Producing Seamless Multi-Source Quality-Dependent Digital Terrain Models

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SUMMARY

Digital Terrain Model (DTM) databases are one of the more common tools for precise and continuous representation of our natural environment. New data acquisition technologies yield rapid and frequent updating of existing topographic databases (from here on it will be referred to as DTMs). These technologies present high accuracies and resolution levels that were not known until recently. As a result, an updating process performed on an existing DTM has to answer a growing number of considerations, which are derived from the significant differences exist amongst the different DTMs. This yields the production of a multi-source seamless topographic DTM - a data model nowadays maintained by several National Mapping Agencies (NMAs) as well as private companies.

An analysis implementation that utilizes two or more different seamless topographic DTMs simultaneously, such as an integration process that make use of the entire available data, will usually show spatial inconsistencies. These multi-scale geometric inconsistencies are a function of various factors, such as production techniques and time of data-acquisition, leading to the presence of global-systematic errors as well as local-random ones. Moreover, because these DTMs may present different levels of accuracy within each seamless DTM, certain considerations are required, considerations that are derived from the varying accuracies each DTM presents. As a result, not only does ambiguity exist regarding the heights required for integration - but also the accuracies needed to be utilized in the process. The common height averaging or smoothing mechanisms will not suffice in this case.

The paper presents a framework for dealing with the problems and considerations in utilizing seamless topographic DTMs that are quality derived while trying to give a solution to the existing ambiguities. A conceptual new algorithmic approach is detailed, which relies on a hierarchical mechanism and is designated for extracting the existing varied-scale discrepancies in order to produce a common geospatial framework. As a result, the resulting seamless DTM preserves the spatially varying quality and trends. This approach is vital in cases where no arranged and seamless mapping is available, or in developing regions, where integrating topographic DTMs from different sources is crucial. This novel approach proved to be accurate while producing adequate seamless DTM that retained the level of detailing and accuracies presented in the source DTMs.

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1. DTM DATABASES GENERATION

The need for updated, precise and continuous representation of our natural environment is one of the more urgent and major tasks the surveying and mapping community has to answer and give adequate solution to. DTM databases are one of the major tools in this field - utilized mainly for 3D topographic analysis. Until recently, these DTMs were produced by traditional technologies, yielding - in general - 3D databases with a specific resolution, accuracy, and level of detailing (to name a few). During the last decades major technological developments in data collection were introduced. These new data acquisition technologies yield that the surveying and mapping community has to give answer to rapid and frequent updating of existing DTMs, and moreover - deal with accuracies and resolution levels that were not known until recently. As a result, an updating process performed on an existing DTM has to answer a growing number of considerations, which are derived from the significant existing differences amongst the different DTMs.
Until recently, data for DTM production and modeling was basically acquired and measured by one of the following three different techniques (Zhilin et al., 2005, El-Sheimy et al., 2005):

a. Photogrammetry, which utilizes stereo pairs of aerial or space imagery that cover approximately the same area;
b. Field surveying that utilizes total station and Global Positioning System (GPS) receivers for a direct field measurements;
c. Cartographic digitization and scanning, which utilizes raster vectorization techniques of existing topographic maps.

Recent technological developments feature two new techniques in addition to the existing ones:

d. Radar based systems, utilizing radargrammetry techniques as well as Interferometric Synthetic Aperture Radar (IfSAR) imaging;
e. Airborne Laser Scanning (ALS) that produces 3D point cloud representing the scanned region.

The paper will not review in which cases each technology is used, but instead will give a brief review of each technology in order to outline their main differences that reflect on the DTMs production.

1.1 Photogrammetry

Photogrammetry utilizes a pair of stereo images (covering approximately the same area from two different directions and positions), i.e., stereoscopic model. The geometric properties in reality of objects are determined from the images acquired, i.e., enabling a metric measurement of 3D coordinates. As a result, aerial imagery is probably the most common and most effective means (source) to produce and update DTMs. Similar to aerial imagery,

satellite imagery are common today and used in photogrammetry, though usually for smaller scale mapping and DTM production. Though satellite imagery resolution is becoming denser, aerial images still present higher resolution - and are relatively more accurate.
Utilizing photogrammetric techniques mostly produce a gridded DTM (raster like) that presents constant resolution, i.e., usually in the range of a few meters - up to several dozens. The height accuracy is a variable figure that is derived from the sources and techniques utilized to produce the DTMs; hence, it can vary from one DTM to another. Still, this value is usually constant within a single DTM that was produced via a specific campaign.

