A Pyramidal Approach for Merging Topographic Datasets

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KEYWORDS: Data Merging, DTM, ICP, Interest Points, Pyramidal Approach

Introduction

Nowadays DTM databases, which describe terrain relief, are among the main interactions between data acquisition and a wide area of applications. One of the main problems in this discipline is data merging, which involves integrating data from different sets. In most cases each dataset has been collected over a different period of time using different production technologies. The discrepancies exist when comparing different DTMs representation of the terrain relief 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 stage or production (Hutchinson & Gallant, 2000). These various factors present global-systematic errors as well as local-random ones, which reflect on a different scale of spatial geometric and radiometric differences. The common "cut and paste" matching procedure on different datasets will produce incorrect results, mainly for the fact that there are irregularities in the topographic representation between the datasets. A sample of these phenomena is depicted in Figure 1. Consequently, the required integration process yields the merging of geo-spatial datasets consisting 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. Therefore, the integration of different geo-spatial datasets can reduce the gaps existing between reality and its representation, and thus attain a unified merged DTM to better describe the terrain relief.

One can divide the merging problem into two main stages: finding the best correspondence between datasets; and, executing the merging process itself. Rusinkiewicz & Levoy (2001) showed that the initial knowledge regarding the geometric spatial relations between the datasets must be known prior to the matching process itself. This can be achieved by implementing initial registration processes on the different datasets – for instance, pairing-up groups of two congruent geomorphologic features existing in the different datasets. This yields the extraction of the geometric spatial relations, i.e. a statistically qualitative initial registration value of the two datasets (three-shift values for example). After extracting 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 dataset matching – ICP (Iterative Closest Point) for example – first presented by Besl & McKay (1992). This algorithm is mainly designated for point cloud matching by a nearest neighbor criteria procedure, using iterative LSM (Least Square Matching) (Gruen A., 1996). The calculation of the accurate spatial affine transformation (three rotation angles and three shifts for example) is more accurate and reliable when using the prior registration knowledge extracted earlier.

This paper describes a new approach to merging datasets, in which a careful examination, investigation and eventually an appropriate solution is given. The idea is to implement a hierarchical solution of pyramidal approach, in which local geometric discrepancies are monitored and prevented. In contrast to the common approach based on global features only, the solution given here for the dataset matching procedure suggests the implementation of two working levels of topographic zoning – global and local. The suggested procedure is 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 procedure achieved with the local extracted corresponding registration values. This new approach showed good results for DTM datasets merging, therefore achieving a singular, unified and spatial continuous surface representation of the terrain relief.

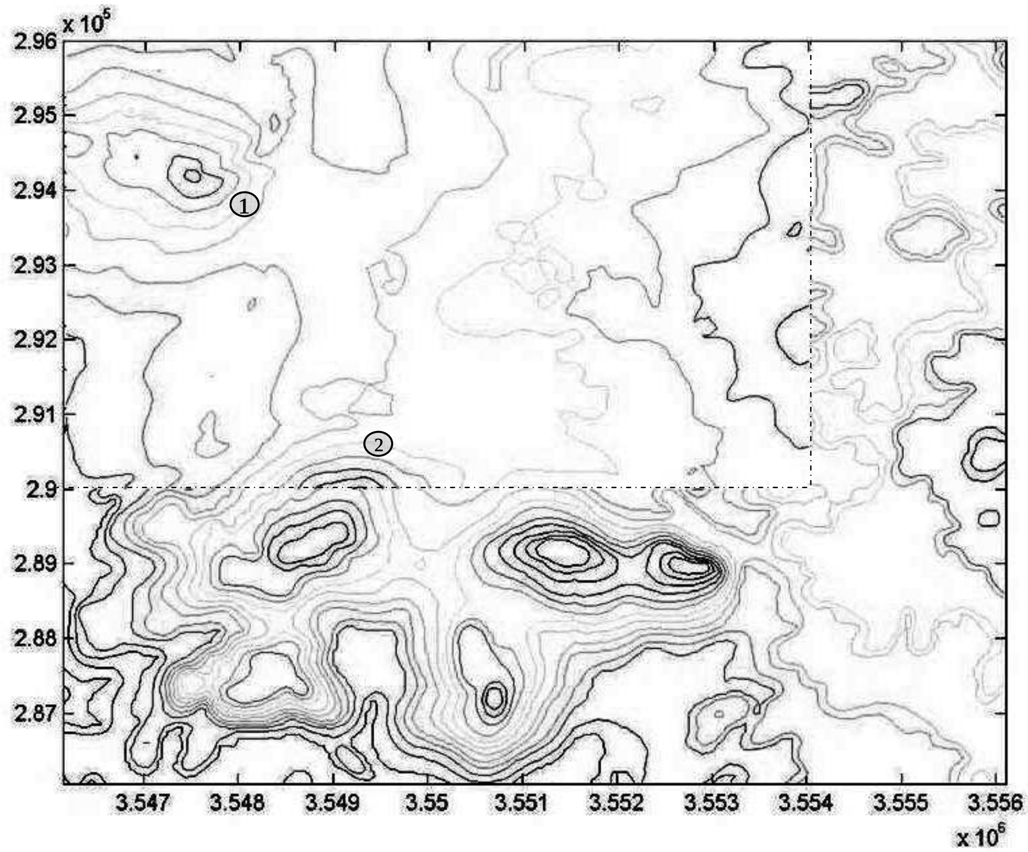


Figure 1. Contour representation of "Cut and Paste" superimposition of two datasets showing topographic discrepancies: 1 hill existing only in one dataset; 2 topographic horizontal shifts

