A HIERARCHICAL APPROACH TOWARD 3-D GEO-SPATIAL TERRAIN MERGING

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ABSTRACT:

Nowadays, DTM databases are vital for a variety of applications, such as visualization or terrain analysis. Therefore, in the fields of civil engineering, mapping and geo-information, or geophysics, this data is on the functional route leading from data acquisition to derived applications. One of the main issues when dealing with DTM database representation is data merging, which involves the integration of data from different sets. Various factors cause global-systematic errors as well as local-random ones, which reflect on geometric and radiometric differences. This paper describes a new approach to merging DTM datasets, which analyze the local inconsistencies of DTM geo-spatial databases in order to give an appropriate integration solution. The idea is to implement a hierarchical solution of pyramidal approach, in which local geometric discrepancies are monitored. The proposed solution suggests the implementation of two topographic zoning working levels – global and local. This solution offers control over the various levels of errors, and is implemented as follows: zonal division of the whole datasets area into patches, in which a local registration is extracted for each; sub-zonal division, in which an accurate 'local' ICP matching process is achieved. This process yields the extraction of a new database, which stores data representing local discrepancies (in the form of transformation parameters) of the integrated DTMs. This new approach yielded accurate results for DTM datasets merging, therefore achieving a singular, unified and spatial continuous surface representation of the terrain relief.

1. INTRODUCTION

Terrain relief is amongst the foremost important information in the representation and characterization of earth and various relevant processes. Hence, DTM databases are today one of the main resources for a wide range of different applications involved with terrain relief analysis. This is mainly a result of recent developments in data acquisition and data processing. When one might compare the representation of the terrain relief, derived from different DTMs, global as well as local discrepancies can be observed. These discrepancies may occur due to natural causes or human activities that took place during the data acquisition epochs, as well as having inherent errors occurring during the observations or production stages (Hutchinson & Gallant, 2000). These various factors present global-systematic errors as well as local-random ones, which reflect on different scales of geometric and radiometric differences.

If the task of integrating or merging different DTM geo-spatial datasets is at hand, a thorough preparation of methods and approaches of dealing with these various factors is mandatory. One can not ignore the topographic discrepancies and integrate the data just by an averaging process, or even by replacing the less accurate data with the higher one. An appropriate solution for the phenomena of topographic differences must be implemented prior to the integration process. For example, the common "cut and paste" merging procedure on datasets representing the same terrain relief area produces incorrect results. This is mainly for the fact that there are irregularities in the topographic representation between the different datasets that can be characterized as 'topographic walls' (Figure 1). In addition, the required integration process yields the merging of geo-spatial datasets that may consist of different resolution, accuracy, datum, orientation, and level of detailing. Furthermore, DTMs only partly describe terrain relief, which is a continuous entity, mainly because of its discrete representation in terms of points or lines. Based on the fact that each DTM describe only partially the terrain, integration of two or more sources can improve the quality of the merged DTM, and thus represent more adequately the terrain relief.

The merging problem can be divided into two main stages, or processes: the first is to find the best correspondence between datasets; while the second is to execute the merging process itself according to the results of first stage. Rusinkiewicz & Levoy (2001) showed that the primary knowledge regarding the geometric spatial relations between the datasets is crucial and must be known prior to the matching process itself in order to extract a non-biased matching solution. This knowledge can be extracted by implementing initial registration processes on the different datasets. For example, pairing-up groups of two congruent geomorphologic features existing in the different datasets, which hence will produce a qualitative initial registration value of the two datasets (three-shift values for example).

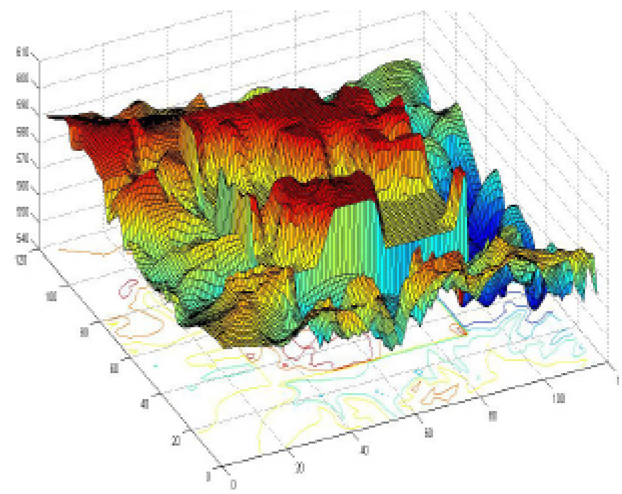


Figure 1. 3-D "cut and paste" superimposition of two datasets: planimetric and altimetric topographic discrepancies