1.2 Field Surveying

Traditional field surveying techniques acquire the precise location (position) of certain points on earth, i.e., coordinates, by direct measurement. This can be done by measuring distances and angles while utilizing total-station, or GPS receiver for the task. Though the accuracy of a position acquired here is very high (in respect to other techniques), this type of equipment deliver much fewer data and is usually used to measure and map small areas. Utilizing this technique is rarely used for producing nationwide DTMs, but it can still deliver missing data in areas that other techniques can not measure. Field measurements are characterized by a process that measures only relevant points, and therefore is typified by irregular and sparse location of data points.

1.3 Cartographic Digitization and Scanning

Digitization and scanning can be performed on maps in order to "extract" existing height contours to produce DTMs. This can be achieved by: i) *vector-based* line following, and; ii) *raster-based* scanning. Though manual digitization is still performed, semi-automated and automated algorithms are becoming more available nowadays, and many on-the-shelf GIS (Geographic Information System) software packages are equipped with tools delivering these tasks. Manual quality assurance was widespread when applying theses tasks, though with new automated developments it is becoming less common - and eventually will disappear soon. Until recently, producing DTMs via these techniques while using medium-scale maps was very common, as in the case of nationwide topographic DTMs in developing regions.

1.4 Radar Based Systems

SAR technology (based on Doppler frequency shifts principle) is utilized mainly to acquire images, and it was proved that these images are very sensitive to terrain variation. As a result, SAR images are utilized to produce DTMs either by radargrammetry algorithms by parallax measurement (principally similar to traditional photogrammetry only here it utilizes intensity data for measurement), or by inteferometery algorithms by phase shifts extracted from two acquired epochs. Though this technique is promising, it was shown that there still exist large accuracy variations that are derived from geometric conditions of observations, as well as from topographic conditions of the acquired data. These can present accuracy inconsistencies varying up to 50m in height (though 5m accuracy can be reached). Still, this technology is excellent to acquire data on large regions, and it is not affected by the lack of sun light and extreme meteorological conditions (such as clouds). DTMs produced are mostly regular ones presenting constant accuracy within the entire area.

1.5 LiDAR

ALS systems utilize laser scanning for acquiring range data, which is integrated with GPS and Inertial Navigation System (INS). As such, the output is a randomly distributed and already geo-referenced point cloud (as opposed to other techniques that require post-processing geo-referencing of data) that represents the elevation data of the acquired region. Consequently, the coordinates of each point is calculated fast and with high certainty and accuracy. Still, because LiDAR data measure terrain data as well as man-made objects and vegetation, i.e., Digital Surface Model (DSM) additional algorithms are usually performed on the raw data. These algorithms are designated for data filtering, i.e., removal of vegetation and buildings, for the production of DTM. As opposed to photogrammetric and cartographic techniques, no selection of single prominent points can take place during LiDAR measurements, so interpolation techniques are usually implemented on the irregular data in order to achieve a desired regular model. It is worth noting that these algorithms will usually add ambiguity to the acquired data as well as contribute to height alterations. Still, this technique produces the densest DTMs with high height accuracy much better than 1m.

1.6 Comparison of Techniques

DTM databases production techniques is based nowadays on different techniques, and each technique uses different measuring methods for DTM generation. Moreover, several techniques require the use of additional algorithms for the production of the desired DTM. These can be interpolation, such as in the case of raw LiDAR DSM data structure that is irregular and hence is usually interpolated to produce gridded DTM, which is the common structure in photogrammetry and other common DTM generation methods. Other algorithms can be filtering of data, data "filling", and manual editing, to name a few. These processes and techniques will eventually affect the produced DTMs, so they can vary by several parameters, such as: model (structure), data-density, level-of-detail (LOD), accuracy, resolution. Vertical accuracy assessment of a DTM produced by these techniques is given in Table 1. As a result, a DTM that is composed from data-tiles where each was produced via a different technique, i.e., multi-source DTM, will eventually show data-alterations and varying accuracy on the entire represented coverage area.