Methodology and Algorithm

The general mathematical strategy is as follows:

First order division

The entire area is divided into medium-sized-patches (*msp*) (Figure 2). The extraction of unique local geomorphologic points, i.e. interest points, and then the calculation of the initial registration value corresponds to each congruent *msp* is carried out.

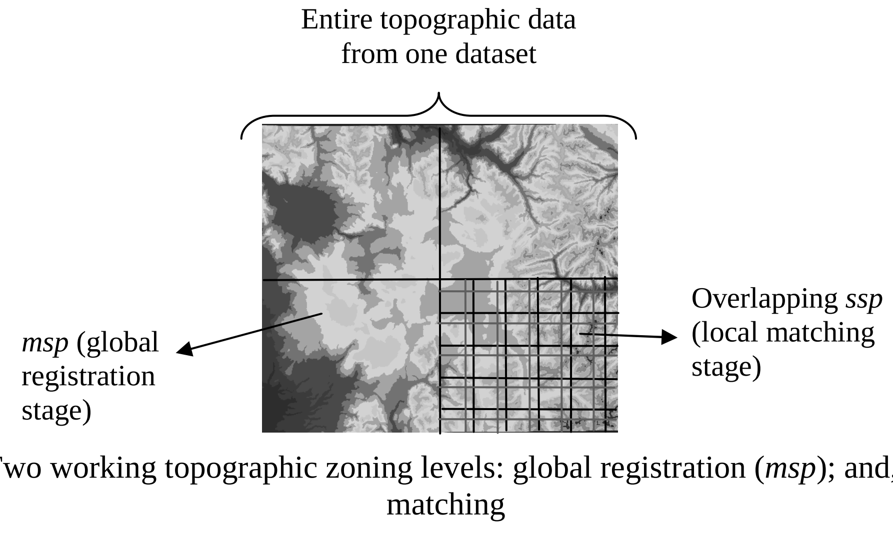


Figure 2. Two working topographic zoning levels: global registration (*msp*); and, local (*ssp*) matching

Extracting interest points

A computational approach for extracting local geomorphologic interest points, such as mountain or hill peaks, is implemented. These interest points will then be used for extracting local registration value – i.e. initial shift vectors - by the pairing-up procedure. The idea is to examine the topological conditions around each grid-point, and then statistically and geomorphologically define by a set of rules whether it is an interest point. This is achieved according to the following steps:

1. Extracting four perpendicular second degree polynomials describing the topography surrounding the grid-point (Figure 3).
2. Calculating the area under each of these polynomials in Z direction (Figure 4).
3. Carrying out statistical tests on the values extracted, which define topologically and geomorphologically whether a preliminary definition of the examined grid-point as an interest point can be considered.
4. Local grouping of the defined interest points, in which the highest grid-point is chosen (Figure 5).
5. A local bi-directional interpolation near each of these interest points calculates the highest topographic location, thus achieving sub-resolution accuracy (Figure 5).