After the extraction of the initial registration value, a full 3-D matching procedure is feasible. This can be done by one of the available processes for spatial geometric datasets matching. In this paper a constrained ICP (Iterative Closest Point) procedure is implemented. This algorithm was first presented by Besl & McKay (1992), and is mainly designated for a full 3-D point cloud matching process by nearest neighbor criteria, using iterative LSM (Least Square Matching) (Gruen, 1996). Knowing the registration values extracted in the first stage, the calculation of a more accurate and reliable spatial affine transformation (three rotation angles and three shifts, for example) is feasible.

Several papers, such as (Laurini, 1998, and Feldmar & Ayache, 1994), have addressed the problem of ensuring continuity of surface description - semantically, topologically, and geometrically - when a merging procedure is implemented. Based on the various iterative algorithms designated for rigid surfaces registration shown in these papers, this task proved as a successful one and the merged data that was produced proved to be statistically reliable. In this paper a merging process based on a "reverse engineering" procedure is implemented, while using bi-directional third-degree parabolic interpolation (Doytsher & Hall, 1997) on the transformation parameters extracted in the registration stage.

In section 2, detailed explanations, as well as the mathematical formulae of the hierarchical solution of pyramidal approach algorithm, are outlined. The procedure suggests the implementation of two working levels of topographic zoning – global and local. The motivation of this is to monitor global zonal discrepancies and thus extract the corresponding registration-values per area. An accurate 'local' ICP matching process is then feasible, enabling the calculation of a singular, unified, and spatial continuous merged surface representation of the terrain relief.

2. PROPSED PYRAMIDAL APPROACH

Addressing the different factors, discussed in the previous section, requires various mathematical procedures. These procedures will be given in this section. Two working zonal levels are proposed as part of the pyramidal approach – global and local. Instead of working with the entire data as a global bundle while ignoring localized topographic trends, the extraction of local discrepancies is possible by working only on localized data. These two working levels – global and local – are required for the initial registration and matching stages respectively. Hence, two data-dividing stages are performed on the entire area that will be discussed in further detail. A localized constrained-ICP and merging processes are carried out, enabling the calculation of the accurate and qualitative registration parameters as well as a spatial continuous surface representation.

2.1 First Order Division

A first order division is required in order to address the preliminary need of extracting local-discrepancies' values exist between the two datasets. This is a significant statistical stage which is required before the implementation of the matching process on the data. The entire area is divided into medium-sized-patches (*msp*), as depicted in Figure 2. The extraction of unique local geomorphologic points, i.e. interest points, and then the calculation of the initial registration value correspond for each congruent *msp* is carried out on these zonal patches.

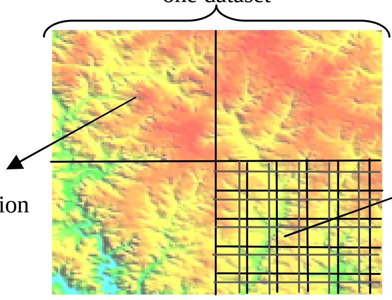


Figure 2. Two working topographic zoning levels: global registration (*msp*); and, local matching (*ssp*)

2.2 Extracting Interest Points

The Extraction of local-discrepancies will rely on unique surface-derived geomorphologic points, such as mountain or hill peaks. It is worth noting that the mathematical approach shown here will use topographic maxima only, and not minima ones. This is due to the fact that local minimum points are very rare topographically, while relying on maximum ones proved to be sufficient for the proposed approach. Extracting these interest-points will satisfy the demand for calculation of initial shifts, i.e. displacements, that exists among congruent *msp*s. This is achieved by pairing-up process on the extracted homologous geomorphologic points. A precise displacement vector extraction will provide the needed initial knowledge regarding the local *msp*s registration values covering the entire topographic area given.