In addition to different accuracies that each technique presents, resolution densities are also a factor worth emphasizing. Nowadays, LiDAR DTMs presents a density of 20-25 pointes per 1 m^2, aerial imagery can reach a pixel size of 0.1-0.2 meter, and satellite imagery can reach a pixel size of 0.4 meter (GeoEye). Nationwide DTMs usually present a resolution of 10-20 m, while the Shuttle Radar Topography Mission (SRTM) that covers most of our globe presents a resolution of approximately 3 arc-seconds, roughly equal to 100 m. So, it is worth noting that while accuracy figures have strong correlation to the measuring and production techniques, resolution is also derived by the expected needs from the DTM. So, the highest resolution is not always a crucial necessity.

If developing regions are considered, contour maps are usually the main source for data acquisition. As a result, nationwide DTMs are the ones generated from these maps. Because digitization is the less preferable technique, this only intensifies the inconsistencies that might exist when data acquired by a more advanced technique is merged into these DTMs.

Technique	Vertical Accuracy (m)
Aerial photogrammetry	0.1 – 1
Satellite photogrammetry	1 – 10
Field surveying	0.01 – 0.1
Digitization	1/3 of contouring interval
Radargrammetry	10 – 50
SAR inteferometery	5 – 20
LiDAR	up to 0.1 – 0.2

Table 1. Vertical accuracy assessment of different DTM production techniques

2. ACCURACY ASSESMENT

It is no surprise that accuracy is perhaps the main factor considered with a DTM. All projects and tasks that make use of the height data it holds are dependent on it, and the statistical certainty they present is derived from it. The accuracy of the data can be assessed as planimetrically (*X* and *Y*), vertically (*Z*) - or as a combined accuracy. Usually, as depicted in Table 1, the accuracy of a DTM is referred to the height accuracy - and not the planimetric one. Though Ley (1986) argued that because planimetric accuracy assessment is hard to achieve and so it is rarely addressed, it will be shown in the next chapter that the planimteric accuracy is of great influence when trying to integrate multi-source DTMs. Moreover, it is quite common that the inner-accuracy (sometimes referred to as relative-accuracy) of an individual DTM can be high, while when compared to a high-quality source, its absolute accuracy is much lower. This is usually the case when integrating several DTMs from different sources - the absolute accuracy issue is evident and is a problematic issue that has to be addressed.

As proposed by Ley (1986) there are four approaches when trying to assess - and predict - height (vertical) accuracy of a DTM:

- *Production Procedures*: this approach tries to assess the most likely errors that were introduced during the various production stages - combined with an assessment of the vertical accuracy of the source materials. The vertical accuracy of the produced DTM is the sum of all errors involved in the production process;
- *Area Characteristics*: it was found that there is a strong correlation between the vertical accuracy of contour lines on a topographic map and the mean slope in that area;
- *Cartometric Testing*: an experimental evaluation of checkpoints within the DTM in respect to a reference known values;
- *Diagnostic Points*: quality check of the model by sampling the source materials at the time of data acquisition.

Li, (1990), states seven factors that derive the accuracy of 3D databases (DTMs) - depicted in Equation 1:

$$A^{DTM} = f\left(C^{DTM}, M^{Modeling}, R^{Terrain}, A^{Data}, D^{Data}, DN^{Data}, O\right) \quad \textbf{(1)}$$

where, A^{DTM} denotes DTM accuracy; C^{DTM} denotes DTM surface characteristics; $M^{Modeling}$ denotes DTM method of modeling; $R^{Terrain}$ denotes DTM terrain surface roughness; A^{Data} denotes DTM source data accuracy; D^{Data} denotes DTM source data distribution; DN^{Data} denotes DTM source data density; and, O denotes other elements not always quantifiable.

The characteristics of the surface derive the number of sample points needed in the DTM. The more complex the terrain is - more sample points are needed to give an adequate representation, i.e., more points are measured. The model (structure) of the DTM is significant as well, as there are two approaches used: i) *direct*, where the surface is constructed from the measurements (such as in the case of LiDAR DSM or field survey); and, ii) *indirect*, where the gridded surface was constructed by an interpolation based on the measurements. Moreover, it is obvious that errors in the sources utilized for the DTM production are propagated on it directly during the modeling stage. Different empirical models are designated to assess the accuracy of a DTM, such as the three ISPRS test data area (Li, 1994), though they will not be addresses here.

