A HIERARCHICAL QUALITY-DEPENDENT APPROACH TOWARD ESTABLISHING A SEAMLESS NATIONWIDE TOPOGRAPHIC DATABASE

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ABSTRACT:

Nationwide geospatial databases in general and topographic ones in particular are today one of the most common infrastructure for mapping and other geo-related tasks. These databases are designated to establish an adequate, continuous and if possible homogeneous representation of our natural environment. New data acquisition technologies, which present high accuracies and resolution levels that were not known until recently, yield rapid and frequent updating of existing nationwide databases. This enables the generation of a multi-source mosaiced database that is multi-quality as well, i.e., introducing varied accuracies within its coverage area. Simultaneous analysis, such as integration, of two or more of these nationwide databases will evidently present multi-scale spatial inconsistencies. These are a function of various factors, among them the different levels of accuracy within each database. Common height integration mechanisms will not suffice here. This paper presents a framework for dealing with the problems and considerations in utilizing topographic databases that are quality derived while trying to give a solution to the existing geometric ambiguities. A conceptual new algorithmic approach is detailed, which relies on a hierarchical modeling mechanism that is designated for extracting the existing varied-scale discrepancies in order to produce a common geospatial framework. Moreover, designated quality-derived constraints are implemented in the process to ensure that accuracy is preserved. This novel approach proved to be accurate while producing seamless topographic database that retained the level of detailing and accuracies presented in the source databases, as well as local trends and morphology.

1. INTRODUCTION

The emergence of nationwide geospatial databases is an evident progression. These seamless databases, such as Orthophoto layers or varied scale Digital Terrain Models (DTM), are an essential requirement for establishing an efficient and computerized management of our environment. The assumption is that they constitute a unique, constant, uniform, reliable, seamless and - as much as possible - homogeneous mapping and Geographic Information (GI) infrastructure (National Research Council, 1990). As such, these databases serve as basis for a wide variety of research and analyses capabilities, as well as many commercial applications. Many national mapping agencies, as well as private companies and public agencies, are involved today in establishing this type of infrastructure (Parry and Perkins, 2000). Forming a reliable nationwide geospatial databases is a growing need, mainly in developing regions.

DTM databases provide up-to-date and detailed representation of the topographical variations in the earth's surface. Until recently, these databases were produced via traditional technologies and techniques, such as photogrammetric means from aerial and satellite imagery or cartographic scanning of existing analogue topographic contour maps. As a result, a nationwide DTM would usually show constant level-of-detailing (LOD), resolution and accuracy. However, local successive updates of the DTM might result in damaging its homogeneous structure. Furthermore, new data acquisition technologies, such as Airborne Laser Scanning (ALS) systems or Interferometric Synthetic Aperture Radar (IfSAR), present today high accuracies and resolution levels that were not known until recently. This intensifies the fact that an updating process performed on an existing DTM with new dense and accurate data will result in varied accuracies and LOD within its coverage area, i.e., loosing the database's homogenous nature (Hovenbitzer, 2004; Hrvatin and Perko, 2005). It can be described as if the nationwide DTM is a mosaiced database composed of patches, each acquired by a different technology, via a different technique and usually on a different period of time. Respectively, each patch presents different level of accuracy, such that an accuracy polygon map for the nationwide DTM is introduced, as depicted in Figure 1.

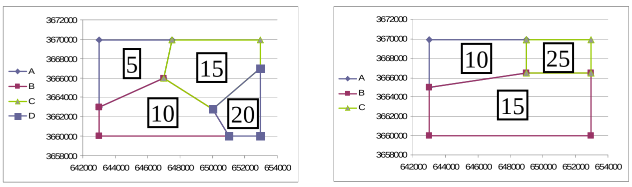

Figure 1. Scheme of two accuracy polygon maps of two nationwide DTMs; accuracy value is depicted in meters