In order to successfully extract interest points, the examination of the topological conditions around each DTM grid-point is required. A new computational approach is carried out, as outlined in this section. Statistical testes and geomorphologic definitions and constraints according to a set of geometric rules are performed in order to ascertain that an examined grid-point can be defined as an interest point. The computational approach is accomplished according to the following steps:

1. Extracting four perpendicular second degree polynomials, derived from the height (Z) and {(X) or (Y)} coordinates in each direction i, function of the grid's spacing {*?X or ?Y*}, as depicted in Equation 1. Each of these polynomials is defined by the geometric conditions registered by six consecutive discrete points in each direction, starting with the examined grid-point. Extracting the three coefficients of each of the polynomials is achieved by a least squares adjustment process. The geometric conditions, described by the extracted four polynomials, quantitatively define the topographic environment of each examined grid-point (Figure 3).

$$Z_i = a_i + b_i \cdot \{X \text{ or } Y\} + c_i \cdot \{X^2 \text{ or } Y^2\} \qquad (1)$$

Where a_i, b_i, c_i = polynomial coefficients
X, Y, Z = grid-point coordinates
i = 1 to 4

2. Calculating the integral (area) of these polynomials in the Z direction relative to the height of the farthest point. This is carried out for each of the extracted polynomials. The calculated integral value defines whether the examined grid-point is above its surrounding and in what magnitude, as can be depicted in Figure 4.

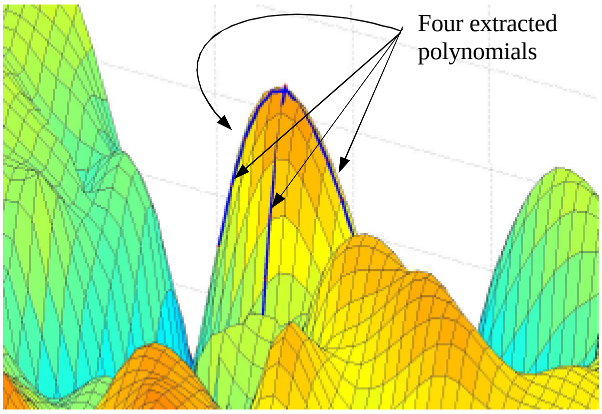


Figure 3. Four perpendicular second degree polynomials defining the examined grid-point topographic neighborhood

3. After the mathematical extraction of the geometric values needed for the interest points definition, statistical tests on these values are carried out. These statistical tests will ensure a preliminary qualitative consideration, both topologically and geomorphologically, of the examined grid-point as an interest point. The statistical tests are carried out on two of the polynomial coefficients values - *c* and *b*, extracted on stage 1, and on the polynomial integral value, calculated on stage 2. These tests examine the polynomials topological behavior and define their type (ascending or descending), as well as defining the height magnitude of the examined grid-point in respect to its surroundings.

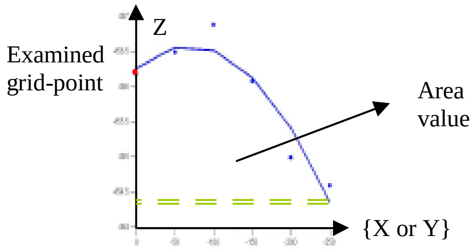


Figure 4. Profile of extracted polynomial

4. After the preliminary geometric evaluation of all grid points, local grouping by distance criteria of the predefined interest points is carried out. A pre-defined number of points' criterion, derived from surface characteristics, is declared in order to qualitatively define a group. Then, in each of these groups the highest grid-point is chosen (Figure 5).

5. A local bi-directional interpolation within each group around the highest grid-point ensures the precise calculation of the highest topographic location, thus achieving sub-resolution accuracy (Figure 5). This calculation is done by extracting local polynomials, similar to the approach outlined on stage 1 (Equation 1), near each highest grid-point in *X* and *Y* directions - Z_x and Z_y respectively. Geometric constraint will ensure that these two local polynomials cross at the highest topographic location. S_x and S_y (Equation 2) denote the shift value - in directions *X* and *Y* respectively - pointing to the precise topographic location relative to the groups' highest grid-point.