Consequently, it is obvious that different factors propagate in different magnitudes on the accuracy of a produced DTM, combined with the different techniques and methods utilized for its generation. It is evident then that different DTMs have different sensitivity of computed terrain attributes and representation, which is derived directly from the fact that the DTMs present heterogeneous geospatial data (Wilson et al., 2001). When trying to produce a seamless DTM, i.e., multi-source one, such as a nationwide DTM, it is a combination of various DTMs that were produced via different techniques and on different acquisition times. Hence, it will present varying accuracies within its entire coverage area (it is obvious that even a single small coverage area DTM can present different accuracies).

These factors are amplified when dealing with a nationwide DTM that is usually presented in a gridded DTM structure while produced via various techniques. Taking all accuracy factors into account, it is evident that certain coverage areas were acquired irregularly but were later interpolated to a grid; certain coverage area present a certain density and resolution - that might differ from its surrounding; sometime a re-sampling is introduced on a certain area; and more. Consequently, these factors can be translated into accuracy polygon maps - one map for each DTM, where each polygon on a certain map corresponds to a certain coverage area describing its vertical accuracy. This only amplifies on the fact that tough the data is supposed to be seamless, moving from one area to another will surely introduce errors to an integrated DTM that utilize this data. Figure 1 schematically depicts two accuracy polygon maps representing the accuracies of two seamless DTMs covering (approximately) the same area. A DTM that will be produced by integrating these multi-source DTMs has to represent a surface that takes into consideration these accuracies: each node in the integrated DTM is derived from the corresponding height nodes in each seamless DTM - and its matching accuracy.

Accordingly, the integrated DTM has to preserve the topography and morphology of both DTMs, and represent correctly and adequately the two given terrain representations.

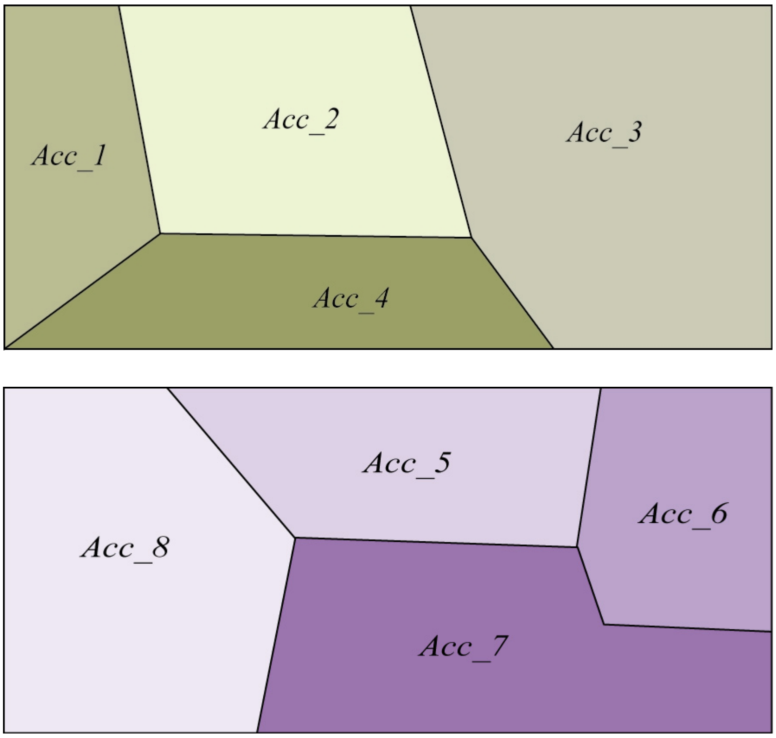

Figure 1. Two accuracy polygon maps representing the varied vertical accuracies of seamless DTMs

3. DTMs INTEGRATION

3.1 Introduction

As mentioned earlier, digital terrain relief data is amongst the foremost important applicable information tool for the representation, characterization, and modeling of earth, and its natural and man-made environmental processes. A frequent updating of outdated DTMs is therefore becoming more common and essential under the assumption that by updating inferior DTMs with updated ones has high potential for achieving an enhanced and more accurate topographic representation of the terrain. This fact is intensified under the assumption that developing regions may utilize out-of-date and non-qualitative nationwide DTMs that require rapid updating: the updated DTM will display more accurate and up-to-date representation of the terrain relief in a denser data structure. An update process will usually integrate (merge) data in order to achieve an enhanced, improved and reliable product.