Utilizing simultaneously several nationwide seamless DTMs for various mapping and GI applications requires the existence of continuous and contiguous terrain relief models. For example, integration is required when these models represent different zones within a larger region and a continuous nationwide terrain relief representation is required. Furthermore, for applications, such as line of sight, visibility maps, Orthophoto production - to name a few, utilizing models that are discontinuous will eventually lead to incorrect outcome. Inconsistencies between the databases are a function of various factors, such as production techniques, time of data-acquisition, LOD, datum framework - to name a few (Lee and Chu, 1996; Wang and Wade, 2008). This reflects semantically on the representation and position of the databases' described entities, thus geometric discrepancies are evident. These discrepancies affect data-certainty, for example when morphologic comparison or change detection process is at hand. Though the utilized databases for the geo-related task are geographically registered to a certain coordinate reference system, i.e., geo-referenced, these factors lead to the presence of global-systematic and local-random errors (Hutchinson and Gallant, 2000). It is evident, then, that each nationwide DTM utilized for an analysis task may present different levels of accuracy, which generally coincide to an area produced by a certain technology and/or via a certain technique, quantified via the accuracy polygon maps. As a result, not only does ambiguity exists regarding the heights required for the geo-related analysis carried out - but also the corresponding relative accuracies needed to be utilized in that process.

Several researches were carried out to solve the framework inconsistencies as well as the data-structure and data-uncertainty problems when the task of integrating different nationwide DTMs is at hand. Still, the majority of these researches handle the DTMs data as already geo-referenced, thus dealing only with the height inconsistencies of the DTMs and its quality - and not the complete geo-spatial mutual inter-relations that exist between them (Hahn and Samadzadegan, 1999; Frederiksen et al., 2004; Podobnikar, 2005).

This paper outlines a novel framework for dealing with the problems and considerations in utilizing seamless topographic DTMs that are quality-dependent. A hierarchical modeling mechanism is generated, in which the varied-scale discrepancies are monitored in order to enable a common geospatial framework that is datum-dependent free. Moreover, designated algorithms responsible for acquiring the correct position-derived accuracy from the quality polygons that are given for each nationwide DTM are integrated into this hierarchical modeling mechanism. This is vital in order to preserve the spatially varying quality and trends exist in the different DTMs, and hence, as in the case of an integration process, achieve a uniform, free of gaps and seamless nationwide DTM. This approach becomes essential in cases where no arranged and seamless mapping is available while the integration of topographic databases from different sources is crucial.

2. ALGORITHM OUTLINE

The hierarchical integration process of two (or more) homogenous DTMs where each has a single constant accuracy was proposed in the work of Dalyot and Doytsher (2008). This research presented a hierarchical modeling and integration mechanism that utilizes complete and accurate sets of different-scale data-relations that exist within the DTMs mutual coverage area. The use of these data-relations enabled precise modeling of the DTMs, i.e., extracting a mutual reference working frame (schema). Thus, the generation of an integrated unified and seamless DTM was achieved. A short review of this mechanism and its main stages is given here:

- **Pre-integration**, i.e. global rough registration, whereas choosing a common schema (framework) of both DTMs is carried out (thus solving the datum ambiguities exist between both DTMs). This is achieved while implementing the Hausdorff distance algorithm that registers sets of selective unique homologous features (objects) exists in both DTMs' skeletal structure. The skeletal structure of each DTM is identified via a novel topographical interest point identification mechanism;
- **Local matching** that is based on geometric and morphologic schema specifications analyses. This is carried out while implementing the Iterative Closest Point (ICP) algorithm with designated constraints for nonrigid surfaces matching. This stage is essential for achieving precise reciprocal modeling framework between the two databases, i.e., localized transformation quantification;
- **Reverse engineering integration** schema, which uses the matching modeling relations evaluated in the local matching stage and the data that exists in both DTMs, i.e., enabling data fusing. Obtaining an enhanced and accurate terrain representation is achieved.

Still, the existence of accuracy polygon map for each DTM requires certain considerations within the proposed hierarchical mechanism.

2.1 Pre-Integration

Data accuracy derives the certainty of a correct positioning of a topographical interest point. Consequently, the rough estimation of a mutual global registration value of both DTMs through the Hausdorff distance algorithm takes into account this factor through a weighting process on the participating points.