2.3 Calculation of Initial Shift Vectors

Now, the calculation of the shift vector corresponding to the zonal topographic displacement is feasible. For each congruent *msp* the values of *dx*, *dy*, and *dz* are calculated by implementing topographic registration and voting search criteria on the interest points and their attributes. Statistical tests are also carried out in this preliminary registration search process in order to achieve a better certainty of the three-shift values calculated, which are needed for the matching stage.

$$s_x = -\frac{a_1}{2\cdot a_2};\; s_y = -\frac{a_4}{2\cdot a_5}$$
$$X_{\text{interest\_point}} = x_{highest} + s_x;\; Y_{\text{interest\_point}} = y_{highest} + s_y \quad (2)$$

Where a_1, a_2 = polynomial coefficients of Z_x
a_4, a_5 = polynomial coefficients of Z_y
S_x, S_y = shift value in direction X and Y respectively

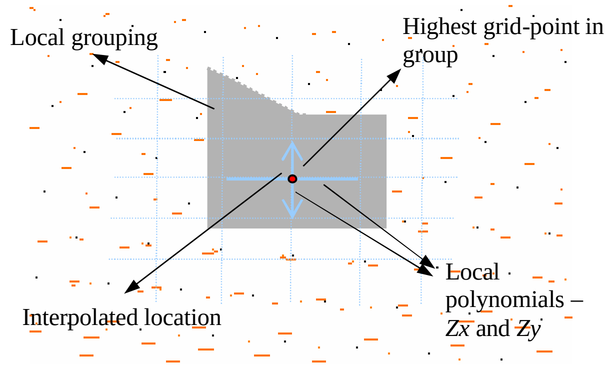


Figure 5. Interest point precise location: grouping process and bi-directional interpolation

2.4 'Local' ICP Matching

A second order division is implemented: every *msp* is sub-divided again into overlapping small-sized-patches (*ssp*), as depicted earlier in Figure 2. Based on the inherent local discrepancies of the DTM, it is clear that small patches may be fitted much better and more accurately than large patches. This will introduce smaller topographic gaps, in contrast to large patches that will introduce bigger ones. Consequently, this ensures that an ICP process implemented on small patches will produce more accurate results for the relations exist between the 3-D point cloud, denoted by *f(x,y,z)* and *g(x,y,z)*.

A matching process is designated to find the best geometric correspondence between two datasets. The magnitude of the correspondence of the two datasets is derived from an error vector, denoted by *e(x,y,z)*, which describe the relations of the two datasets, that can be denoted by *{f(x,y,z) - g(x,y,z)}*. Vector *e* includes local-random errors as well as global-systematic ones. The extraction of this vector can be achieved by minimizing the target function, i.e. extracting the best possible correspondence between the two datasets *f* and *g*.

A constrained ICP process is implemented locally on each congruent *ssp* in order to extract the best geometric correspondence of the two datasets. The constrained ICP process, as outlined in Equations 3a, 3b, and 3c, suggests a nearest neighbor search criteria process according to these three constraints:

(3a) the coordinates of the paired-up nearest neighbor *i* in dataset *g* (X^g_i, Y^g_i, Z^g_i), which correspond to point *i* in dataset *f*, fit to a local cell-plane in dataset *g*;

(3b) the line-equation, derived from the coordinates of point *i* transformed from dataset *f* to dataset *g* with the best known transformation parameters (denoted by *x_p*, *y_p* and *z_p*), and the paired-up nearest neighbor *i* in dataset *g* (X^g_i, Y^g_i, Z^g_i), is perpendicular to the local cell-plane in dataset g in X direction (achieved by first order derivative);

(3c) same constraint as outlined in (3b) only this time the line-equation is perpendicular to the local cell-plane in dataset g in Y direction (achieved by first order derivative).

$$Z^g{}_i = \frac{h_1 \cdot X^g{}_i}{spc} + \frac{h_3 \cdot Y^g{}_i}{spc} + \frac{h_4 \cdot X^g{}_i \cdot Y^g{}_i}{spc^2} \tag{3a}$$

$$\frac{\partial Z^g{}_i}{\partial X} = \frac{h_1}{spc} + \frac{h_4 \cdot Y^g{}_i}{spc^2}; \quad \frac{\partial Z^g{}_i}{\partial X} = \frac{Z^g{}_i - z\_p}{X^g{}_i - x\_p}; \tag{3b}$$

$$\frac{\partial Z^g{}_i}{\partial Y} = \frac{h_3}{spc} + \frac{h_4 \cdot X^g{}_i}{spc^2}; \quad \frac{\partial Z^g{}_i}{\partial Y} = \frac{Z^g{}_i - z\_p}{Y^g{}_i - y\_p}; \tag{3c}$$