The fact that each DTM involved in the integration process presents geospatial data acquired from different sources, which consists of various geometries, scales, resolutions, types, accuracies, epochs (date acquired), etc., might lead to observing global as well as local discrepancies inherent in the different DTM databases. These discrepancies may occur due to natural causes (such as underground activities, landslides, earthquakes, and more) or human activities that took place during the data acquisition epochs, as well as having inherent errors occurring during the observations or production (object modeling) stages (Hutchinson and Gallant, 2000). These various non-uniform factors present global-systematic errors as well as local-random ones, which reflect different scales of geometric differences. Ignoring the topographic discrepancies and integrating the data as is with no prior inspection of their magnitude and value by one of the common mechanisms, such as "cut and paste", height averaging, "height smoothing" or mosaicing, will probably result in wrong representation and spatial gaps and entities that appear twice in the integrated terrain relief representation. These common mechanisms address only the height representation issue of the terrain, and not its characteristics - topology and morphological structures (Laurini, 1998). Morphologic and accuracy adjustments are essential to achieve a correct representation. The result of implementing these types of mechanisms will be expressed in visible terrain relief discontinuities. The characteristics of the integrated terrain are not preserved, and may even result in a final product that is inferior to any of the original datasets. Add to this the fact that different and varying accuracies are involved - and a bigger ambiguity regarding the quality of the final product is introduced to the process. Therefore, the solution that will be chosen must present a spatial approach, and hence preserve the morphologic and topographic inter-relations and representations that exist in each DTM.

3.2 Related Work

Papers, which addressed the problem of integration of multiple DTM databases with various accuracies, such as (Podobnikar, 2000) or (Frederiksen et al., 2004), relied on the fact that all the DTMs involved in the integration process were already geo-referenced to a certain coordinate reference system - and as such are already mutual geo-referenced, so there are no morphological incongruities between them. This will sometime not stand in reality, where it is evident that morphological discontinuities exist, which reflects on datum inconsistencies among the different DTMs. Both papers did not address the different accuracies each DTM introduced, and furthermore, as in the case of (Podobnikar, 2000), additional interpolation on the data was carried out, which further contributes to accuracy ambiguity. Hahn and Samadzadegan (1999) have addressed the problem of different scale DTMs by applying the wavelet concept - while relying on the fact that each DTM presents a constant accuracy and that there are no spatial irregularities between them.

Kaab et al., (2005) used multi-temporal and multi-scale DTMs for the task of terrain elevation changes by subtracting them. Though the authors utilized DTMs, which were acquired by different technologies, for the differencing task, they argued that though systematic errors might exist but still relied on the fact they have no existing orientation and registration ambiguities - as long as they were produced via the same technology and means. The authors recommended registration only when multi-temporal or different acquisition technologies were involved. No special accuracy-driven considerations were discussed.

Katzil and Doytsher, (2006) have addressed the issue of the seam line between two adjacent DTMs and its close surrounding by using a new conflation algorithm based on homologous 3D polylines in order to achieve a continuous strip of DTM datasets. It is worth noting that this paper have addressed the issue of the seam line (similar to the "height smoothing" mechanism), and not the issue of a complete integration and updating between two (or more) datasets, which involves the extraction of the inner inherent topological characteristics and their relations.

The authors of this paper have addressed the problem of integrating DTMs by implementing a hierarchical procedure - from global to local, and by this overcoming the different scale of existing inconsistencies among the DTMs (Dalyot and Doyther, 2008). The general guidelines of this process and its accompanied algorithms are given in the next chapter, while the conceptual idea of addressing the polygon accuracy maps in the procedure is detailed.