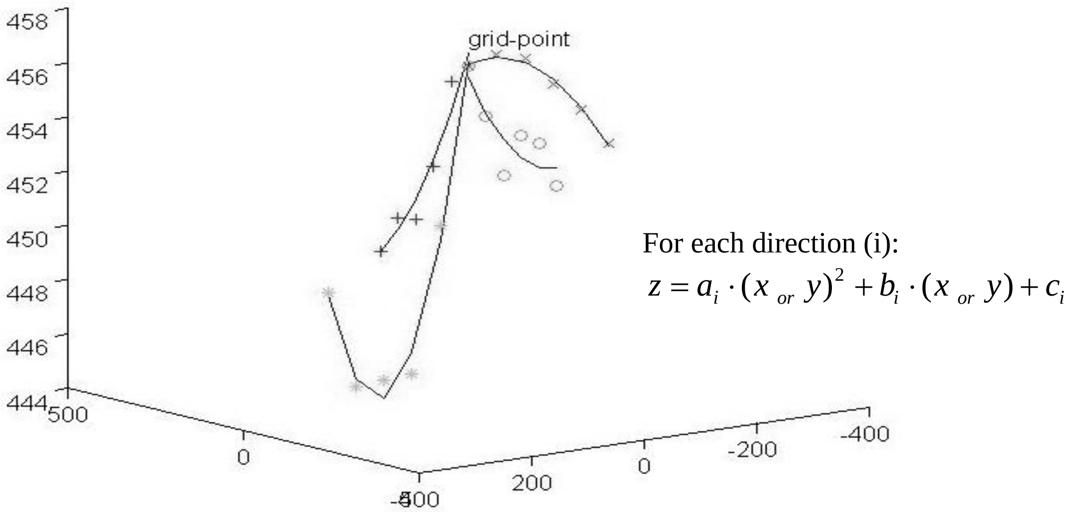


Figure 3. Four perpendicular second degree polynomials extraction

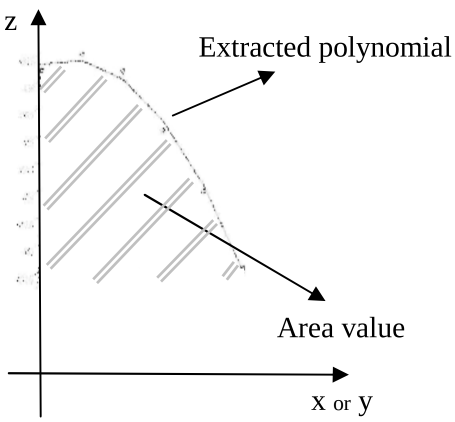


Figure 4. Side view – area under polynomial

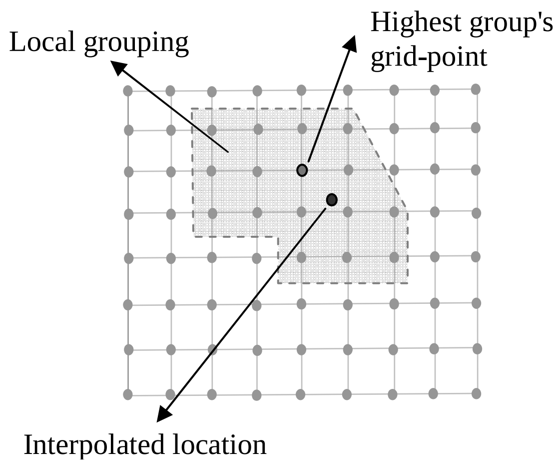


Figure 5. Grid representation of fragment from a DTM outlying grouping procedure and bi-directional interpolation calculation of the interest point exact location

__Calculation of initial shift vectors__
The shift vector for each congruent *msp* is calculated by implementing topographic registration search on all interest points extracted in the previous stage. A statistical procedure is implemented in this registration search procedure to achieve a better certainty of the three-shift values calculated.

__'Local' ICP matching__
Every *msp* is sub-divided into overlapping small-sized-patches (*ssp*) – second order division (Figure 2). A constrained ICP procedure is then implemented locally on each congruent *ssp*. The initial shift vector used for each *ssp* ICP-matching is the one that corresponds to its *msp*. This procedure on *ssp* yields a better localized six registration-parameters calculation, thus ensuring topographic continuity of the entire area, as well as excluding a local minima solution for the ICP procedure and minimizing computation time. The output of this stage is a database, a 'DTM' look like (Figure 6), assembled of six-parameter registration values corresponding to the center of mass for each congruent *ssp*.

__Merging__
The calculation of the merged Geo-spatial dataset is now feasible through a merging procedure implemented on the entire data available: two Geo-spatial datasets and six-parameter registration database. This is performed iteratively by using a "reverse engineering" procedure on the registration values extracted, until a pre-defined degree of accuracy is achieved. Among other factors the procedure takes into consideration the accuracy of each dataset.