2.2 Local Matching

The registration value extracted in 2.1 gives the required information regarding the 'global' reciprocal working reference frame. Thus, the implementation of an adequate autonomous ICP matching process on homologous corresponding local data frames divided from the complete mutual coverage area is feasible. An independent and separate matching of small frames is more effective in monitoring and modeling the local random incongruities and trends (and consequently prevents local minima solution). The ICP algorithm is based on coupling up pairs of counterpart points (from each DTM frame that participates in the matching process) that are considered as the nearest ones exist. Thus, the estimation of the rigid body transformation that aligns both models 'best' is attained. This 'best' transformation is applied to one model while the procedure continues iteratively until convergence is achieved.

ICP matching is accomplished via Least Squares Matching (LSM) of a goal function, which measures the squares sum of the Euclidean distances Γ between the surfaces, depicted in Equation 1.

$$\sum \| \Gamma \| = \min \tag{1}$$

Monitoring errors (Γ) is achieved by minimizing the goal function, i.e., extracting the best possible correspondence between the frames. The geometric goal function is defined by a spatial transformation model between the DTM frames, and is described by a general 6-parameter 3D similarity transformation model, depicted in Equation 2.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_f = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} + R \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_g \tag{2}$$

where, $[x, y, z]^T_f$ denote the target DTM, $[t_x, t_y, t_z]^T$ denote the 3D translation vector, R denote the 3D orthogonal rotation matrix, and, $[x, y, z]^T_g$ denote the source DTM. R is a function of the three rotation angles $[\omega, \varphi, \kappa]$.
It is important to remember that the rotation magnitude is in respect to the center of mass of each frame. Thus, $[x, y, z]^{T\,0}_f$ and $(x, y, z)^{T\,0}_g$, which denote the center of mass for each counterpart frame, are subtracted from the original coordinates before transformation is carried out.
In order to perform Least Squares estimation, i.e., linearization, Equation 2 is expanded using the Taylor series, of which only the linear terms are retained (2nd and higher orders are omitted). Consequently, each observation formula is related to a linear combination of the 6-parameters, which basically are variables of a deterministic unknown (Besl and McKay, 1992). This model is written as a matrix notation in Equation 3.

$$-e = A \cdot x - l \qquad (3)$$

where, A is the design matrix (derivatives of the 6 unknown parameters), x is the unknown 6-parameter vector $\{dt_x, dt_y, dt_z, d\omega, d\varphi, d\kappa\}^T$, and, l is the discrepancy vector that is the Euclidean distance between the corresponding DTMs' elements, i.e., frames data points: $f(x, y, z) - g(x, y, z)$.
The Least Squares solution gives as the generalized Gauss-Markov model the unbiased minimum variance estimation for the parameters, as depicted in Equation 4.

$$\begin{aligned} x &= \left(A^T \cdot P \cdot A\right)^{-1} \cdot \left(A^T \cdot P \cdot l\right) \\ v &= A \cdot x - l \\ \sigma_0^2 &= \frac{\left(v^T \cdot P \cdot v\right)}{n-u} \end{aligned} \qquad (4)$$

where, x denotes the solution vector of the 6-parameters transformation, v denotes the residuals vector of surface observations, σ_0^2 denotes the variance factor, n denotes the number of observations, and, u denotes the number of (unknown) transformation parameters in the model, i.e., $u=6$.
Due to the fact that both nationwide DTMs are actually nonrigid bodies, several aspects are to be considered:

- Nationwide DTMs represent different data-structures - namely LOD and resolution - implying that the existence of homologous points for the ICP process is not at all explicit;
- Nationwide DTMs that were acquired on different times (epochs) will surely represent different surface topography and morphology (either natural or artificial activities);
- Data and measurement errors can reflect on the position certainty of points in relatively large scale.