4. SEAMLESS QUALITY-DEPENDENT DTM PRODUCTION

The hierarchical integration of two (or more) DTMs process proposed by Dalyot and Doyther, (2008), utilizes complete and accurate sets of data-relations that exist within the entire mutual coverage area. The use of these data-relations enables a precise modeling, i.e., extracting a mutual reference working frame. The procedure is divided into three main stages:

- *Pre-integration*, i.e. geo-registration, whereas choosing a common schema of both geospatial datasets is carried out while relying on sets of selective unique homologous features (objects);
- *Matching*, which is based on geometric schema specifications analyses, and is essential for achieving precise reciprocal modeling framework between the two datasets;
- *Integration*, which uses the matching modeling relations and the data that exists in both datasets for data fusing, hence achieving an enhanced and accurate terrain representation.

4.1 Pre-Integration

A novel interest-points extraction mechanism is implemented on both DTMs in order to identify selective unique homologous features. The features extracted on each DTM were later coupled-up with conjoint features on the other DTM. This was achieved by implementing the forward Hausdorff distance algorithm, and hence extracting the global discrepancy vector exists. These two steps in this stage achieve a global reciprocal working frame that enables a more precise local matching process implementation. It is worth noting that no relative accuracy considerations of the two DTMs are implemented in these stages.

4.2 Matching

In order to achieve correct local matching of the two DTMs, the dividing of the entire mutual coverage area into local frames is implemented. On each frame an Iterative Closest Point (ICP) process is carried out independently and separately (Besl and McKay, 1992). Each grid-node from one DTM is coupled-up to its correct spatial location in the other DTM by implementing a designated set of geometric rules and constraints. The differences in X, Y, and Z values of the two coupled points are inserted into a matrix - each two points coupled-up constitutes a row, and by implementing a least square matching process a single difference vector for the entire local frame is computed. It is worth noting that the ICP process utilizes the reference frame extracted earlier, hence achieving a more reliable solution. Here, the accuracy of both DTMs is taken into consideration. Instead of giving each row in the matrix the same weight, a different weight will be given to each row, which is derived from the accuracy polygons each of the points fall in. For example: if point *a* from DTM *A* ($a \in A$) falls in an accuracy polygon *Acc_1*, and its corresponding point *b* from DTM *B* ($b \in B$) falls in an accuracy polygon *Acc_2*, then their relative weight in the matching process for that frame is derived by *Acc_1* and *Acc_2* values, as depicted in Equation 2. The more accurate the polygon is (smaller *Acc* value), the higher the weight value is. Hence, more accurate coupled-up points will have higher influence in the ICP process, producing a more reliable solution that characterizes correctly the given data.

$$Weight_{1-2} = \frac{Acc\_0}{\sqrt{(Acc\_1)^2 + (Acc\_2)^2}} \quad \textbf{(2)}$$

where, *Acc_0* denotes the accuracy of a weight unit.

4.3 Integration

The previous stage outcome is a set of difference vectors, where each characterizes the correct geo-registration - transformation - parameters of corresponding frames. Practically, one can now calculate where each point from one DTM "falls in" the other via the defined parameters of a certain frame. Still, due to the fact that each frame covers many DTM points and in order to prevent discontinuities in the transformation parameters utilized while moving between adjacent frames, specific interpolation algorithms on the transformation parameters of these frames are implemented. An integration process can now be implemented by calculating for each $(X, Y)_i$ coordinates in the integrated DTM the accurate position and hence corresponding height values in both DTMs. This is achieved by utilizing difference values calculated based on an interpolation implemented on the difference vectors that were computed in the ICP process. The corresponding calculated two height values in both DTMs are then relatively weighted to extract the corresponding height value in the integrated DTM (matching the origin/point of departure $(X, Y)_i$ values used) - depicted in Equation 3. It can be described spatially, as if the integrated DTM is situated spatially in the space between the two original DTMs, as depicted in Figure 2.

Because each DTM presents internal varying accuracies - along with existing accuracy differences among the DTMs - a process that will take this into consideration is essential. Moreover, it is important that the integrated DTM will present seamless terrain relief, regardless of abrupt accuracy changes derived from the polygons. In order to achieve this we suggest building a new "smoothed" accuracy map - for each existing map - that will present gradual accuracies change by implementing a buffer-like process around each accuracy polygon. The resulting process of the new accuracy polygon map is depicted in Figure 3, where continuous accuracy transitions now exist.