Where Z_1 to Z_4 = height of local grid's cell corners in dataset g
$h_1=Z_1-Z_0$, $h_2=Z_2-Z_0$, $h_3=Z_3-Z_o$, $h_4=h_2-h_1-h_3$
spc = grid's spacing
g, f = datasets
($X^g{}_i$, $Y^g{}_i$, $Z^g{}_i$) = paired-up nearest neighbor
(x_p, y_p, z_p) = transformed point i from dataset f

As the two DTMs represent the same terrain relief, we can assume that the two datasets have the same scale factor (*S*). Hence, the transformation model was assembled from six parameters – three translation parameters: *dx*, *dy*, and *dz*, and three rotation angles: *f* , *?*, and *?* . The initial shift vector used for each local *ssp* ICP-matching is the one that corresponds to its higher-level *msp* (i.e., dx_0, dy_0, and dz_0). Furthermore, because linearization is needed to solve the transformation model, the initial values needed for the rotation angles - f_0, $?_0$, and $?_0$ - where evaluated initially as 0 (zero) degrees, relying on the fact that the diagonal values in the rotation matrix *R* are close to 1 (one).

For each point in dataset *f* a nearest point from dataset *g* is paired-up as long as the criteria outlined above are fulfilled. Consequently, with all the pairs extracted, a local six-parameters registration is achieved. The transformation model used for each congruent *ssp* is shown in Equation 4. This process on each *ssp* is carried out iteratively until a pre-defined statistical criterion is achieved. The process yields a better localized registration calculation, thus ensuring topographic continuity of the entire area, as well as excluding a local minima solution for the ICP process and minimizing the computation time. The output of this stage is a database, a 'DTM' looklike (Figure 6), assembled of six-parameters registration values corresponding to the center of each congruent *ssp*.

$$\begin{bmatrix} X_g - X^M{}_g \\ Y_g - Y^M{}_g \\ Z_g - Z^M{}_g \end{bmatrix} = R(j, k, w) \bullet \begin{bmatrix} X_f - X^M{}_f \\ Y_f - Y^M{}_f \\ Z_f - Z^M{}_f \end{bmatrix} + \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} \tag{4}$$

Where g, f = datasets
X, Y, Z = dataset (*g* and *f*) coordinates
R = rotation matrix
dx, dy, dz = three translation parameters
f , ?, ? = three rotation angles
M = center of each congruent *ssp* (*g* and *f* respectively)

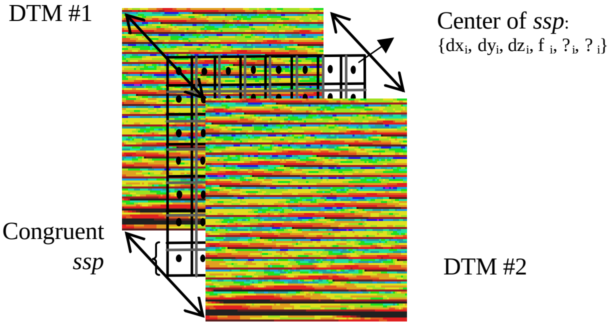


Figure 6. 'DTM' looklike database representing the corresponding six-parameters registration values for overlapping congruent *ssp* zones denoted by index *i*

2.5 Merging

The topographic relationship of the two DTM datasets are now known thorough the transformation parameters extracted locally for each *ssp*. The calculation of the merged geo-spatial dataset is now feasible through a merging process implemented on the data available: two given geo-spatial datasets and six-parameters registration database extracted. This process is performed iteratively using a "reverse engineering" procedure, divided into two main stages:

(i) for each merged DTM grid-point the corresponding six-parameters transformation are calculated. These values will be used respectively for the two-way transformation (merged DTM toward each of the datasets). The calculation is achieved by implementing bi-directional third-degree parabolic interpolation on the neighboring six registration values, as outlined in Equation 5. This computation ensures a smooth interpolation within the grid cells;