To ensure convergence of the ICP process as well as to assure that the nearest neighbor search criteria is achieved correctly and fast between two homologous local frames, three geometric constraints are implemented in the ICP process - outlined in Equations 5. These constraints verify that each of the counterpart paired-up point is the closest one exists, as well as having the same relative topography surroundings. It is worth noting that these constraints are suitable for grid-space. Though not very common, Triangulated Irregular Network (TIN) structure of topographic databases does exist (mainly in areas acquired by ALS technology). With slight modifications, these equations can fit TIN characteristics as well.

$$\begin{aligned} Z_i^g &= \frac{h_1}{D} \cdot X_i^g + \frac{h_3}{D} \cdot Y_i^g + \frac{h_4}{D^2} \cdot X_i^g \cdot Y_i^g \\ Z_i^g &= -\frac{h_4 \cdot y_f'}{D^2} \cdot X_i^g + \frac{h_3}{D} \cdot Y_i^g + \frac{h_4}{D^2} \cdot X_i^g \cdot Y_i^g + \left(z_f' - \frac{h_3 \cdot y_f'}{D}\right) \\ Z_i^g &= \frac{h_1}{D} \cdot X_i^g - \frac{h_4 \cdot x_f'}{D^2} \cdot Y_i^g + \frac{h_4}{D^2} \cdot X_i^g \cdot Y_i^g + \left(z_f' - \frac{h_1 \cdot x_f'}{D}\right) \end{aligned} \qquad (5)$$

where h_1 to h_4 are calculated from the height of local DEM grid cell corners: Z_1 to Z_4 ($h_1=Z_1-Z_0$, $h_2=Z_2-Z_0$, $h_3=Z_3-Z_o$, $h_4=h_2-h_1-h_3$); D denotes the database's grid resolution; g and f denotes the source and target databases; (X^g_i, Y^g_i, Z^g_i) denotes the paired-up nearest neighbor in g; and, (x_f', y_f', z_f') denotes the transformed point from dataset f.
Here, the assumption that each coupled-up point in every observation equation within the matching process has a different accuracy. This can be depicted as if each counterpart point 'falls' within certain polygon in the accuracy polygon map associated with the nationwide DTM. Thus, the accuracy polygon maps of both DTMs are taken into consideration during the ICP implementation. Instead of giving each row (i) in the design matrix (A) of size (n by 6) the same weight (where $i \in n$), a different weight is given to each row, which is derived from the accuracy polygons each of the points falls in. For example: if point a from DTM f ($a \in f$) falls in a polygon with accuracy value of *Acc_1*, and its corresponding counterpart point b from DTM g ($b \in g$) falls in a polygon with accuracy value of *Acc_2*, then their relative weight in the matching process for that frame is derived by these accuracy values, as depicted in Equation 6 (*Acc_0* denotes the accuracy of a unit-magnitude weight). The more accurate the polygon is (smaller value of *Acc*), the higher the weight value is. Hence, more accurate coupled-up points will have higher influence on the ICP process, producing a more reliable solution that characterizes correctly the given data and its quality. Thus, a weight matrix P (p_{ii}) can be added to the linear approximation depicted earlier in Equation 4.

$$Weight_i = \frac{Acc\_0}{\sqrt{(Acc\_1)^2 + (Acc\_2)^2}} \qquad (6)$$

Each matching set includes 6-parameters transformation model that best describes the relative spatial geometry of the mutual homologous frames that were matched. Since this process yields better localized registration definition, it ensures matching continuity on the entire area (as opposed to matching the entire data in a single matching process). These registration sets can be described as elements stored in 2D matrix: each set is stored in the cell that corresponds spatially to the homologues frames it belongs to. This data structure contributes to the effectiveness of the integration process.

2.3 Integration

Integration is achieved via a "reverse engineering" mechanism that utilizes the quantified correspondence between the two nationwide DTMs. This spatial correspondence is expressed by the sets of transformation, or registration parameters, which are stored in a 'registration matrix', where the values in each cell express the modeling between two matched frames. A "reverse engineering" mechanism implies that each height in the integrated DTM is calculated independently and regardless to the other values. For each position in the integrated DTM a weighted height average is calculated based on the complete spatial relations between the DTMs (stored in the matrix) and their corresponding heights. The integrated DTM can be depicted as if it exists in the space between the two source DTMs. Thus, a two-way transformation from all nodes (planar position) of the integrated DTM to each of the source DTMs while utilizing the spatial relations is implemented. Because two heights are obtained via the process (two sources) the weight of each of the two heights is derived from the corresponding accuracy polygon it falls in, thus a weighted average process is carried out. (For further reading the reader is kindly referred to Dalyot and Doytsher, 2008).