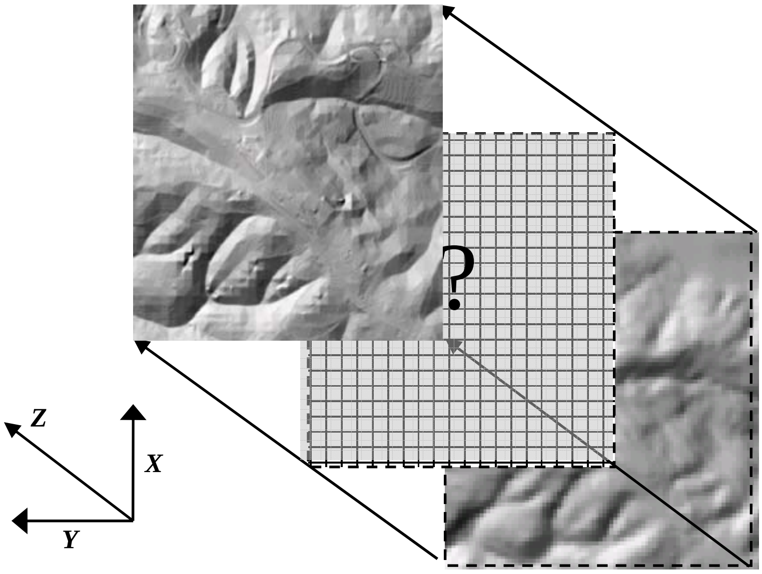

Figure 2. A schematic representation of an integrated DTM that is situated spatially in the space between the two original DTMs

Accordingly, when implementing the height calculation of all nodes in the integrated DTM by executing the outlined process ensures that the resulting integrated DTM presents continuous terrain relief representation. Utilizing exact local transformation parameters from one DTM to the other accompanied by a continuous accuracy transition change in and between both DTMs ensures just that.

$$\begin{aligned} (diff\_values)_i &= \mathrm{int}\,erpolation(diff\_values)_{ICP} \\ h_1 &= f\left[m_1, (difference\_values)_i, X_i, Y_i\right] \\ h_2 &= f\left[m_1, (difference\_values)_i, X_i, Y_i\right] \\ h_{final} &= f\left(m_1, m_2, h_1, h_2\right) \end{aligned} \qquad \textbf{(3)}$$

where, $(diff\_values)_i$ denotes the difference values calculated by interpolating ICP difference vectors; $(X, Y)_i$ denote a node in the integrated DTM; h_1 and h_2 denote corresponding source DTMs heights; and, m_1 and m_2 denote corresponding source DTMs weights.

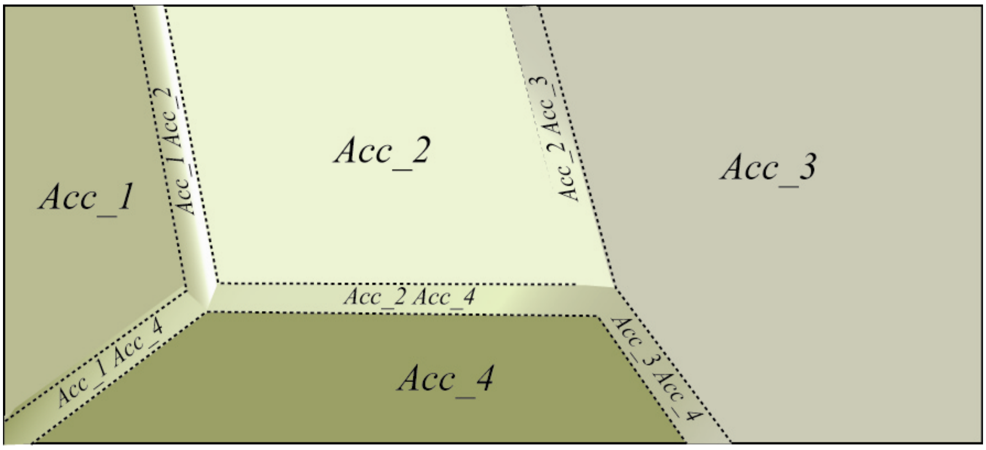

Figure 3. A "smoothed" accuracy polygon map, which is the outcome of the buffer-like process, presenting continuous transition between polygons

Summarizing the above three stages, the integrated DTM produced by implementing the hierarchical process and taking into account the reciprocal and varying accuracy satisfies the preliminary requirements: obtaining a singular, unified, and spatial continuous surface representation of the terrain relief. The unified DTM that takes into account the existing global - as well as local - trends and discrepancies among the various DTMs preserves the topologic relations and morphologic entities represented in each of the given DTMs separately. An example of two DTMs and the integrated DTM produced via the process presented here is depicted in Figure 4.