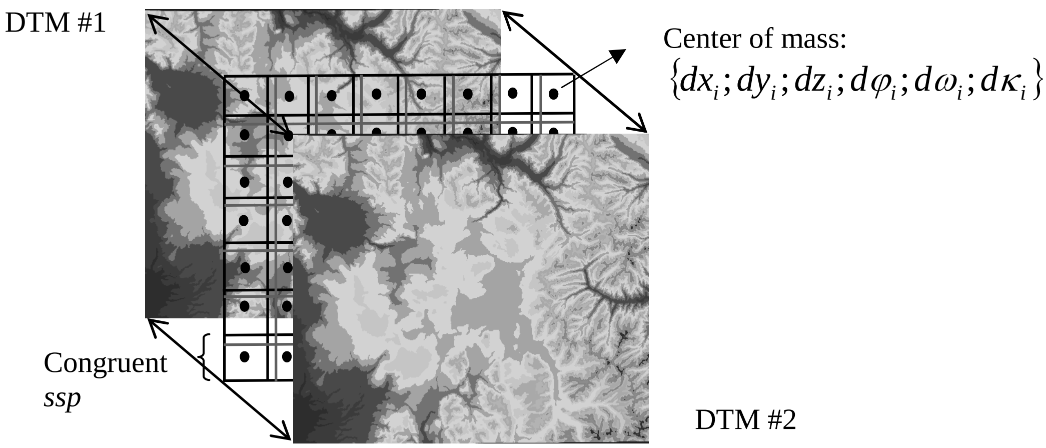
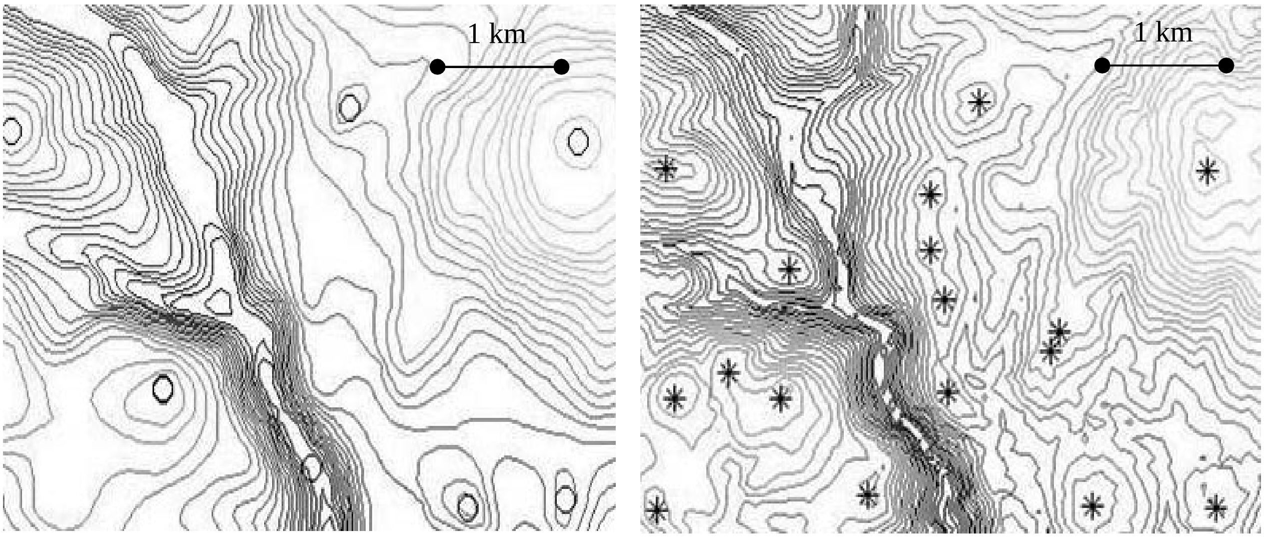


Figure 6. 'DTM' look like database representing the corresponding six-parameter registration values for overlapping congruent *ssp* zones of the two datasets

Experimental Results
The suggested approach was tested on different DTMs with spatial discrepancies ranging up to hundreds of meters. The interest points extraction procedure proved geomorphologically to be accurate and efficient, by defining local surface-derived extremes in the topographic relief - i.e. hills and mountains (Figure 7). As can be seen from these figures of the two DTMs the level of detailing, which is mainly dependent on the resolution of the dataset, has an effect on the number of the extracted interest points. Furthermore, the precise identification of the interest points' location enabled the accurate calculation of the registration shift-vector values between the congruent *msp*s. Finalizing with the implementation of the constrained ICP and merging procedures, the algorithm yielded very good results in terms of topographic accuracy and topographic topology of the merged DTM, which was unified and continuous throughout the entire area of the datasets (Figure 8). Statistical tests which compared the discrepancies between the different datasets before the merging procedure and after – compared to the merged DTM – proved that the merged dataset made use of both data available in the different sets, and hence represented the surface accurately.



DTM #1 DTM #2

Figure 7. Extraction of interest points in both DTMs, showing effective results in identifying and extracting local geomorphologic surface-derived points

Discussion and Conclusions

Generally, when two Geo-spatial datasets designated for merging - while one is with 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. The common situation is when the two datasets have 'similar' level of detailing and accuracy while having some local or global discrepancies. In that case, the merging procedure of the two datasets must preserve the internal morphology, while achieving a more accurate and reliable result than any of the two datasets separately.

This new pyramidal approach ensures the preservation of local geometric features and their topological relations, while preventing any distortions. The solution outlined in this paper is a reliable and accurate one as long as the topographic conditions derived from the data enables it. In extreme geometric conditions, such as major discrepancies or even no correspondence, or in case of very smooth surfaces that might lead to a wrong registration-vector or very few interest points extraction, the solution given by the ICP matching procedure may divert to a local minima instead to an implicit one.

The implementation of relying on local registration values calculated accurately from a qualitative procedure of identifying surface-derived geomorphologic interest-points, is in contrast to ignoring or 'smearing' these local-features when using the data of the whole area at once. Hence, this solution ensures better degree of reliability of the calculated merged dataset, as well as resulting with a singular, unified, and spatial continuous surface.