2.4 Smoothed Polygon Map Establishment

Each DTM presents internal varying accuracies - along with existing accuracy differences among the DTMs. Still, the integrated DTM has to present seamless terrain relief, regardless of abrupt accuracy changes derived from the polygons. This is obtained via the establishment of a new "smoothed" accuracy map that is based on the data exists in the source accuracy polygon map. The "smoothed" map presents gradual accuracies change by implementing a buffer-like process around each source accuracy polygon. A schematic description of this concept is depicted in Figure 2; where there exists continuous values transition from accuracy polygon *A* (turquoise) to accuracy polygon *B* (yellow) along a buffer distance of *D*.

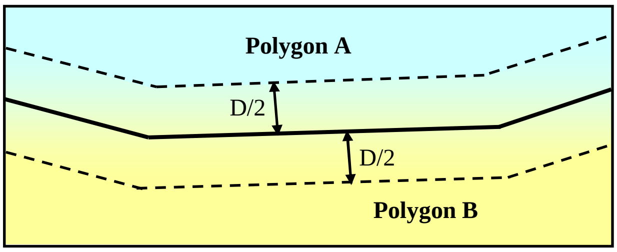

Figure 2. Schematic description of smoothing concept: gradual change from polygon *A* (turquoise) to polygon *B* (yellow). Bold line denotes the original conjoint border of two polygons

This algorithm is based mainly on the polygons' topology and their planar layout within the accuracy polygon map. The input of this algorithm is composed of polygon sets assemble each map, and their corresponding accuracy. An automatic process generates the following additional information:

- Polylines composing each polygon and their corresponding start and end point coordinates;
- Start and end points index, where:
  - 0 denotes point positioned on a map corner;
  - 1 denotes point positioned on the east/west map limits;
  - 2 denotes point positioned on the north/south map limits;
  - 3 denotes an inner point connecting two lines;
  - 4 denotes an inner point connecting three lines;
- The width of the buffer size vertical to two polygon's conjoint line; this value is derived by the difference magnitude of accuracy values of two adjacent polygons.

It is obvious that in the general case a point can connect *n* lines - and not merely three (as index 4 indicates). Still, practically this case is rare where an accuracy polygon map is at hand, so the common topologic cases are considered here. This algorithm suggests the computation of a new accuracy polygon map based on the topology and accuracies presented. New polygons are generated via the smoothing process; each holds gradually changing accuracy values. More specifically, the process generates new trapeze and triangle shaped polygons, such as the example depicted in Figure 3. An accuracy map presenting four polygons connected by two points (*11* and *22*) is transformed into a new accuracy map presenting two new triangles and five new trapezes (along with the four 'reduced' original polygons).

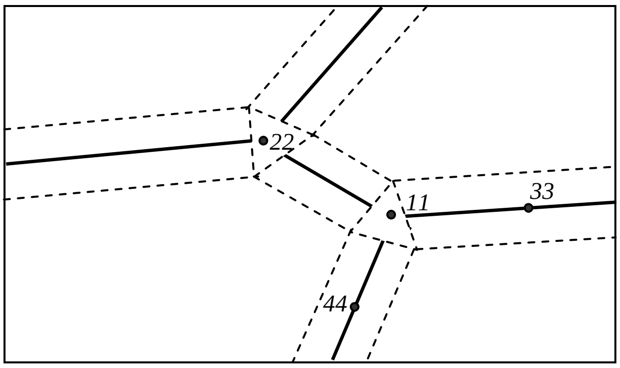

Figure 3. Schematic representation of new smoothed accuracy polygon map. Bold lines depict original polylines; dashed lines depict computed polylines (whereas the bold ones are erased in the new generated accuracy map)