(ii) knowing the relative transformation parameters, the height of the merged DTM grid-point can now be calculated. This is achieved via a "reverse engineering" procedure that calculates two corresponding heights from the two original DTMs respectively. This stage takes into consideration the accuracy of each dataset, which derives a weighted height calculated from the two datasets.

$$\begin{gathered} F_1(t) = -0.5 \cdot t + 1.0 \cdot t^2 - 0.5 \cdot t^3 \\ F_2(t) = 1.0 - 2.5 \cdot t^2 + 1.5 \cdot t^3 \\ F_3(t) = 0.5 \cdot t + 2.0 \cdot t^2 - 1.5 \cdot t^3 \\ F_4(t) = -0.5 \cdot t^2 + 0.5 \cdot t^3 \\ Z_P = \sum_{i=1}^{4} \sum_{j=1}^{4} F_j(x) \cdot F_i(y) \cdot H(i,j) \end{gathered} \tag{5}$$

Where $F_1(t)$ to $F_4(t)$ = third-degree parabolic equations
Z_p = height interpolation
t = normalized coordinates 0=t=1
x,y = inner cell normalized coordinates
$H_{(i,j)}$ = elevations of corner points, i.e. six transformation parameters from registration database
i, j = index of 4^x4 neighboring corner points

3. EXPERIMENTAL RESULTS

The suggested approach was tested on different DTMs with planar discrepancies ranging up to hundreds of meters. The interest points' extraction process proved geomorphologically to be accurate and efficient. The automatic process was able to define accurately local surface-derived extremes in the represented topographic relief - i.e., hills and mountains (Figure 7). Moreover, it was concluded that the level of detailing of the DTMs, which is mainly dependent on the resolution of the dataset, has an effect on the number of the extracted interest points: The more detailed the DTM - the more interest points were extracted, and hence their topographic positioning calculation was more accurate. Furthermore, the precise identification of the interest points' location enabled the accurate calculation of the registration shift-vector values between congruent *msp*s necessary for the matching stage.

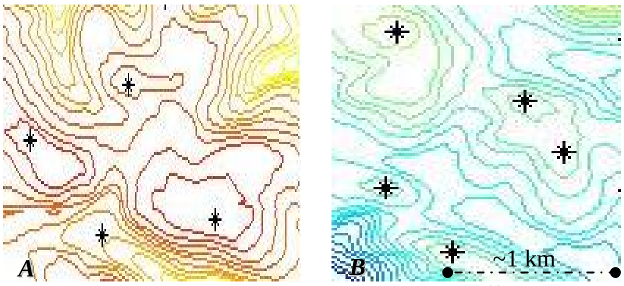


Figure 7. Contour representation showing effective identification and extraction of local geomorphologic surface-derived points

Table 1 shows the necessity and importance of a correct initial shift-vector extraction for the ICP process. Left column shows statistical results when an ICP process utilized the initial shift-vectors extracted on the first stage. The right column shows the results when no prior knowledge was used for the ICP process. Main results that can be pointed out are:

(i) the number of iterations needed for the process to converge was much smaller, and hence the computation time was shorter. It is worth noting that the implemented ICP process was limited to a maximum of 20 iterations per *ssp*, which otherwise would have pushed the number presented on the right column to be even higher.

(ii) more important, when the extracted initial shift-vector was used for the ICP process, the transformation parameters extracted for the *ssp*s were consistent and close to the initial shift-vector values, in contrast when there is no knowledge. This can be seen from the small standard deviation values.

(iii) comparing the quality of the transformation parameters extracted from both ICP processes, it is clear that the statistical quality of those calculated using the initial shift-vector extracted was better. This evaluation was done using a statistical test value *z_s* (Equation 6).

$$
\begin{aligned}
h^{tg} &= f(transformation)h^{oog} \\
dz &= h^{odg} - h^{tg} \\
z\_m &= mean(dz) \\
z\_s &= STD(z\_m)
\end{aligned}
\tag{6}
$$

Where h^{tg} = height of transformed original origin grid (*oog*) using transformation parameters calculated from icp
dz = vertical height difference between original destination grid (*odg*) and transformed grid (*tg*)