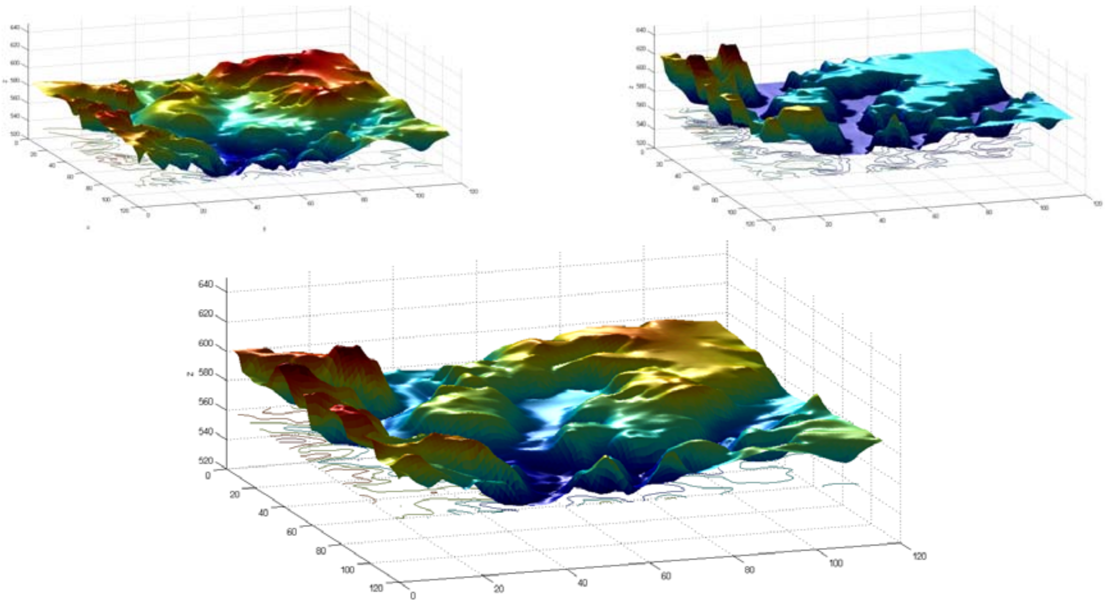

Figure 4. Source DTMs (up left and right) and integrated DTM (down) - topologic relations and morphologic entities are preserved

5. CONCLUDING REMARKS

The problems that the geo-community face when the task of using simultaneously two - or more - topographic databases were reviewed. It was found that as different techniques and algorithms are involved in the process of DTM production, certain accuracy-derived factors that influence mutual geometric ambiguities exist. An integration process has to answer certain aspects in order to produce a qualitative solution. The aim is to produce an integrated DTM that will present a terrain relief that will retain all the topologic and morphological inter-relations exist in the DTMs involved in the process.

A novel approach was 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 approach implements a process that begins with a global stage, which is designated to extract a global reciprocal working frame. Only then, the local stage is introduced, which is designated to extract existing local trends. These ensure that all different levels of existing discrepancies are taken into account in the integration process. Moreover, it was shown that nationwide seamless DTMs present varied accuracies within their coverage area. These varied accuracies can be depicted as an accuracy polygon maps. The outlined process takes into account these mutual accuracies in order to achieve a continuous terrain relief representation despite the abrupt accuracy changes - within a DTM and between DTMs. The terrain relief representation of the integrated DTM is unified and continuous; it preserved the inner geometric characteristics and topologic relations (morphology); thus, preventing any 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 terrain relief data from diverse sources and accuracies into a single, coherent DTM, enabling the creation of a seamless DTM.

This approach is vital when there is requirement for integrating topographic DTMs from different sources and accuracies. This becomes crucial in cases where no arranged and seamless mapping is available, such as in developing regions. This novel approach proved to be accurate while producing adequate seamless DTM that retained the level of detailing and accuracies presented in the source DTMs.

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