Due to the fact that many possible topologies exist (and the size limit of this paper), only the most complicated one is described. Consider point *11* (indexed 4) connected to three other points: *22*, *33*, and *44* (depicted in Figure 3). For each connecting line two accuracies exist: along the left and right sides: *Acc_L* and *Acc_R*, correspondingly. For each connecting line the azimuths are calculated, as well as the azimuth values from point *11* to points *20*, *30*, and *40*, which are calculated using the buffer distance (in case the buffer size is a constant value for all polygons, these points lie on the angles' bisectors), as depicted in Figure 4. Consequently, points *20*, *30*, and *40* can be computed via geometric and trigonometric functions utilizing azimuths values, the known points' coordinates, and the given buffer distance *D*. A triangle is formed by these new points, where the accuracies corresponding to each of these points is also known.

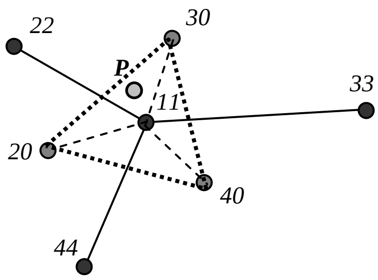

Figure 4. Formation of a triangle shaped new polygon (index 4) storing gradual accuracy values

With this, for each point within the formed triangle the accuracy calculation that corresponds to point with position value of *P* (depicted in Figure 4) is feasible. Let *P* have planar coordinates of (x_P, y_P), thus utilizing triangular coordinates can be implemented, as depicted in Equation 7. Similar process is carried out for the trapeze shaped polygons: instead of using triangular coordinates the utilization of linear transition along the buffer direction between polylines edges is implemented.

$$2S = \begin{vmatrix} 1 & 1 & 1 \\ x_{20} & x_{30} & x_{40} \\ y_{20} & y_{30} & y_{40} \end{vmatrix}$$

$$\begin{vmatrix} t_{20} \\ t_{30} \\ t_{40} \end{vmatrix} = \frac{1}{2S} \cdot \begin{vmatrix} (x_{30} \cdot y_{40} - x_{40} \cdot y_{30}) & (y_{30} - y_{40}) & (x_{40} - x_{30}) \\ (x_{40} \cdot y_{20} - x_{20} \cdot y_{40}) & (y_{40} - y_{20}) & (x_{20} - x_{40}) \\ (x_{20} \cdot y_{30} - x_{30} \cdot y_{20}) & (y_{20} - y_{30}) & (x_{30} - x_{20}) \end{vmatrix} \cdot \begin{vmatrix} 1 \\ x_P \\ y_P \end{vmatrix} \quad (7)$$

$$Acc\_P = Acc\_20 \cdot t_{20} + Acc\_30 \cdot t_{30} + Acc\_40 \cdot t_{40}$$

3. EXPERIMENTAL RESULTS

The proposed quality-dependent hierarchical mechanism was tested on several DTM databases; two of them are depicted in Figure 5. One was generated via satellite photogrammetric means (top), while the other was produced based on vectorization of 1:100,000 contour maps (bottom). Data of both databases was acquired on different times, where both cover the same area that is approximately 100 sq km.