Using: / Calculated for all *ssp*s	Initial shift-vector extracted (*dx*=130m, *dy*=-50m, *dz*=30m)	No prior knowledge (*dx*=0m, *dy*=0m, *dz*=0m)
Mean sum of iterations	3.83 [-]	15.29 [-]
Dx_{mean}	124.62 m	16.16 m
Dy_{mean}	-50.07 m	-9.03 m
Dz_{mean}	30.02 m	28.16 m
Dx_{STD}	0.36 m^2	7.59 m^2
Dy_{STD}	0.64 m^2	4.25 m^2
Dz_{STD}	0.16 m^2	1.60 m^2
z_s_{mean}	0.23 m^2	12.16 m^2

Table 1. Statistics of ICP process executed on 132 *ssps*

The quality of a merged DTM can be examined and measured by the preservation of morphologic entities exist in the terrain relief represented by the original datasets. This criterion can be examined visually, by inspecting the merged DTM and the datasets used for its calculation, or evaluated computationally when comparing the discrepancies between the original DTMs and those calculated from the merging process and used to calculate the merged DTM.

Figure 8 present an area of close to 40 square kilometers of two original real datasets - *A* and *B* - as well as the merged DTM. As can be seen from this figure, monitoring local spatial discrepancies and finalizing with the implementation of the constrained 'local' ICP and "reverse engineering" merging processes, the algorithm yielded very good results in terms of topographic accuracy and topographic topology of the merged DTM. The merged DTM presented in this figure is unified and continuous throughout the area of the datasets, and the examination of the represented morphologic structures showed that the merged dataset described the surface correctly.

In order to have a statistical evaluation of the proposed solution, synthetic tests were executed. In these tests real DTMs were transformed using a sinusoidal wave height transformation with added planar shifts. The statistical evaluation of these tests was carried out by analyzing and comparing height gaps: (i) while imitating the "cut and paste" mechanism; (ii) after the implementation of the proposed mechanism.

Table 2 shows this statistical comparison: calculating the standard deviation of the heights difference values per grid-point location *(X, Y)*. The left column shows the gaps range received from the proposed mechanism, while the right column shows the gaps range received from imitating the "cut and paste" mechanism. It is clear that the proposed mechanism show much smaller residual values. This can be explained by the fact that the proposed algorithm takes into account the local topographic relations that exist between the DTMs, whereas this is ignored otherwise. Furthermore, it is worth noting that in synthetic tests where constant height shifts were used for transformation (along with planar shifts), the STD values of the mechanism proposed were very close to 0 (zero).

Comparison on:	Calculated DTMs	Original DTMs
STD value	0.2-0.8 m^2	3.5-5.6 m^2

Table 2. Standard deviation of vertical heights difference of local *ssps*: original DTMs vs. DTMs calculated using transformation parameters

4. DISCUSSION

When discussing the problem of merging geo-spatial DTM datasets, considering different strategies has to be taken into account. In a case where one dataset has much better accuracy and level of detailing than the other - in most cases the better one will be chosen as the correct terrain representation - while ignoring the inferior one. Still, the common situation when merging geo-spatial DTM datasets is when the two datasets has 'similar' level of detailing and accuracy while having some local and/or global discrepancies. In that situation, the merging procedure of the two datasets must preserve the internal morphology, and thus achieve a more accurate and reliable representation of the terrain than any one of the two datasets separately.

The implementation of the new pyramidal approach and algorithms for DTM datasets merging, described here, ensures the preservation of local geometric features and their topological relations while preventing any distortions. The solution outlined is reliable and accurate. Furthermore, the new 'DTM' looklike database that is extracted, which stores the topographic relations between the datasets, can contribute to a better seaming process on the DTMs - small area DTM seamed into a large one. The merging process will consider the topographic conditions exist on the DTMs terrain borders, and hence will prevent the presence of 'topographic walls' in the terrain relief representation.

However, in extreme geometric conditions, such as large discrepancies or no correspondence, or in case of very smooth surfaces, the attempt to extract the registration-values might lead to wrong results. This will probably lead to a biased solution given by the ICP matching process that hence will divert to local minima instead to an implicit one. These cases are very rare, and the suggested solution will result in a satisfactory solution of the merged DTM for non extreme geometric conditions.