References

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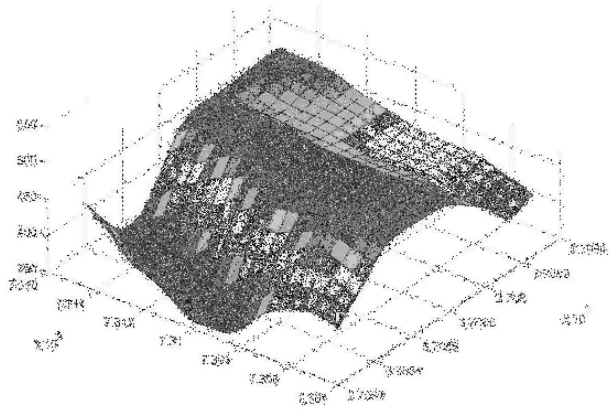
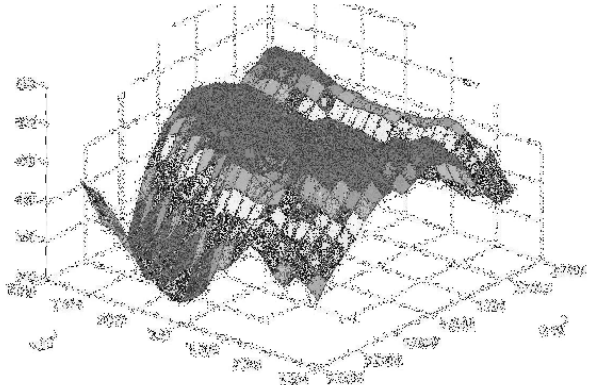
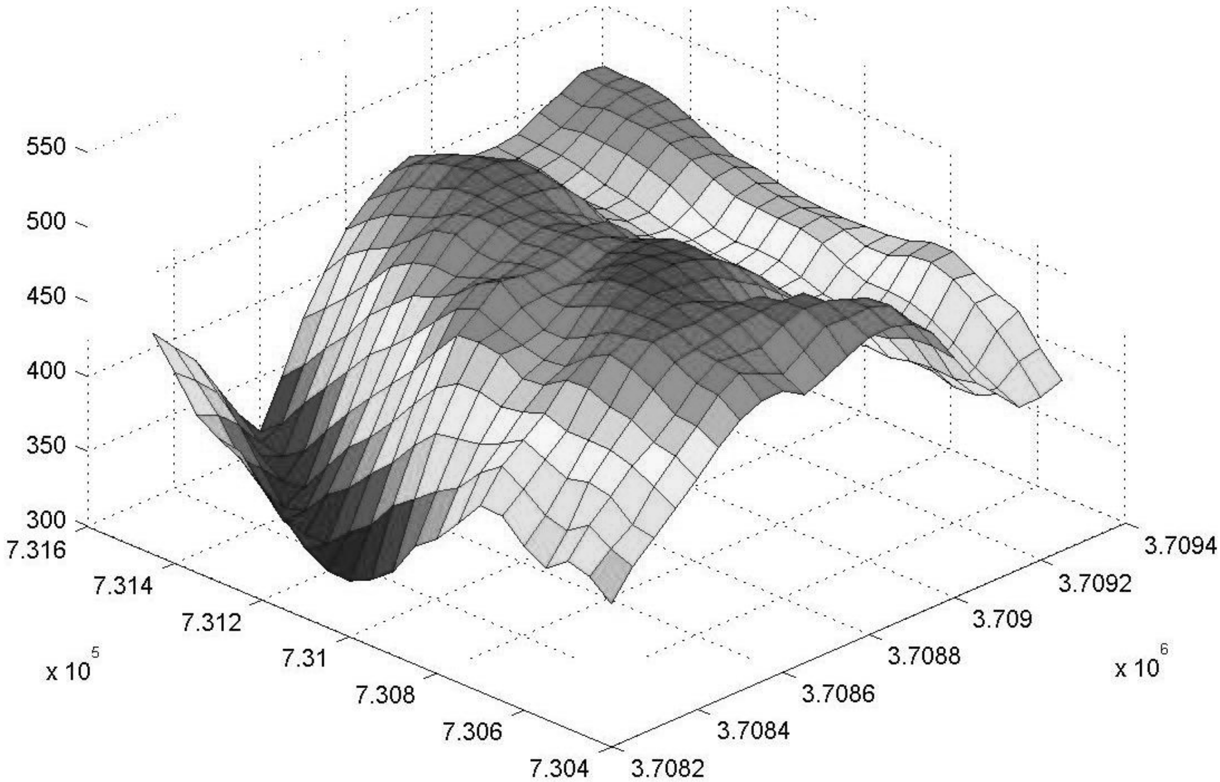