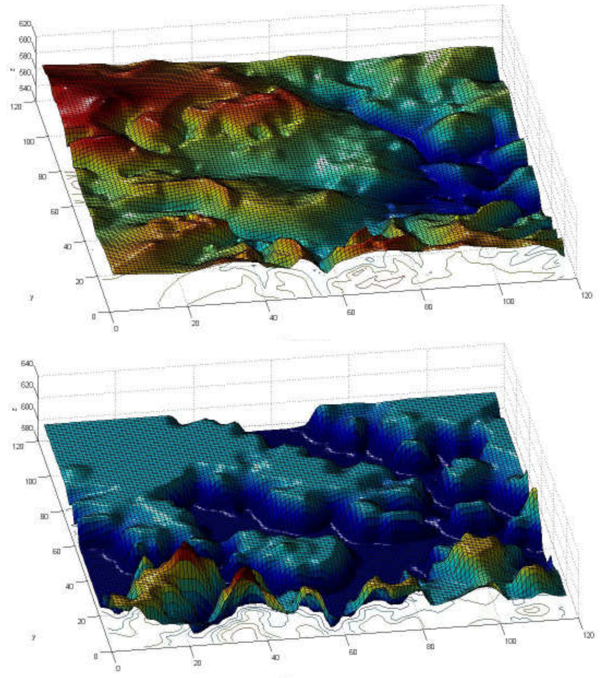

Figure 5. Two DTM databases generated via different observation technologies and on different times

Several experiments evaluating the proposed concept were carried out, of which two are presented here. On the first experiment two synthetic generalized accuracy polygon maps were produced, which showed abrupt accuracy changes and large values differences - depicted in Figure 6. This experiment is aiming to validate that inner morphology is maintained and no discontinuities exist while "moving" between neighboring accuracy polygons; accuracies chosen enabled emphasizing this. The outcome of implementing the proposed concepts is an integrated DTM topography that is continuous with no data holes - depicted in Figure 7. Moreover, inspecting the representation closely clearly shows that the eastern area is basically a copy of the topography that exists in the 1st source DTM (as can be seen by the underlying contour lines, which are nearly the same). This is due to the fact that within this area the accuracies values are 5m from one map and 30m from the other. This translates to weighted heights average magnitude of 1:36. The western area is generated basically by an averaging process derived by the corresponding accuracy polygons that have the same weight magnitude in the process.

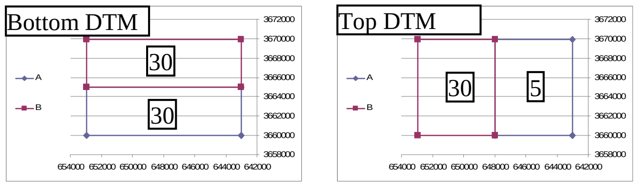

Figure 6. Generalized accuracy polygon maps; accuracy value is depicted in meters

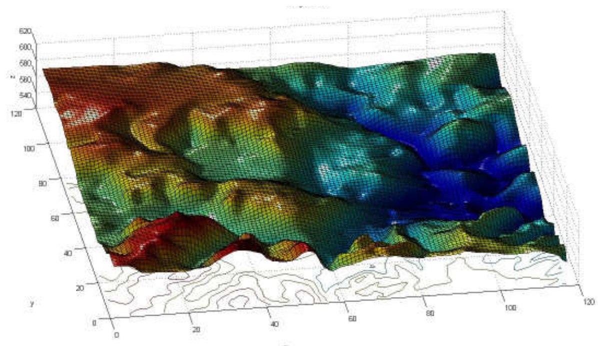

Figure 7. Integrated DTM generated in the first experiment

For the second experiment real accuracy polygon maps are utilized, describing realistic nationwide DTMs accuracies ranging between 5 - 25m, depicted in Figure 1 (left map relates to the top DTM, while the right map to the bottom DTM). Figure 8 (left) depicts contour representation of the accuracy values of the left accuracy polygon map after the proposed smoothing process, where two triangles and five trapezes were generated. It is clear that there are no visible accuracy discontinuities - accuracy transition is constant and smooth - thus presenting a qualitative and reliable smoothing process. Figure 8 (right) depicts contour representation of the weight values used in the reverse-engineering integration process in respect to one source DTM heights. These values take into account both smoothed accuracy polygon maps generated, resulting in a continuities weighing. The contour representation resembles the geometry and topology of both accuracy polygon maps (from Figure 1), resembling a superposition of both maps, with no contour discontinuities or abrupt value changes. Consequently, the generated DTM, which is depicted in Figure 9, shows continuous and uniform topography while preserving inner and mutual morphology - as well as local trends.