By implementing separate levels of working-data, the pyramidal approach described, enables monitoring local discrepancies, which exist locally between two different DTM geo-spatial datasets. This approach is in contrast to the common used merging procedure, in which one global transformation, derived from the entire data, is implemented. Using global transformation in a merging procedure might lead to ignoring or 'smearing' any local existing geomorphologic-features. The implementation of this new pyramidal procedure yields a unified and continuous representation of the terrain relief, while preserving the internal morphology, and thus achieving a more accurate and reliable representation of the terrain relief.

REFERENCES

Besl P. J., and McKay N. D., 1992. *A Method for Registration of 3-D Shapes*. In: IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 14, No. 2, pp. 239-256.

Doythser Y., and Hall J. K., 1997. *Interpolation of DTM using bi-directional third-degree parabolic equations, with FORTRAN subroutines.* In: Computers and Geosciences, Volume 23, Number 9, pp. 1013-1020(8).

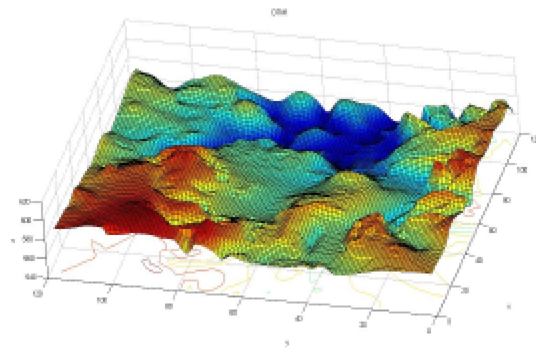
Feldmar J., and Ayache N., 1994. *Rigid, Affine and Locally Affine Registration of Free-Form Surfaces*. In: International Journal of Computer Vision, Vol. 13, No. 2, pp. 99-119.

Gruen A., 1996. *Least Squares Matching: A Fundamental Measurement Algorithm.* K. B. Atkinson (ed.), Close Range Photogrammetry & Machine Vision, Whittles, pp. 217-255.

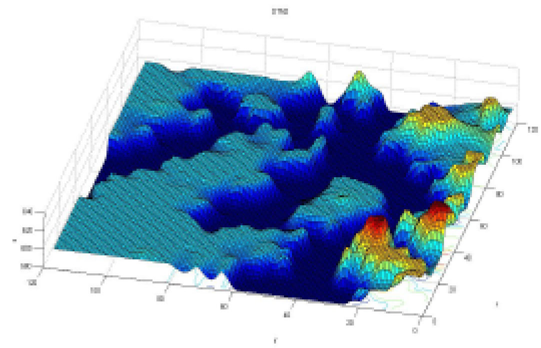
Hutchinson, Michael F., & Gallant, John C., 2000. *Digital Elevation Models and Representation of Terrain Shape.* Wilson, John P. & Gallant, John C. (ed.), Terrain Analysis: Principles and Applications, John Wiley & Sons, Inc., pp. 29-50.

Laurini R., 1998. *Spatial Multi-Databases Topological Continuity and Indexing: A Step toward Seamless GIS Data Interoperability*. In: International Journal of Geographical Information Science, Vol. 12, No. 4, pp. 373-402.

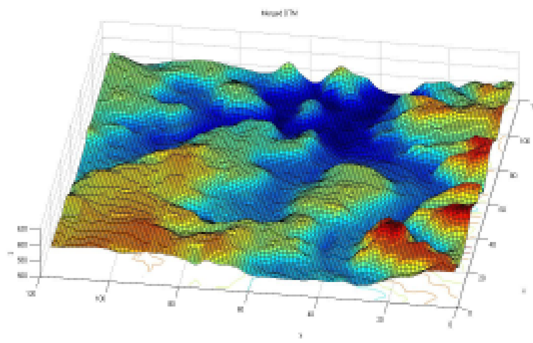
Rusinkiewicz Szymon and Levoy Marc, 2001. *Efficient Variants of the ICP Algorithm.* In: Proc. 3D Digital Imaging and Modeling 2001, IEEE Computer Society Press, pp. 145-152.



DTM A



DTM B



Merged DTM

Figure 8. Two DTMs – A and B – and the corresponding merged DTM