines by knowledge-based classification of problem regions. Proceedings of the International Symposium on "GIS – Between Visions and Applications", ISPRS Comm. 4, 32(4), Stuttgart, Germany, pp. 230-237.

Kraus, K., 1998. Interpolation nach kleinsten Quadraten versus Krige-Schätzer. Österreichische Zeitschrift für Vermessung und Geoinformation, 98(1), pp 45-48.

Martinoni, D., Bernhard, L., 1998. A Conceptual Framework for Reliable Digital Terrain Modelling. Proceedings 8th Symposium on Spatial Data Handling, Vancouver, Canada, pp. 737-750.

Pfeifer, N. Extension for Laser Scanner Data Processing. Manual for the robust estimation and the consideration of slope values in SCOP.DTM. Technical University Vienna, Institute of photogrammetry and remote sensing. pp. 26.

Podobnikar, T., 1999. Monte Carlo simulations in Slovenia. Modelling and visualisation of spatial data error. GIM International, 13(7), pp. 47-49.

Rihtaršic, M., Fras, Z., 1991. Digitalni model reliefa. 1 del: teoreticne osnove in uporaba DMR. Univerza v Ljubljani, FAGG – KFK, pp. 143.

Stanonik, B., 1995. Digitalni model reliefa Republike Slovenije. Pregled možnosti in zahtev. Geodetska uprava Republike Slovenije in Geoinformacijski center, Ljubljana pp. 15.