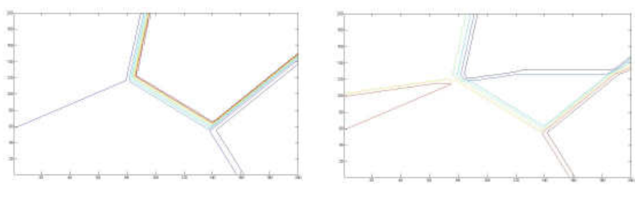

Figure 8. Contour representation of smoothed accuracy polygon map generated (left); Contour representation of the weight values used in the integration process (right)

Emphasizing the reliability of the proposed mechanism, a DTM was generated that is the outcome of the straight-forward height averaging integration mechanism - depicted in Figure 10. The height averaging integration mechanism, which utilizes the source accuracy maps, shows abrupt topography changes and discontinuities (denoted by dashed circles); as well morphology that is not natural in respect to those presented in the source DTMs. The proposed hierarchical concept, on the other hand, shows continuous topography and morphology preservation. As the proposed hierarchical concept takes into consideration the complete multi-scale geospatial inter-relations, the averaging process ignores theme and relates to the heights alone.

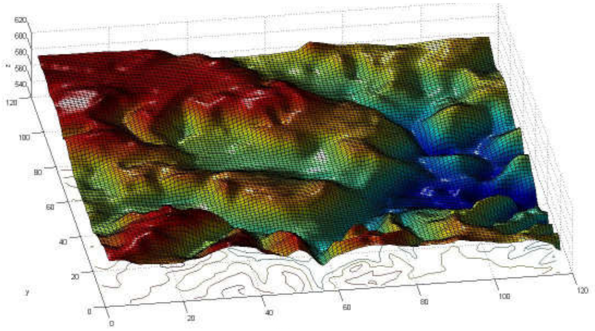

Figure 9. Integrated DTM generated in the second experiment

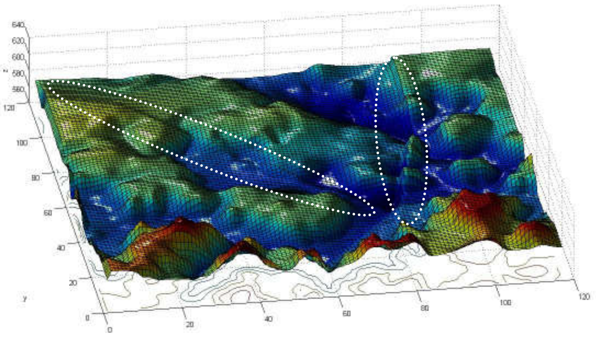

Figure 10. Integrated DTM generated by the common height averaging integration mechanism

4. CONCLUSIONS

The importance of establishing and maintaining nationwide DTM databases was discussed. Different data acquisition technologies, as well as DTM generation techniques and algorithms, derive its inner accuracy, as well as its LOD and resolution - to name a few. These factors influence mutual geometric ambiguities that exist among DTMs representing the same coverage area. A straight-forward integration mechanism can not answer the multi-scale spatial inconsistencies and multi-accuracies issues that might exist in order to produce a qualitative solution.

Novel approach is introduced that ensures the preservations of all existing mutual local correlations and inter-relations between the DTMs - instead of coercing a singular global one. This aims at retaining all topologic and morphologic inter-relations. Moreover, the varied accuracies exist in nationwide DTMs within their coverage area - depicted as an accuracy polygon maps - are taken into consideration. Utilizing the mutual accuracies in the process is important to ensure a continuous terrain relief representation despite the existence of abrupt accuracy changes - within a DTM and between DTMs - as was proved in the experiments that were carried out. The terrain relief representation of the integrated DTM is unified and continuous; it preserves inner geometric characteristics and topologic relations (morphology); it introduces more accurate modeling results of the terrain than any of the original surfaces individually by selecting the significant data out of the two available sources; thus, preventing representation distortions. Moreover, it is important to note that this approach has no dependency on the source DTMs resolution, density, datum, format and data structure. It presents a step toward integrating wide coverage terrain relief data from diverse sources and accuracies into a single and coherent DTM, thus enabling the creation of a seamless and homogenous nationwide DTM.

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