DTM #1



DTM #2



Merged DTM

Figure 8. Two DTMs and the merged DTM

Biography

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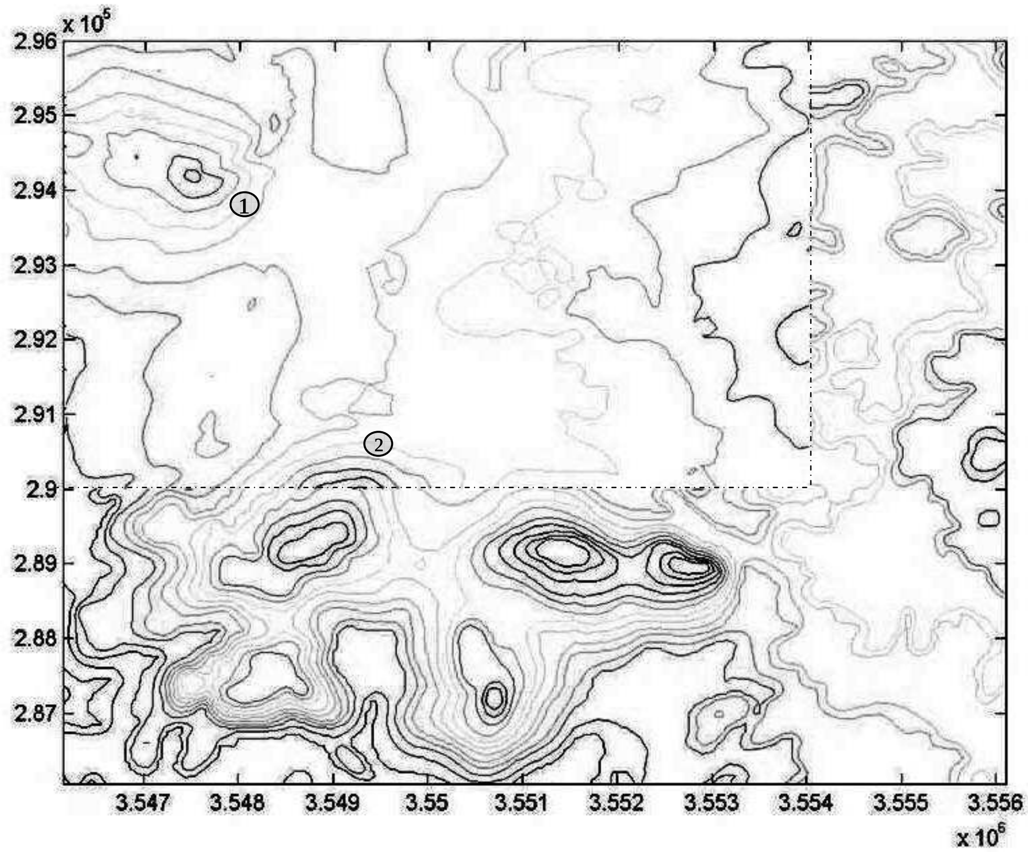

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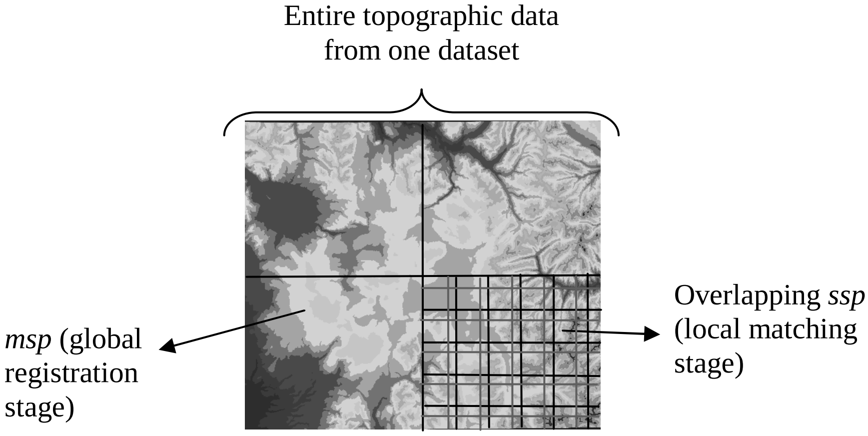

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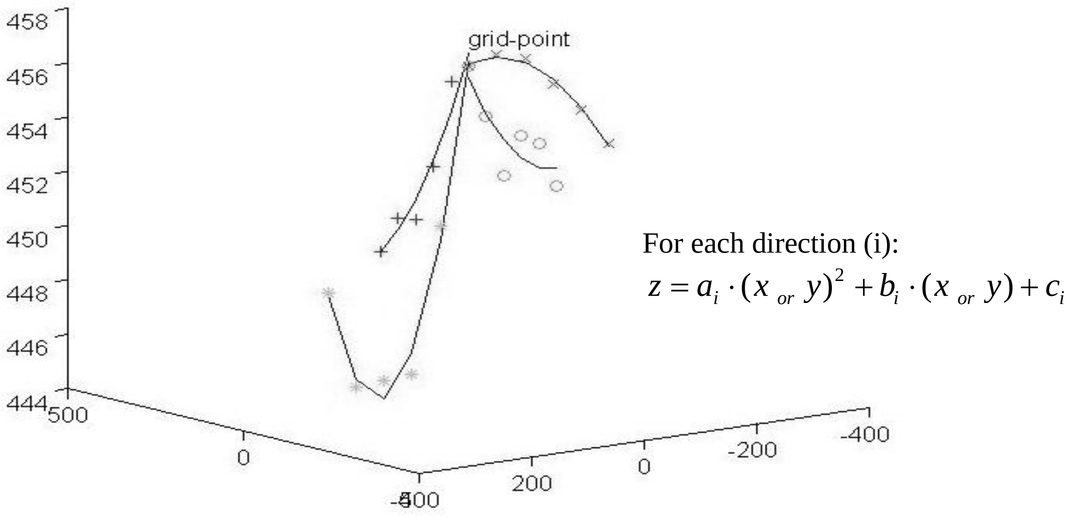

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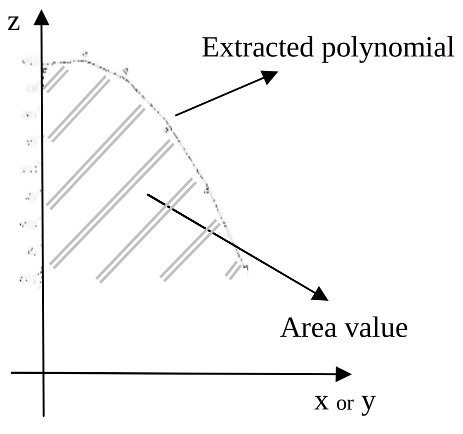

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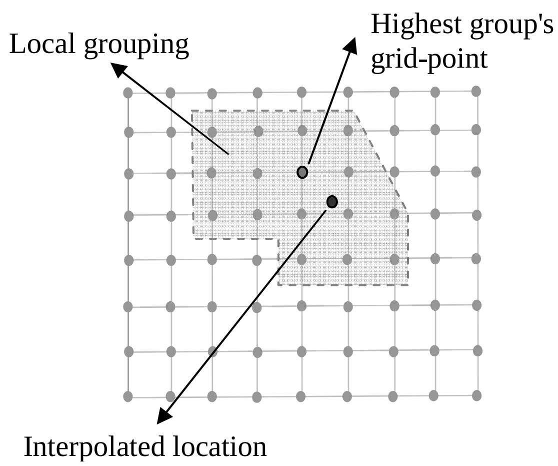

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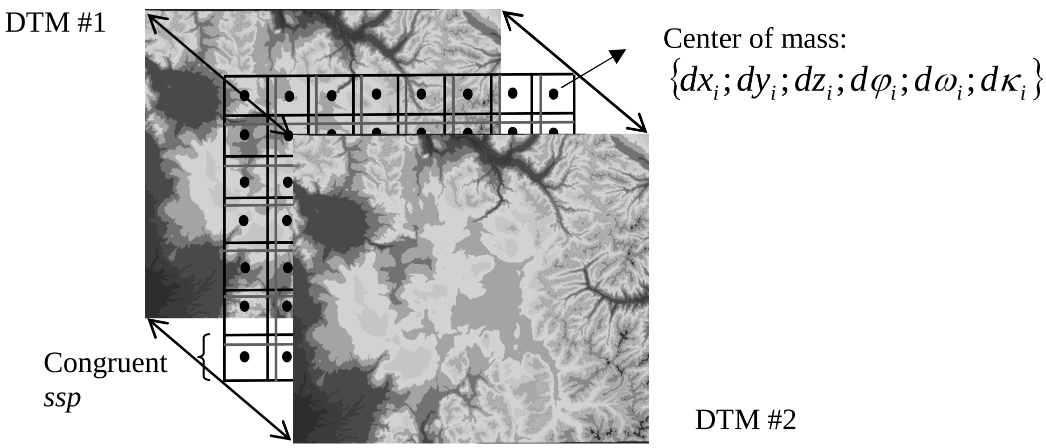

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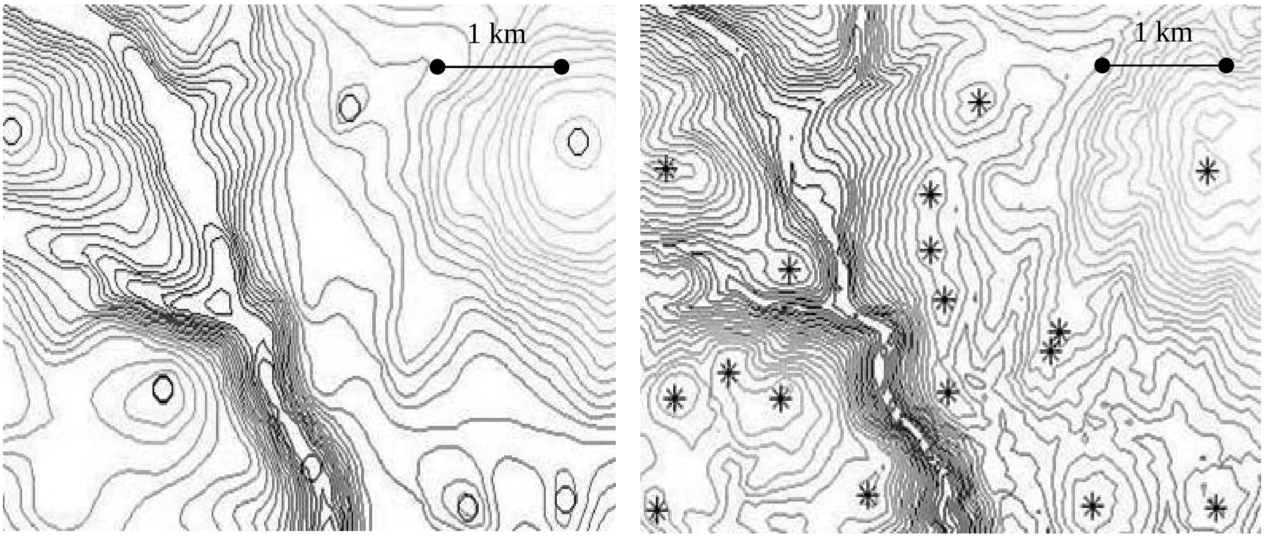

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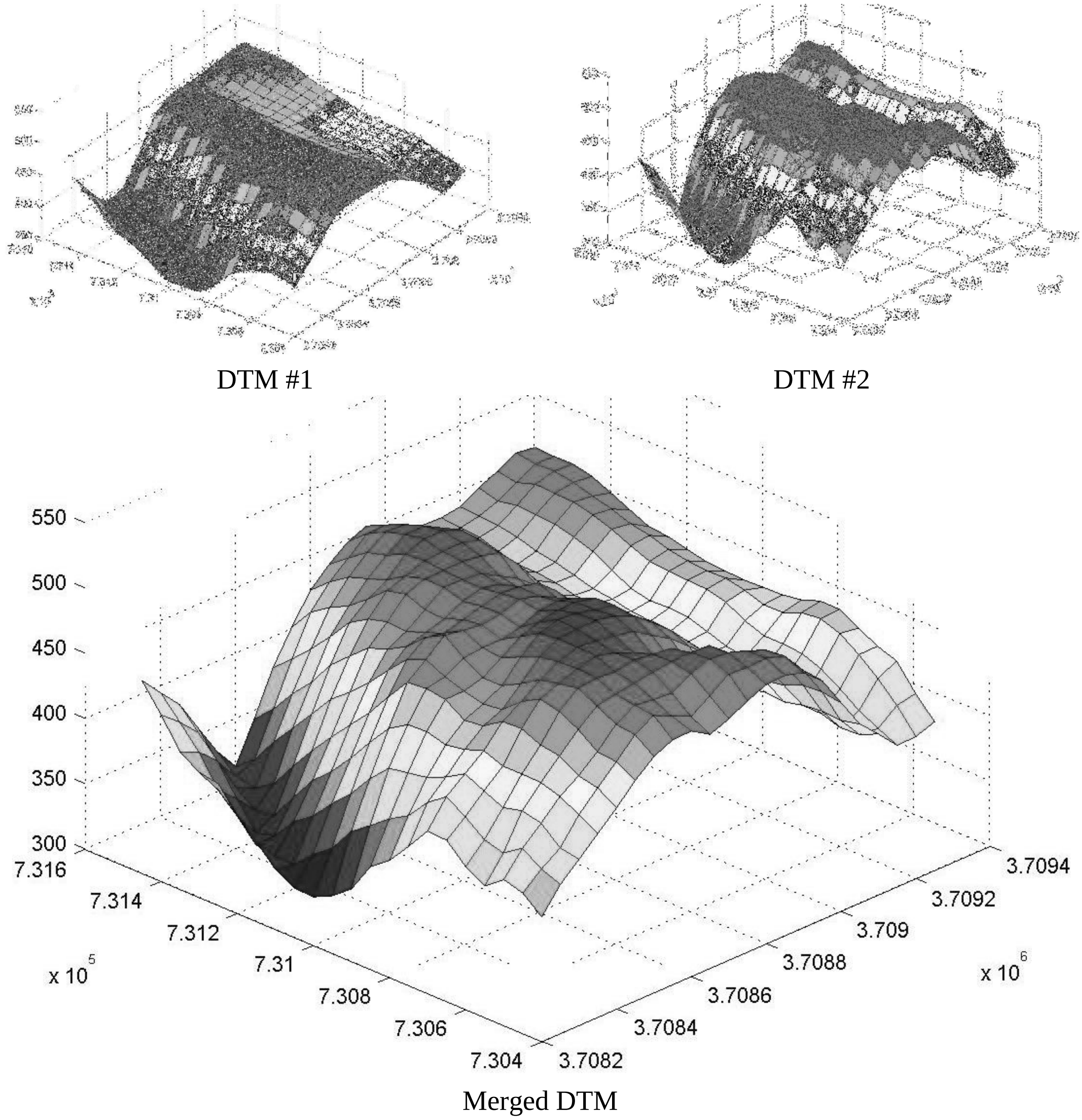

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